Scientists seek explanations of natural phenomena based on empirical evidence.

(1) Advances in the understanding of evolution over the past two centuries provide a superb example of how science works. Scientific knowledge and understanding accumulate from the interplay of observation and explanation. Scientists gather information by observing the natural world and conducting experiments. They then propose how the systems being studied behave in general, basing their explanations on the data provided through their experiments and other observations. They test their explanations by conducting additional observations and experiments under different conditions. Other scientists confirm the observations independently and carry out additional studies that may lead to more sophisticated explanations and predictions about future observations and experiments. In these ways, scientists continually arrive at more accurate and more comprehensive explanations of particular aspects of nature.

(2) In science, explanations must be based on naturally occurring phenomena. Natural causes are, in principle, reproducible and therefore can be checked independently by others. If explanations are based on purported forces that are outside of nature, scientists have no way of either confirming or disproving those explanations. Any scientific explanation has to be *testable* — there must be possible observational consequences that could support the idea *but also ones that could refute it*. Unless a proposed explanation is framed in a way that some observational evidence could potentially count against it, that explanation cannot be subjected to scientific testing.

Definition of Science

The use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process.

(3) In science it is not possible to prove with absolute certainty that a given explanation is complete and final. Some of the explanations advanced by scientists

turn out to be incorrect when they are tested by further observations or experiments. New instruments may make observations possible that reveal the inadequacy of an existing explanation. New ideas can lead to explanations that reveal the incompleteness or deficiencies of previous explanations. Many scientific ideas that once were accepted are now known to be inaccurate or to apply only within a limited domain.

(4) Science is not the only way of knowing and understanding. *But science is a way of knowing that differs from other ways in its dependence on empirical evidence and testable explanations.* Because biological evolution accounts for events that are also central concerns of religion — including the origins of biological diversity and especially the origins of humans — evolution has been a contentious idea within society since it was first articulated by Charles Darwin and Alfred Russel Wallace in 1858.

CREATIONIST PERSPECTIVES

Creationist views reject scientific findings and methods.

(5) Advocates of the ideas collectively known as "creationism" and, recently, "intelligent design creationism" hold a wide variety of views. Most broadly, a "creationist" is someone who rejects natural scientific explanations of the known universe in favor of special creation by a supernatural entity. Creationism in its various forms is not the same thing as belief in God because, as was discussed earlier, many believers as well as many mainstream religious groups accept the findings of science, including evolution. Nor is creationism necessarily tied to Christians who interpret the Bible literally. Some non-Christian religious believers also want to replace scientific explanations with their own religion's supernatural accounts of physical phenomena.

(6) No scientific evidence supports these viewpoints. On the contrary, as discussed earlier, several independent lines of evidence indicate that the Earth is about 4.5 billion years old and that the universe is about 14 billion years old. Rejecting the evidence for these age estimates would mean rejecting not just

biological evolution but also fundamental discoveries of modern physics, chemistry, astrophysics, and geology.

(7) Creationists sometimes cite what they claim to be an incomplete fossil record as evidence that living things were created in their modern forms. But this argument ignores the rich and extremely detailed record of evolutionary history that paleontologists and other biologists have constructed over the past two centuries and are continuing to construct. Paleontological research has filled in many of the parts of the fossil record that were incomplete in Charles Darwin's time. The claim that the fossil record is "full of gaps" that undermine evolution is simply false. Indeed, paleontologists now know enough about the ages of sediments to predict where they will be able to find particularly significant transitional fossils, as happened with *Tiktaalik* and the ancestors of modern humans.

(8) Creationists sometimes argue that the idea of evolution must remain hypothetical because "no one has ever seen evolution occur." This kind of statement also reveals that some creationists misunderstand an important characteristic of scientific reasoning. Scientific conclusions are not limited to direct observation but often depend on inferences that are made by applying reason to observations. Until the recent development of extremely powerful microscopes, scientists could not observe atoms, but the behavior of physical objects left no doubt about the atomic nature of matter. Scientists hypothesized the existence of viruses for many years before microscopes became powerful enough to see them.

(9) Thus, for many areas of science, scientists have not directly observed the objects (such as genes and atoms) or the phenomena (such as the Earth going around the Sun) that are now well-established facts. Instead, they have confirmed them indirectly by observational and experimental evidence. Evolution is no different. Indeed, for the reasons described in this booklet, evolutionary science provides one of the best examples of a deep understanding based on scientific reasoning.

(10) This contention that nobody has seen evolution occurring further ignores the overwhelming evidence that evolution has taken place and is continuing to occur. The annual changes in influenza viruses and the emergence of bacteria resistant to antibiotics are both products of evolutionary forces. Another example of ongoing evolution is the appearance of mosquitoes resistant to various insecticides, which has contributed to a resurgence of malaria in Africa and elsewhere. The transitional fossils that have been found in abundance since Darwin's time reveal how species continually give rise to successor species that, over time, produce radically changed body forms and functions. It also is possible to directly observe many of the specific processes by which evolution occurs. Scientists regularly do experiments using microbes and other model systems that directly test evolutionary hypotheses.

(11) Creationists reject such scientific facts in part because they do not accept evidence drawn from natural processes that they consider to be at odds with the Bible. But science cannot test supernatural possibilities. To young Earth creationists, no amount of empirical evidence that the Earth is billions of years old is likely to refute their claim that the world is actually young but that God simply made it *appear* to be old. Because such appeals to the supernatural are not testable using the rules and processes of scientific inquiry, they cannot be a part of science.

(12) The arguments of creationists reverse the scientific process. They begin with an explanation that they are unwilling to alter — that supernatural forces have shaped biological or Earth systems — rejecting the basic requirements of science that hypotheses must be restricted to testable natural explanations. Their beliefs cannot be tested, modified, or rejected by scientific means and thus cannot be a part of the processes of science. Despite the lack of scientific evidence for creationist positions, some advocates continue to demand that various forms of creationism be taught together with or in place of evolution in science classes.

These passages are adapted from *Science, Evolution, and Creationism* by the National Academy of Sciences Institute of Medicine, Washington DC.