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Paradoxes contradictions and the limits of science

Recent results find boundaries of what cannot be known, classifying these limitations shows us the structure of science and reason

Noson Yanofsky

Science and technology have always amazed us with their powers and ability to transform our world and our lives. However, many results, particularly over the past century or so, have demonstrated that there are limits to the abilities of science. Some of the most celebrated ideas in all of science, such as aspects of quantum mechanics and chaos theory, have implications for informing scientists about what cannot be done. Researchers have discovered boundaries beyond which science cannot go and, in a sense, science has found its limitations. Although these results are found in many different fields and areas of science, mathematics, and logic, they can be grouped and classified into four types of limitations. By closely examining these classifications and the way that these limitations are found, we can learn much about the very structure of science. [...]

# Discovering Limitations

The various ways that some of these limitations are discovered is in itself informative. One of the more interesting means of discovering a scientific limitation is through paradoxes. The word *paradox* is used in various ways and has several meanings. For our purposes, a paradox is present when an assumption is made and then, with valid reasoning, a contradiction or falsity is derived. We can write this as:

*Assumption→Contradiction.*

Because contradictions and falsehoods need to be avoided, and because only valid reasoning was employed, it must be that the assumption was incorrect. In a sense, a paradox is a proof that the assumption is not a valid part of reason. If it were, in fact, a valid part of reason, then no contradiction or falsehood could have been derived. [...]

The central idea of a paradox is the contradiction that is derived. Where the contradiction occurs tells us a lot about the type of limitation we found. The paradox could concern something concrete and physical. There are no contradictions or falsehoods in the physical universe. If something is true, it cannot be false, and vice versa. The physical universe does not permit contradictions, and hence, if a certain assumption leads to a contradiction in the physical universe, we can conclude that the assumption is incorrect. [...]

# Physical Limitations

The first and most obvious type of limitation is one that says certain physical objects or processes cannot exist, like the village in the barber paradox.

Another example of a physical process that is impossible is time travel into the past. This limitation is usually shown through a self-referential paradox that is often called the *grandfather paradox*. In it, a person goes back in time and kills his bachelor grandfather. Thus his father will not be born, the time traveler himself will not be born—and hence the time traveler will not be able to kill his grandfather. One need not be homicidal to obtain such a paradox: In the 1985 movie *Back to the Future*, the main character starts to fade out of existence because he traveled back in time and accidentally stopped his mother and father from getting married. A time traveler need only go back several minutes and restrain the earlier version of himself from getting into the time machine.

What is different about events in time travel that cause these paradoxes? Usually, an event affects another, later event: If I eat a lot of cake, I will gain weight. With the time travel paradox, an event affects itself. By killing his bachelor grandfather, the time traveler ensures that he cannot kill his bachelor grandfather. The event negates itself. The simple resolution to the grandfather paradox is that, in order to avoid contradictions, time travel is impossible. Alternatively, if perchance time travel is possible, it is impossible to cause such a contradiction.

Another example of a limitation that shows the impossibility of a physical process is the *halting problem*. Before engineers actually built modern computers, Alan Turing showed that there are limitations to what computers can perform. In the 1930s, prior to helping the Allies win World War II by breaking the Germans’ Enigma cryptographic code, he showed what computers cannot do by way of a self- referential paradox. As anyone who deals with computers knows, sometimes a computer “gets stuck” or goes into an “infinite loop.” It would be nice if there were a computer that could determine whether a computer will get stuck in an infinite loop. Essentially, we are asking computers to be self- referential. Turing showed that no such computer could possibly exist. He showed that if such a computer could exist, he would make a computer that would negate its own “haltingness.” Such a program would perform the following task: “When asked if I will halt or go into an infinite loop, I will give the wrong answer.” However, computers cannot give wrong answers because they do exactly what their instructions tell them to do, hence we have a contradiction, which occurs because of the assumption that we made about a computer that can determine whether any computer will go into an infinite loop. That assumption is incorrect. Many other problems in computer science, mathematics, and physics are shown to be unsolvable by piggybacking off the fact that the halting problem is unsolvable.

There are many other examples of physical limitations. For instance, Einstein’s special theory of general relativity tells us that a physical object cannot travel faster than the speed of light. And quantum theory tells us that the action of individual subatomic particles is probabilistic, so no physical process can predict how a given subatomic particle will act.

# Mental Construct Limitations

Recall that although our minds are full of contradictions, we must, when dealing with science and mathematics, steer clear of them, and that means restricting certain mental and linguistic activities.

In the first years of elementary school, we learn an easy mental construct limitation: We are not permitted to divide by zero. Despite the reasons for this rule being so obvious to us now, let us justify it. Consider the equation 3×0=4×0. Both sides of the equation are equal to zero and hence the statement is true. If you were permitted to divide by zero, you could cancel out the zeros on both sides of the equation and get 3=4. This outcome is a clear falsehood that must be avoided.

A more advanced result in which one sees the mental construct limitation more clearly is in what’s called *Russell’s paradox*. In the first few years of the 20th century, British mathematician Bertrand Russell described a paradox that shook mathematics to its core. At the time, it was believed that all of mathematics could be stated in the language of *sets,* which are collections of abstract ideas or objects. Sets can also contain sets, or even have themselves as an element. This idea is not so far-fetched: Consider the set of ideas that are contained in this article. That set contains itself. The set of all sets that have more than three elements contains itself. The set of all things that are not red contains itself. The fact that sets can contain themselves makes the whole subject ripe for a self-referential paradox.

Russell said that we should consider all sets that do not contain themselves and call that collection *R* (for Russell). Now simply pose the question: Does *R* contain*R*? If *R* does contain *R*, then as a member of *R* that is defined as containing only those sets that do not contain themselves, *R* does not contain *R*. On the other hand, if *R* does not contain itself, then, by definition, it belongs in *R*. Again we arrive at a contradiction. The best method of resolving Russell’s paradox is to simply declare that the set *R* does not exist.

What is wrong with the collection of elements we called *R*? We gave a seemingly exact statement of which types of objects it contains: “those sets that do not contain themselves.” And yet, we have declared that this collection is not a legitimate set and cannot be used in a mathematical discussion. Mathematicians are permitted to discuss the green apples in my refrigerator but are not permitted to discuss the collection *R*. Why? Because the collection *R* will cause us to arrive at a contradiction. Mathematicians must restrain themselves because we do not want contradictions in our mathematics.

In 1931, Austrian mathematician Kurt Gödel, then 25 years old, proved one of the most celebrated theorems of 20th-century mathematics. Gödel’s Incompleteness Theorem shows that there are statements in mathematics that are true but are not provable. Gödel showed this result by demonstrating that mathematics can also talk about itself. Mathematical statements about numbers can be converted into numbers. Using this ability to self-reference, he formulated a mathematical statement that essentially says: “This mathematical statement is not provable.” It’s a mathematical statement that negates its own provability. If you analyze this statement carefully, you realize that it cannot be false (in which case it would be provable), and hence it would be true and contradictory. But since it is true, it must also be unprovable. Gödel showed that not everything that is true has a mathematical proof.

Throughout mathematics and science, there are many other examples of mental construct limitations. For instance, one cannot consider the square root of two to be a rational number (*see box above*). Zeno’s famous paradoxes, created by Greek mathematician Zeno of Elea around 450 BCE and involving such conundrums as motion being an illusion, can also be seen as examples of mental construct limitations.

# Practical Limitations

So far we have seen limitations that show it is impossible for something or some process (physical or mental) to exist. In a practical limitation, we are dealing with things that are possible, albeit extremely improbable. That is, it is impossible to make some prediction or find some solution in a normal amount of time or with a normal amount of resources.

The classical example is the butterfly effect from chaos theory. The phrase comes from the title of a 1972 presentation by mathematician Edward Lorenz of the Massachusetts Institute of Technology: “Predictability: Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?” Lorenz was a meteorologist and a mathematician. He was discussing the fact that weather patterns are extremely sensitive to slight changes in the environment. A small flap of a butterfly’s wing in Brazil might cause a change that causes a change that eventually causes a tornado in Texas. Of course, one should not go out and kill all the butterflies in Brazil; the butterfly flap might instead send a coming tornado off course and save a Texas city. The point of the study is that because there is no way we can keep track of the many millions of butterflies in Brazil, we can never predict the paths of tornados or of the weather in general. This thought experiment shows a limitation of our predictive ability.

Many other problems from chaos theory show limitations. Predicting tomorrow’s lottery numbers is also beyond our ability. If you wanted to know the numbers, you would have to keep track of all the atoms in the bouncing ball machine—far too many for us to ever be able to do.

Perpetual motion machines are another example of a practical limitation. There is essentially no way that one can make a machine that will continue to move without losing all its energy. One might be tempted to say that this limitation is really a physical one because it says that a perpetual motion machine cannot exist in the physical universe. But by the second law of thermodynamics, it is extremely improbable for there to be a machine that does not dissipate its energy. Improbable, but not impossible.

The theory of thermodynamics and statistical mechanics is about large groups of atoms and the heat and energy they can create. Because in such systems there are too many elements to keep track of, the laws in such theories are given as probabilities, and are ripe for finding other examples of practical limitations.

# Limitations of Intuition

The fourth type of limitation is more of a problem with the way we look at the world. Science has shown that our naive intuition about the universe that we live in needs to be adjusted. There are many aspects of reality that seem obvious, but are, in fact, simply false.

One of the most shocking examples of this false perception comes from Einstein’s special theory of relativity. The notion of *space contraction* says that if you are not moving and you observe an object moving near the speed of light, then you will see the object shrink. This observation is not an optical illusion: The object actually shrinks. Similarly, the phenomenon of *time dilation* says that when an object moves close to the speed of light, all the processes of the object will slow down. Of course, an observer traveling with the object will see neither space contraction nor time dilation. Thus our naive view that objects have fixed sizes and processes have fixed duration is faulty.

Some of the most counterintuitive aspects of modern science occur within quantum mechanics. Since the beginning of last century, physicists have been showing that the subatomic world is an extremely strange place. In addition to finding that the properties of things (such as a photon acting like a wave or a particle) depend on how they are measured, researchers have found that rather than a particle having a single position, it can be in many places at one time, a property called *superposition*. Indeed, not only position, but many other properties of a subatomic particle, might have many different values at the same time. Heisenberg’s uncertainty principletells us that objects do not have definitive properties until they are measured. A famous concept called Bell’s theorem shows us that an action here can affect objects across the universe, which is called *entanglement*. (For more on Bell’s theorem and entanglement, see “[Quantum Randomness](http://www.americanscientist.org/issues/pub/2014/4/quantum-randomness),” July–August 2014.)

One might think that mathematics is always intuitive and that our intuitions in that field at least might never need to be adjusted. But this assumption is also not true. In the late 19th century, German mathematician Georg Cantor, a pioneer in set theory, showed us that our intuition about infinity is somewhat troublesome. The naive view is that all the infinite sets are the same size. Cantor showed that in fact there are many different sizes of infinite sets. (*See box below.*)

In the sciences, whenever there is a paradigm shift, all of our ideas about a certain subject have to be readjusted. We have to look at phenomena from a new viewpoint.

## Estimating the Unsolvable

How much is beyond our ability to solve? In general, such things are hard to measure. However, in computer science there is an interesting result along these lines. We all know of many different tasks that computers perform with ease. However, there are many problems that are beyond the ability of computers. We can examine whether there are more solvable problems than unsolvable problems.

First, a bit about infinite sets. Mathematicians have shown that there are different levels of infinity. The smallest infinity corresponds to the natural numbers: {0, 1, 2, 3 …}. We say that this set of numbers is “countably infinite.” Although we can never finish counting the natural numbers, we can at least begin listing them. In contrast, the set of all real numbers—that is numbers such as –473.4562372... and pi—are “uncountably infinite.” We cannot even begin to count them. After all, what is the first real number after 0? 0.000001? What about 0.0000000001? It can be shown easily that uncountably infinite sets are vastly larger than countably infinite sets.

Now let us turn to computers that solve problems. There are a countably infinite number of potential computer programs for solvable computer problems. In contrast, there are uncountably infinite computer problems. If one takes all the uncountably infinite computer problems and subtracts the countably infinite solvable problems, one is left with uncountably infinite unsolvable problems. Thus the overwhelming vast majority of computer problems cannot be solved by any computer. Computers can only solve a small fraction of all the problems there are.

# The Unknowable

The classification of the limitations of science is only beginning, and many questions still arise. Is this classification complete, or are there other limitations that are of a different type? Is there a subclassification of each of the classes? How do the methods of finding the limitations correspond to the types of limitation? Are there results that are in more than one classification? Because some of the results in the other classes might also be counterintuitive, there might be some overlap between categories.

How widespread is this inability to know? Most scientists work in the areas in which progress in knowing happens every day. What about what cannot be known? In general, the concept is hard to measure. There are reasons to believe that there is a lot more “out there” that we cannot know than what we can know. (*See box above for such a calculation in computer science.*) Nevertheless, it is hard to speculate. Isaac Newton said, “What we know is a drop, what we don’t know is an ocean.” Similarly, Princeton University theoretical physicist John Archibald Wheeler is quoted as saying, “As the island of knowledge grows, so does the shore of our ignorance.” Newton and Wheeler were talking about what we do not know. What about what we cannot know?

Most of the limitations discussed here are less than a century old, a very short time in the history of science. As science progresses, it will become more aware of its own boundaries and limitations. By looking at these limitations from a unified point of view, we will be able to compare, contrast, and learn about these many different phenomena. We can understand more about the very nature of science, mathematics, computers, and reason.

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Y a-t-il des questions auxquelles aucune science ne répond ?

An Entangled Drama

[David Mermin](http://www.americanscientist.org/authors/detail/david-mermin)

Attention was drawn to entanglement by a 1935 critique by Albert Einstein, Boris Podolsky and Nathan Rosen. They pointed out that, according to the quantum theory, two spatially separated physical systems that had interacted in the past could be so strongly correlated that it would be possible to predict the result of measuring one or the other of two “complementary” properties of the first system from a prior measurement of one or the other of two corresponding properties of the second system.

What makes this peculiar is that the quantum theory refuses to assign joint values to both of two complementary properties, justifying the refusal by the fact that any measurement needed to reveal one of the hypothetical values must necessarily disturb the system enough to alter uncontrollably the other hypothetical value. But in the situation described in the Einstein-Podolsky-Rosen (EPR) paper, the measurement acts only on the second system, which no longer interacts with the first. Having thus undermined the rationale for the nonexistence of joint complementary properties, the authors conclude that quantum mechanics offers an incomplete description of physical reality.

Those few quantum physicists who took the time to look away from their amazing experiments and spectacular calculations were generally unimpressed by this metaphysical point. Wolfgang Pauli wrote to Werner Heisenberg that “Einstein has once again expressed himself publicly on quantum mechanics. . . . [T]his is a catastrophe every time it happens.” Niels Bohr wrote a paper that almost everybody agreed showed that the EPR paper was wrong, though opinions have differed ever since on what the mistake was that Bohr identified.

Erwin Schrödinger was one of the very few contemporaries immediately to see the power behind the EPR argument, which he expanded on in interesting ways, giving the name *entanglement* to the strong quantum correlations that the EPR paper had exploited. Nearly 30 years were to pass before John Bell proved clearly, explicitly and unambiguously that the quantum mechanical description of physical reality could not be completed in the manner advocated by Einstein, Podolsky and Rosen.

L’expérience peut-elle démontrer quelque chose ?

*American Scientists*

What Everyone Should Know about Statistical Correlation

A common analytical error hinders biomedical research and misleads the public.

[Vladica Velickovic](http://www.americanscientist.org/authors/detail/vladica-velickovic)

In 2012, the *New England Journal of Medicine* published a paper claiming that chocolate consumption could enhance cognitive function. The basis for this conclusion was that the number of Nobel Prize laureates in each country was strongly correlated with the per capita consumption of chocolate in that country. When I read this paper I was surprised that it made it through peer review, because it was clear to me that the authors had committed two common mistakes I see in the biomedical literature when researchers perform a correlation analysis.

Correlation describes the strength of the linear relationship between two observed phenomena (to keep matters simple, I focus on the most commonly used linear relationship, or Pearson’s correlation, here). For example, the increase in the value of one variable, such as chocolate consumption, may be followed by the increase in the value of the other one, such as Nobel laureates. Or the correlation can be negative: The increase in the value of one variable may be followed by the decrease in the value of the other. Because it is possible to correlate two variables whose values cannot be expressed in the same units—for example, per capita income and cholera incidence—their relationship is measured by calculating a unitless number, the *correlation coefficient* . The correlation coefficient ranges in value from –1 to +1. The closer the magnitude is to 1, the stronger the relationship.

The stark simplicity of a correlation coefficient hides the considerable complexity in interpreting its meaning. One error in the *New England Journal of Medicine*paper is that the authors fell into an ecological fallacy, when a conclusion about individuals is reached based on group-level data. In this case, the authors calculated the correlation coefficient at the aggregate level (the country), but then erroneously used that value to reach a conclusion about the individual level (eating chocolate enhances cognitive function). Accurate data at the individual level were completely unknown: No one had collected data on how much chocolate the Nobel laureates consumed, or even if they consumed any at all. I was not the only one to notice this error. [...]

The example of chocolate consumption and Nobel Prize winners brings me to another, even more common misinterpretation of correlation analysis: the idea that correlation implies causality. Calculating a correlation coefficient does not explain the nature of a quantitative agreement; it only assesses the intensity of that agreement. The two factors may show a relationship not because they are influenced by each other but because they are both influenced by the same hidden factor—in this case, perhaps a country’s affluence affects access to chocolate and the availability of higher education. Correlation can certainly point to a possible existence of causality, but it is not sufficient to prove it. [...]

Even though scientists are well aware of the mantra “correlation does not equal causation,” studies conflating correlation and causation are all too common in leading journals. A widely discussed 1999 article in *Nature* found a strong association between myopia and night-time ambient light exposure during sleep in children under two years of age. However, another study published a year later—also in *Nature* —refuted these findings and reported that the cause of child myopia is genetic, not environmental. This new study found a strong link between parental myopia and the development of child myopia, noting that myopic parents were also incidentally more likely to leave a light on in their children’s bedroom. In this example, authors came to a conclusion based on a spurious correlation, without checking for other likely explanations. But as shown in the figure below, completely, laughably unrelated phenomena can be correlated. [...]

Aggregate data are often easier to obtain than data on individuals and may offer valuable clues about individualbehavior when analyzed correctly, but that requires individual-level data. Then, modeling at the individual level must be performed in an attempt to determine the connection between individual and aggregate levels. Only then is it possible to conclude whether the correlation at the aggregate level applies to the individual level. Ecologic data alone do not allow one to determine whether ecologic bias is likely to be present for this type of data set; the only solution is to supplement the ecologic data with individual-level data. This type of modeling usually involves mixed or multilevel statistical models, which allow for individuals to be nested into aggregates. [...]

o make it possible for reviewers to test and replicate analyses, the following three principles must become mandatory for all authors intending to publish results: publishing data sets as supplementary information alongside articles, giving reviewers full access to the software code used for the analysis, and registering the study in a publicly available database online with clearly stated study objectives before the beginning of research, with mandatory submission of summary results to avoid publication bias toward positive results. These steps could speed up the process of detecting errors even when reviewers miss them, provide increased transparency to bolster confidence in science, and, most important, avoid damage to public health caused by unintentional errors. [...]

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Peut-on être sûr d'avoir raison?

Les apparences sont-elles trompeuses ?

Peut-on se fier à l´intuition?

First Person: Aaron Chou

[Fenella Saunders](http://www.americanscientist.org/authors/detail/fenella-saunders)

*Is there a fundamental unit of space, and hence a baseline graininess to the universe? If so, that limit caps the total possible amount of information the universe can store. It also has a weirder implication: The three-dimensional reality we perceive might be an illusion—a projection of space similar to a hologram, which is actually encoded in two dimensions. As bizarre as those ideas may sound, they are actually testable. Aaron Chou, a physicist at the Fermi National Accelerator Laboratory in Batavia, Illinois, is the lead scientist and project manager for the Holographic Interferometer, or Holometer for short. Chou explained to Managing Editor Fenella Saunders how the instrument may help answer some of these questions.*

What is a holographic interferometer and what are you trying to find?

It’s two 40-foot-long laser interferometers, which make extremely precise measurements of the relative positions of different objects, in particular the relative positions of the mirrors inside these devices. Interferometers provide the best resolution of any instrument because they use billions and billions of photons, so you can make that measurement over and over again. We’re using about 1022 photons per second. We’re resolving positions to about 1,000 times smaller than the size of an atomic nucleus.

We are trying to see if there is any ultimate limit in the precision that one can possibly make in this kind or any other kind of measurement. There are some ideas originating from gravitational physics and quantum mechanics that imply that the information storage capacity of the space-time itself that we live in is finite, that it’s just like in a hard drive or a memory stick, there’s a maximum amount of information that you could possibly pack in. If you try to measure it better than that precision, you won’t be able to because space doesn’t have any more digits to give you.

Can you describe how this limit relates to the 3D nature of the universe?

The information content of all the matter that you throw into a black hole would end up being stored on the surface of the black hole. The bizarre thing about black hole physics is the information content is not proportional to the volume of the black hole, but rather just the surface area. This is called the holographic principle; it’s an analogy to a hologram in which you store an apparently 3D image on a 2D surface. But if you scatter light off the surface in a particular way, the pattern of the scattered light apparently reconstructs the three-dimensional image. This is similar to what’s believed to happen when objects fall into black holes, that somehow the three-dimensional information of the object that fell in gets transcribed and encoded on the two-dimensional surface of the black hole.

How does that affect the information storage limit of the universe?

Say you start with a situation where you don’t have any black holes at all but you have a bunch of memory sticks, and you say well, gee, I don’t have enough storage here in the memory sticks in my backpack, and I need more storage capacity. I’m going to go to buy a bunch more memory sticks, cram them all in my backpack and then I’ll have more storage capacity. Eventually what happens is if you’re super strong, like Hulk strong, you cram all those memory sticks in, and the density of all that matter inside your backpack gets so large that you form a black hole. You might say, well, that wasn’t very good, but no matter, I’ll go buy some more memory sticks. But then you see to your dismay that instead of being able to cram more information into this backpack-shaped black hole, the black hole grows, so the actual density of information storage you have in your backpack stays the same. That’s kind of what we mean when we say that it could be that space-time itself has some maximum information storage capacity. Once you reach the black hole limit, if you try to cram in more information, it just takes up more space.

How would this limit be reflected in the Holometer measurements?

There’s a prediction that if space runs out of digits, it gives you the same kind of error in the measurement of the two devices that are situated close to each other. Your measurements start being correlated at that point for no reason.

If you do find this limit, does that mean that 3D is a construct?

If it turns out to be true that the information is stored on two-dimensional surfaces like in a hologram, rather than in three-dimensional volume, I think that it would be a very interesting curiosity, and maybe it would lead us down to other paths of thought and study. I don’t think it really affects our everyday three-dimensional lives. One could ask if you find it disturbing that all the instructions for constructing a person or an animal or a plant could actually be encoded in one dimension using an alphabet based on four different letters.

What’s your timeline for figuring out whether there is a limit?

We have recently commissioned our detectors to be operating at full sensitivity, so we are beginning to collect data. We’re expecting to have reportable results on a one-year time scale. Any time you operate an instrument at greater sensitivity than you have ever done before, you’re going to find all sorts of problems, so at that point you enter in a long debugging phase to make sure that if you do see something that looks a little bit odd, that you really figure out what it is, so if we do see this unexpected limit on the precision of our measurements, that we can confidently draw some sound scientific conclusions from it.

How do you handle the pressure that you might not find anything?

One of my favorite professors from graduate school described basic research to us as it’s like going out for a midnight swim in the ocean. Maybe by chance you’re going to bump into something floating out in the water, but most likely it’s just going to be perfectly clear waters. But that doesn’t prevent you from wanting to go out for a midnight swim. A lot of the fun and the excitement is in the process itself. I personally think of each experiment I work on as a lottery ticket. The probability that I’m actually going to find anything in any particular experiment is pretty small. But on the other hand, it’s not vanishing. All of these experiments I work on have a very good theoretical motivation. So if we do find something, life is really good.

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X

The Origins of Lying and Deception in Everyday Life

How do children make sense of the complex social code that dictates when they should or should not lie?

[...]

Our human experience confirms that lying, falsehood, and the masking of our inner selves exist as part of the social world in which we live. Saarni, a professor of psychology at Sonoma University, has shown some of the methods people use to deceive, which derive from social norms prescribing how people should express their feelings. Such rules of comportment usually seem completely natural to the people who have been brought up with them, yet they vary greatly from one culture to another. [...]

Of course, there are many varieties and degrees of deception; masking one’s emotions is very different from deliberately uttering a falsehood. One way to sort out the various forms of lying is to consider the state of the deceiver’s awareness of his or her deception. [...]

Deception or lying without awareness is more problematic. If someone makes a false statement without knowing that what she or he said is contrary to fact, the speaker cannot be said to be lying. Acknowledging this point then brings us to questions about deception in nonhuman animals. Although there is considerable evidence of deceitful behavior in animals, it is not clear that chimpanzees, for example, have a third-level perspective that can be characterized as “I know the other chimp knows that I know.” Without this perspective, animal deception has to be distinct from that of humans. [...]

In earlier work, I have suggested a taxonomy of lying and deception that may be useful in examining children’s behavior in this regard. This taxonomy may turn out not to encompass all types of deception, nor does it imply that the types are mutually exclusive. In many cases, an act of deception may meet more than one of these criteria:

Lying to protect the feelings of another;

Lying for self-protection to avoid punishment;

Lying to the self, or self-deception; and

Lying to hurt others.

The first three types, although often considered moral imperfections, will be shown to be positively related to other cognitive skills. [...]

Lying to Protect the Feelings of Another

*Rana, a three-year-old girl, was eagerly awaiting a Christmas present from her grandmother. She’s hoping for a fun toy. Nevertheless, when her grandmother presents her with a sweater she has knitted, Rana rips open the package and smiles at her grandmother, saying, “I like it.”*

Rana, like many children her age, has already learned how to adjust her facial expression and speech to meet social requirements. This practice is often taught under the name of “little white lies,” although I prefer the description “lying to protect the feelings of others.” In *The Rise of Consciousness and the Development of Emotional Life*, I have argued that the function of this type of deception is socially adaptive. As summarized by the Norwegian sociologist Stein Braten, there is considerable evidence that the human infant has built-in mechanisms for helping others. Although some say that such deception detracts from interpersonal relationships, it seems reasonable to assume that the maintenance of social interaction requires some deceptions of this type. [...]

Often, their early coaching in this skill takes place in the home. Given that parents lie to spare the feelings of others, they are likely to coach their children in this practice (“Tell Grandma that you like her gift/cooking/choice of movie even though it may not be what you wanted”). Children may also see their parents engage in deception to save the feelings of others. Thus, for example, Rana may hear her mother say, “My friend is coming over for tea and I am too tired to see her,” but when the friend arrives, the child sees her mother smiling and hears her say, “I am so glad you stopped by.” [...]

Although the experimental data are still limited, they show that deception to spare the feelings of others can be seen as early as three years of age and that girls may be better at it than boys. Moreover, parental instructions to lie to protect the feelings of another appear to be effective. [...]

These studies touch on the interesting challenge between a child’s developing moral behavior and his or her developing prosocial behavior—that is, any behavior that is intended to help others. Clearly there is a conflict between not telling a lie and not hurting another’s feelings, especially given that honesty is considered to be part of moral behavior. To address this question, in 2009 Gail Heyman led a study at the University of California–San Diego in which children were asked their reasons for telling a lie. The researchers gave children between the ages of seven and 12 years old a series of vignettes, some of which were about children who receive an undesirable gift and are asked whether they like it or not. In half the stories the children tell the truth, and in the other half they do not. In another series of stories, a child transgresses by damaging a library book. Again, in half the stories the children confess to the damage, whereas in the other half they do not.

When asked to evaluate the behavior of the children in the stories they had been told, the participants in this study gave more neutral ratings of the politeness stories and more negative ratings of the transgression stories. Such findings as these support the view that children learn and evaluate positively lies that protect the feelings of others more than other types of lies. [...]

More support for the prosocial view of lying comes from an unpublished study by developmental psychologist Antonella Brighi, of the University of Bologna, who found that four-year-olds who masked their emotions more successfully when placed in the “disappointing gift” paradigm were more likely to be chosen by other children to be their play dates. As we will see, lying and deception are often associated with other prosocial and cognitive abilities. [...]

Lying to Avoid Punishment

*Two-year-old Maron is told not to eat a cookie, but when his mother is out of the kitchen, he does so. When his mother questions him about eating the cookie, he lies and says “No.”*

Another common form of lying in children has to do with the motive to avoid punishment. Children learn readily to lie when they have committed some undesirable act or have not done something they were asked to do. In this example, Maron remembers that eating a cookie has in the past evoked parental anger or punishment, and he tries to avoid these predictable consequences by lying. [...]

In a similar study, we looked at more than 180 children between three and six years of age. As expected from other studies, as children become older, they become better at resisting temptation. By the age of six, 35 percent of the children were able to sit with nothing to do and resist the temptation to peek. At the same time the prevalence of lying increased, so that by at age six all the children who had peeked denied having done so. While 25 percent of children two to three years of age admit to peeking, this number drops to near zero when the children are five years or older. Thus, even by two to three years, most children have learned to lie when they violate a rule. Although girls are less likely to peek than boys, there are no sex differences in lying.

From the similar data on age-related changes in lying that have been found in Japanese, West African, and Chinese children, it appears that lying to avoid punishment may well be a universal phenomenon. Moreover, lying to avoid punishment becomes more common as the child grows older, a pattern that also has been repeatedly observed. Given the widespread use of this type of lie, as well as its increase with the children’s increasing age, it may be an important adaptive response in humans, associated with other adaptive functions and competencies. Telling a lie successfully requires not only the ability to create a false belief deliberately but also to have some idea about what another person may or may not know; this capacity, known as a “theory of mind,” commonly develops in children around the age of two to three years.

The “peeking task” itself taps two skills: the ability to delay or avoid peeking, and once having peeked, the ability to lie. Although it is not central to deception, a child’s inability to resist peeking is related to several features associated with dysfunction. As an example, the speed with which a child gives in to the temptation to peek is inversely related to his or her IQ and emotional intelligence: Those who peek sooner tend to have lower scores on emotional knowledge as measured by tests such as being able to name emotional faces when shown to them, and lower scores on their knowledge about what emotions are likely to be seen in particular contexts. Children from risky family environments peek sooner, as do children with higher neonatal risk scores. The ability to resist peeking for a shorter or longer interval is clearly related to children’s competence.

However, the picture changes when lying is examined with regard to the child’s social and cognitive competence. Children with higher IQ are more likely to lie than those with lower IQ. Moreover, children who score higher on measures of emotional knowledge are also more likely to lie than truth-tellers. The truth-tellers had lower IQ scores by more than 10 points.

Other studies of children from three to eight years old have looked at lying and its possible relation to various aspects of mental development. In another study by Talwar and Lee, children were asked about the nature of the toy after they denied having seen it. Younger children were unable *not* to name the toy, thus revealing they had peeked, whereas older children had no difficulty concealing the fact. In another study, children who lied and those who did not were compared on several tasks that assessed moral judgment, theory of mind, and executive functioning, which included the challenge of inhibiting certain responses. In all these assessments, children who had lied scored better than those who had told the truth—a result that strongly suggests the ability to lie is positively related to cognitive competencies!

Such findings support the view that people who commit a transgression and confess are less capable in many capacities, a view that bears important personal as well as sociobiological implications. Robert Trivers, in his book *The Folly of Fools: The Logic of Deceit and Self-Deception in Everyday Life,* argues that deception can be useful in protecting the immune system by reducing the stress response (that is, preventing an increase of the stress-related steroid cortisol) that would result from the child’s failure to meet her or his standards or goals. Increases in cortisol have been shown to be inversely related to immunological competence.

The notion that lying to protect oneself from punishment may be adaptive is consistent with the work of anthropologists such as Richard Byrne, who in 2004 found a positive relation between neocortex size and deception in primates. At the same time, the association of lying with prosocial behavior has been amply demonstrated. Moreover, psychologist Roy Baumeister and others have suggested that in some cases lying may be important for mental health, whereas Francesca Gino and others have shown lying to be related to creativity. [...]

Self-deception

The third type of deception in our taxonomy has been the hardest to study, particularly in young children. Nevertheless it is common among both adults and children, and clearly it presents both advantages and disadvantages:

*Benjamin, a shy young man, calls a woman for a date and is told that she cannot see him because she is busy for the next three weekends. He now has a choice: He can conclude that she does not want to go out with him, and feel humiliated and shamed at the rejection. Alternatively, he can conclude he does not want to date such a busy woman. This spares him the shame and humiliation. In fact, both thoughts pass through his mind, but he remembers only that he does not want to date her.*

The psychic advantage of this way of thinking seems clear; in some circumstances, there may be little reason to lower one’s self-esteem by being honest with oneself. On the other hand, self-deception may close off the possibility of learning from one’s mistakes or taking some necessary action—for example, if a person examines his body and discovers an unexplained lump. If the individual persuades himself that the lump has always been there—a false memory—he is likely to take no action. Should the lump be recognized later as a first sign of cancer, the delay of treatment stemming from this self-deception could bring serious consequences. It is fair to say self-deception may be psychologically valuable but also sometimes self-defeating. [...]

Self-deception in children has received scant scientific attention to date, but fortunately there are data available on the development of pretend play, with which it shares many features. [...]

By three years of age, a child’s ability to maintain internal rules and goals enables him to consider the success or failure of his behavior and even to apportion blame or credit for it. (Psychologist Carol Dweck gives an excellent account of this with older children.) This new ability also allows for the emergence of the self-conscious emotions of embarrassment, shame, guilt, and pride. In my book *Shame: The Exposed Self,* I show that by age three, children show shame when they fail a task and pride when they succeed. These powerful emotions provide the motivation for ways of thinking about themselves, which also allows them to self-deceive around their own success and failure.

Although it is easiest to observe in young children, where it may be dismissed as simple “play,” self-deception is important for emotional life at all ages. Moreover, as we and Trivers believe, self-deception may be needed for all forms of deception. [...]

Lying to Hurt Others

The fourth category in our taxonomy is the type of lie designed to inflict suffering. Far from being adaptive, such lies represent some form of psychopathology. For the most part, lying that injures another has not received much attention, although Richard Rogers has studied pathological lying. Of all of the four types of lies mentioned here, this is the least prosocial.

Attempting to protect oneself from punishment by lying about another is likewise maladaptive, because such lies, although sparing oneself from punishment, simply transfer the punishment to another person. From the point of view of a young child who scribbles on the wall, blaming the mischief on a sibling makes sense as a way to try to escape punishment. From a broader perspective, however, placing the blame on another is not an adaptive response, for it does not lead to social coherence.

More to Learn About Lying

Our concern about lying is not solely a national issue, even though we have as a focus the invented story of George Washington’s immaculately truthful childhood. Some studies with children across the globe suggest that lying and deception may exist as a feature of the human condition. Our current national debate about federal or state agencies lying to us is just part of the larger discussion in which the morality of lying is pitted against its evolutionary function and its prosocial needs.

Lying to others is most often seen as an interpersonal failure because it damages trust, believed to be one of the hallmarks of a relationship. Yet, as we have already noted, lying to protect the feelings of another appears a necessary act similar to other prosocial behaviors such as helping and empathy. Whether any type of lying is justified remains an issue of conflict for most of us, even though there are times when it seems justified.

This conflict over lying has become more pronounced over the last 50 years as the rules of etiquette, which in the past have been used to control much of social behavior, have been replaced by the idea that we should speak our minds—that is, not to lie by words or emotional behavior.

The change from fixed rules, independent of internal feeling, to frank expression of our feelings has intensified our ideas about lying and deception, making such behavior socially as well as morally unacceptable. This may explain why parents are so upset about their children’s lying.

*When Margaret comes home from a play date with Rana she is holding a doll, which she claims was given to her by Rana’s mother. However, a phone call from Rana’s mother, mentioning that the doll can be brought back at the children’s next play date, reveals that Margaret has taken something that was not hers. Margaret’s false statement now becomes the central issue, as her mother says, “You lied to me! Now you will be punished.”*

Thus, the focus of the problem has shifted: The point at issue is now the failure in the relationship between Margaret and her mother because Margaret has lied to her, rather than the girl’s moral failure in taking her friend’s doll. Had her mother known that lying to protect oneself from punishment is likely a natural and adaptive response of our species, she might not have lost the opportunity to educate Margaret on the fundamental moral issue in this incident, namely that of stealing.

The research up to now suggests strongly that lying is a human behavior and that most forms of deception have adaptive significance. It is fair to say, however, that our conflicted feelings about lying and deception probably reflect an inherent conflict between two evolutionarily derived needs: the need for some form of trust and for social harmony. In fact, Lee, when examining lies to protect others’ feelings and lying for protection, found that school-age children can make this distinction.

What we need to learn from the work carried out so far is that some forms of lying, for example, to protect ourselves from punishment, are necessary only because we have violated a social or moral sanction. It is toward this, the teaching of social and moral standards, that parents can most effectively direct their efforts for the sake of their children’s future well-being—not toward the eradication of lying, because the studies discussed here show that lying (whether to avoid punishment, to protect the feelings of others, or as a form of self-deception) may well constitute an important aspect of prosocial behavior.

Future research on the relation between lying and deception as they relate to subsequent moral behavior will be important to explore. We will need to continue to study how lying and deception affect social-emotional behavior and the forming and maintaining of adult social relationships. In addition, the relation between self-deception and psychopathology needs careful study, because the role of self-deception in the maintenance of self-esteem has important implications for the treatment of psychological distress as a consequence of traumas related to conflict and war.

American Scientist, [March-April 2015](http://www.americanscientist.org/issues/id.113/past.aspx) - Volume 103, Number 2

Faut-il préférer le bonheur à la vérité ?

N’y a-t-il aucune vérité dans le mensonge ?

Ce qui est vrai en théorie peut-il être faux en pratique ?

The Next Great Exoplanet Hunt

What strange new worlds will our future telescopes find?

[Kevin Heng](http://www.americanscientist.org/authors/detail/kevin-heng), [Joshua Winn](http://www.americanscientist.org/authors/detail/joshua-winn)

[...]

Amid this rush of activity, we often have to explain ourselves to our fellow physicists, who perceive exoplanetary science as being “not fundamental” and qualifying only as “applied physics.” But purity does not always equate with importance, and what is not pure is not always trivial. Although exoplanet hunters are certainly not expecting to stumble on new insights into grand unified theories, the scientific stakes are no less high: to remove humanity from the center of the physical, chemical, and biological universe, thus completing the Copernican-Galilean revolution, which established that the Earth revolves around the Sun. To quote exoplanet hunter Sara Seager: “Hundreds or a thousand years from now, people embarking on interstellar travel will look back and remember us as the society that first found the Earthlike worlds.” The hunt is on.

American Scientist, [May-June 2015](http://www.americanscientist.org/issues/id.114/past.aspx), Volume 103, Number 3, Page: 196

Qu'est-ce qui a du sens ?

How Can Art Move Us Beyond Eco-Despair?

Grim news about climate change easily triggers a sense of helplessness. Art can help redirect that feeling into one of active engagement.

[Robert Louis Chianese](http://www.americanscientist.org/authors/detail/robert-louis-chianese)

[...]

Many Americans seem willing to wait out what they believe to be temporary aberrations in climate, despite all the evidence to the contrary. Already on the West Coast we are starting to see flare-ups of class contention over water, the present-day equivalent of California’s gold. The sense of an imminent crisis is inescapable: Something is likely to crack.

Something already has—our psyches. A June 2014 study by social scientists charts the ill effects of climate change on people’s emotional states. *Beyond Storms and Droughts: the Psychological Impacts of Climate Change* , a 50-page report by the American Psychological Association (APA), gauges human reactions to environmental disturbance and catastrophe. At the community level, it finds climate change causing a loss of social cohesion, as well as increased violence, crime, social instability, aggression, and domestic violence. This bleak catalogue of ills mainly afflicts people whose communities have been devastated by climate change–induced fire or flood or hurricane, even more so for the poor and alienated. Feeling beset upon and hopeless, their very identity and autonomy become threatened, with manifestations of post-traumatic stress syndrome. Our planetary disturbance infiltrates our inner lives, with alarming and often unacknowledged effects.

These social ills have been with us for a long time. But today, for those of us who are fully aware of—who are dreading—the seemingly inevitable unfolding of climate change, the consequences may be even more personal and interior. The APA report refers to this condition as “ecoanxiety“ and cites a trio of disastrous symptoms: helplessness, fatalism, and resignation. This is what a lot of us feel. We may not put a name to it, but a sure sign of ecoanxiety is the humorless tone of environmental discourse. I would label this state as eco-depression, or more dramatically, *eco-despair*. I suspect anyone paying close attention to ecological effects feels it.

Eco-despair presents an interesting challenge. We want to remain engaged in actions that work to understand and communicate, as well as to reverse or slow climate change—but taking action requires excitement, and often a sense of mission. Keeping up protracted, often fractious connections to others can drain a lot of energy. Depression of any sort can sap motivation and leave one isolated with a triumvirate of mental pains: that “helplessness, fatalism, and resignation” that can leave one overwhelmed, bitter, and cynical. How might we treat eco-depression?

Art can help here—specifically, a certain kind of art that deliberately depicts and imaginatively confronts us with climate change. [...]

Artist Chris Doyle creates a light box entitled *History of the Twentieth Century I* , illuminating the discarded, unrecycled junk of our “Waste Generation.” Old televisions dominate, with abandoned, obsolete factories and oil rigs in the background, and appliances to one side. On first look, the colorful jumble has a fantasy, theme-park aspect; the blue skies and boundless clean gear intrigue us. Yet, what sort of history have we here? What about this arrangement? [...]

As we condemn smoke stack industries, lament cars and oil, and scorn empty, frivolous television entertainments, we need to remind ourselves that we are major buyers and discarders of electronic devices. Even our recycled e-waste may just get dumped in a landfill in China or Ghana or be dismantled for materials by the poorest of people. [...]

This could lead to guilty despair—our junk eats up enormous resources and carbon-based energy. Or, it might lead to revised policies that work to ensure recycling, or to devising e-products easy to dismantle, or simply to holding on to our gear for longer periods of time. Careful reflection on the content of Doyle’s work opens us up to a wider vision of who the culprits are, scaling back our anxious anger at large ominous forces and giving us pause about what we might individually do to lessen the waste stream. [...]

Ed Ruscha’s *LAX-Sunset-Malibu* (1981) depicts a murky panorama of the Pacific and its famous coastal highway, with three lightly-lettered place markers barely discernable through the blackening haze. This is a land- and seascape from the dog days before the Clean Air Act would clear the smog from the atmosphere. The Weisman Museum itself perches right on the coast in Malibu, but the prospect these days is pristine, the air transparent with a healthy glow. Some things we apparently can improve. This encouraging note may be incidental, because Ruscha obviously meant to indict, not to praise. But who knows what the painter and his lurid light show hoped to instill beyond our disgust with our endless combustions? Once the universal butt of jokes about car culture, Los Angeles now leads the country in reducing pollution. How might this art have effected such change? [...]

What about that title? Ah, “Sunset” refers to the street, not just to the time of day. Viewers who have driven along Sunset Boulevard to the beach will recognize themselves in the picture, perhaps enjoying the iconic drive through downtown, to Hollywood, the Strip, Beverly Hills, and finally the Pacific Coast Highway. Confronted not with the anticipated grandeur of the ocean but a dark layer of what looks like fiery smoke, viewers can be pulled out of their presumed fascination with tourist spots and celebrity culture and realize that our “good-time” excitement itself causes the stain. This early sign of climate change spreads ominously along the coast and into our consciousness.

This realization can make us guilty, anxious, depressed. Yet we are viewing the problem at human scale, with an implied human perpetrator—us—and by extension a human remediator. We can change our ways, become more conscious of how our recreations and simple pleasures can blight the landscape, and take stock of the unseen consequences of tootling around the country clueless about its effects.

Ruscha’s painting, rather than overwhelming us with atmospheric data or depersonalizing the problem, instills a kind of calm, a slow, deliberate looking around ourselves to see what is so obviously there, but unseen. (Scientists too move into this reverie and observe and reflect before they analyze and experiment.) Art wishes to sustain that reverie as long and intensely as possible and draw personal insight and human wisdom from it. [...]

American Scientist, [May-June 2015](http://www.americanscientist.org/issues/id.114/past.aspx), Volume 103, Number 3, Page: 176

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L’art peut-il manifester la vérité ?

L’art transforme-t-il notre conscience du réel ?

L’art sait-il montrer ce que le langage ne peut pas dire ?

L'oeuvre d'art peut elle nous apprendre quelque chose ?

Une oeuvre d'art peut-elle échapper aux critères du beau et du laid ?

L'art est-il moins nécessaire que la science ?

Restoring Depth to Leonardo’s Mona Lisa

Was *La Gioconda* the model for one of the world’s earliest attempts at three-dimensional imaging?

Despite its singular fame, the Mona Lisa is not one of a kind. In fact, another Gioconda graces the permanent collection of the Prado Museum in Madrid.

Although it strongly resembles the Mona Lisa, the portrait in Madrid had long been considered an insignificant copy of Leonardo da Vinci’s masterpiece, mainly on account of its dull black background. [...]

Almost certainly, the individual who painted the Prado Gioconda was witness to the entire process of creation of one of the most famous paintings in the world. By this reasoning, the Prado Gioconda is itself a product of Leonardo da Vinci’s studio, produced simultaneously with the Mona Lisa. For all the two portraits have in common, a side-by-side comparison makes it clear that they differ in two major ways: perspective and coloring. [...]

The angle between the two painters’ perspectives was apparently very small: An average of the participants’ estimates yielded a disparity between the two portraits of 69.3 millimeters. This measurement, which perhaps does not sound significant in itself, is actually very close to what several international anthropometric studies have found to be the average distance between the pupils of the two eyes of adult Italian males, 64.1 millimeters—a point worth noting in the context of binocular vision and depth perception. So far, we have two brilliantly executed oil paintings that correspond to each other in many fine details but differ in one essential point: the perspective. Moreover, the difference in perspective closely approximates that found between the two eyes of the adult male face. This opens up a unique opportunity: We can now compile a 3D image of the Mona Lisa. [...]

We know from Leonardo’s artistic but not entirely systematic notebooks that he was pondering the problem of how to depict 3D information on a two-dimensional canvas: On the facing page, at top, a sketch he made in preparation for his altarpiece painting *Adoration of the Magi*shows the meticulous care with which he planned a complex scene. From his notebooks, we also know (as shown at right, bottom) that he pondered at length the workings of binocular vision, developing a theory to account for the differential occlusion of objects as seen from the different perspectives of the two eyes. In fact, Leonardo was one of the few painters—of the Renaissance or of any period since then—to study 3D vision so intensively.

There is no proof in the notebooks, however, that he came to the correct answer in the end, identifying binocular disparity as the basis of stereovision or *stereopsis.* Today,influential vision scientists such as Nicholas Wade, Emeritus Professor in the Department of Psychology at the University of Dundee, Scotland, therefore assume Leonardo never took that essential final step.

Nevertheless, more than three centuries before the *stereoscope* (the first standard device capable of displaying 3D images) was invented by British scientist Charles Wheatstone, Leonardo created a pair of oil paintings in which certain areas, although not the entire work, meet the criteria for producing a 3D image. [...]

A newly emerging *joint science of aesthetics* can provide a fascinating and powerful framework for future research on aesthetics. As an example, we are currently collaborating with researchers at the Smith-Kettlewell Eye Research Institute, in San Francisco, to test the surprising hypothesis that the Dutch artist Vermeer developed and secretly applied optic devices for creating his stunning, photographically appealing paintings. In another project, together with artists at the Cardiff School of Art in Wales, we are investigating how the geometry of a painting would best simulate the viewer’s everyday habits of perception. With studies of this kind, the science of aesthetics offers an opportunity for reconsidering unsolved questions and opens new perspectives on not-yet-questioned issues in a thrilling interdisciplinary way.

[Claus-Christian Carbon](http://www.americanscientist.org/authors/detail/claus-christian-carbon), [Vera M. Hesslinger](http://www.americanscientist.org/authors/detail/vera-m-hesslinger), American Scientist, [November-December 2015](http://www.americanscientist.org/issues/id.117/past.aspx), Volume 103, Number 6, Page: 404

Peut-on aimer une oeuvre d'art sans la comprendre ?

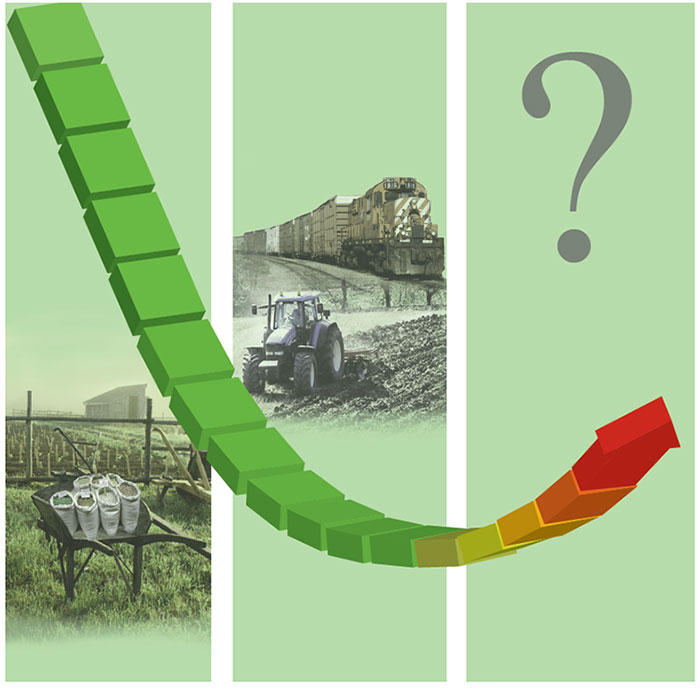
L'art est-il moins nécessaire que la science ?

# The Rising Cost of Resources and Global Indicators of Change

**The turn of this century saw the cheapest-ever energy and food combined, and here’s why we may never return to those historic low numbers.**

[Carey W. King](http://www.americanscientist.org/authors/detail/carey-w-king)

American Scientist, [November-December 2015](http://www.americanscientist.org/issues/id.117/past.aspx), Volume 103, Number 6



Contemporary discussions of energy resources and technologies are full of conflicting news, views, and opinions from extreme sides of arguments. The average person is understandably confused. Depending on who you listen to, horizontal drilling and hydraulic fracturing have either placed the United States on the verge of energy independence, or exposed the insolvency of oil and gas companies as they spend more money than they collect from sales. Renewable energy technologies can either obviously serve all of our needs, or are a subsidized path to economic ruin.

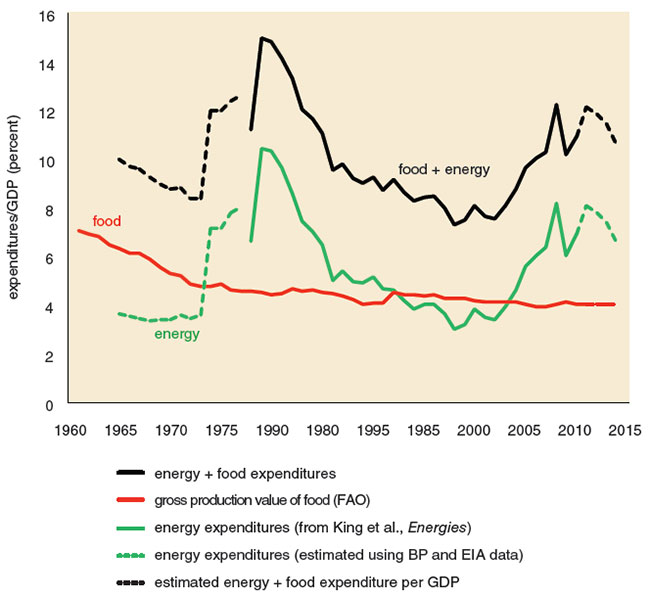
In the vast majority of instances, the extreme views are hyperbole of a much more subtle reality. It is tantamount that we properly consider future energy options in the context of relevant biophysical and socioeconomic trends. Otherwise, we risk merely treating symptoms of the true underlying causes.

One approach to a deeper understanding of energy, particularly for the general consumer, is to put the numbers into practical context. For instance, here’s an essential takeaway shown by my recent data analysis: The turn of the 21st century marked an important societal turning point, as the time of the cheapest food and energy the world has ever known.

For developed countries, and likely the world overall, the trend of increasing food and energy services consuming a declining proportion of our economic output (in terms of gross domestic product, or GDP) seems to be over, perhaps permanently. The implications for future economic growth and social relations are extremely important, particularly as we come to grips with the slow rates of growth that continue to define the current world economy.

It is practically impossible for us to significantly alter many of the long-term causes of energy and food cost trends. As a consequence, the ability of our energy system to aid in the achievement of environmental and socioeconomic goals lies primarily in using technology to consume less energy and deal with the obvious: Earth is a finite planet.

# Measuring Costs



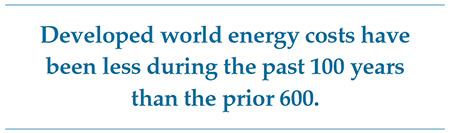
Consider the world more than 200 years ago, before industrialization and the pervasive consumption of fossil fuels. In this world, biomass (firewood, for instance) and food were the dominant fuels. Food and fodder powered the main prime movers of society (and still do for many parts of the developing world): human and animal muscles working the land. Wind and water mills made important use of renewable sources, but biomass stocks drove most of society. Thus, for a long-term perspective, we must consider food as part of the world’s energy supply.

How do we measure whether energy is cheap? Many people think prices determine if something is cheap versus expensive: how many dollars for a gallon of gasoline, how many cents for a kilowatt-hour of electricity. However, tracking energy prices tells only half of the story. The other half is how much food and energy people actually purchase. Prices are the signals that inform what we consume, but they alone do not tell us how much we spend in total.

Thus, it is useful to measure the *energy-food cost share* as total expenditures (price×consumption) on food and energy relative to GDP (and also as a percentage of personal income). The lower the energy-food cost share, the easier it is to attain basic needs, and the more money is available for invention and consumption of discretionary goods, services, and industries (such as movies and vacations). Of course, if the energy-food cost share increases, then the opposite is true.

Economic historians have collected data to estimate energy expenditures going back more than 100 years. Data assimilated by Roger Fouquet (for the United Kingdom and England back to 1300) and Astrid Kander (for Sweden back to 1800) provide insight into the energy cost trends during the transition to the fossil fuel era.

In the United Kingdom, only after 1830 did energy expenditures relative to GDP drop below 20 percent, and in Sweden only after 1920 (largely because cheaper coal was adopted later). The cheapest energy in the United Kingdom’s history was in the mid-2000s, and the Swedish data indicate a flat energy cost share from the mid-1980s to 2000. Developed world energy costs have been less during the past 100 years than the prior 600.



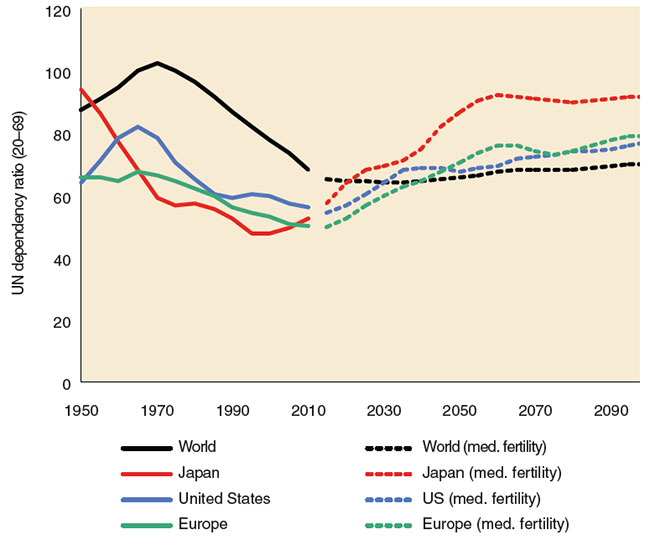
The United States Bureau of Economic Analysis maintains a shorter time-series that shows the same pattern of declining energy and food costs for the United States. The share of GDP allocated to U.S. consumer food and energy purchases declined for 70 years until 2002. After that year, energy and food became more, not less, expensive.

Considering world energy (not including food) expenditures since 1978, the minimum was around 1998, predominately because of extremely low oil prices at that time. World expenditures for food production have also stopped decreasing over the past decade. Combining world energy and food expenditures data shows that the world trend of energy and food costs as a share of GDP reached its minimum around the year 2000. Thus, considering the more than 200-year trends of the United Kingdom and Sweden, the 70-year trends of the United States, and the 30-year trends for the world, the data support the finding that the turn of the 21st century marked the cheapest energy and food in history, but are now reversing that long-term course and trending upward.

# Age and Infrastructure

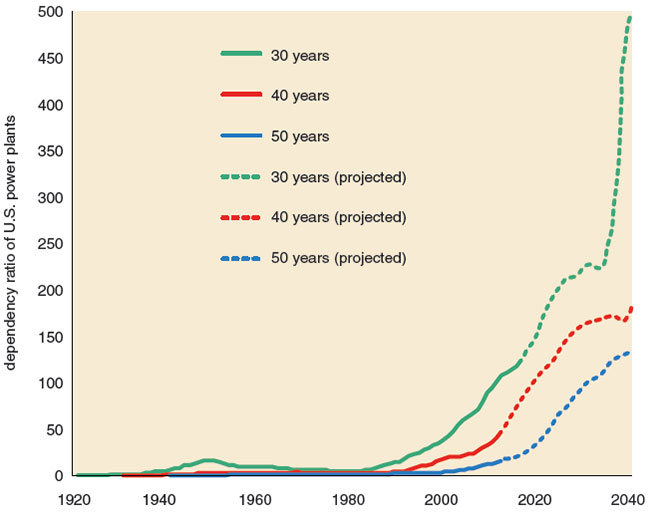
Stein’s Law, named for economist Herbert Stein, states: “If something cannot go on forever, it will stop.” Applying Stein’s Law to declining food and energy cost shares implies they cannot decline eternally, unless energy and food become free and/or GDP grows to infinity, neither of which are likely on a finite planet. There are several driving factors that make it unlikely that the world will reverse its recent course and pay less for food and energy than that already achieved around the turn of the century.

One driving factor is population. Living populations grow exponentially until they reach constraints. A decreasing population growth rate is a natural system response to negative feedbacks from diminishing returns on increasing the population within finite space, time, and resource inputs. United Nations (UN) data show that post-World War II world population growth rate peaked in 1968 and has been slower every year since. In other words, the cost-benefit ratio of having children is decreasing because of inherent constraints of a finite planet. However, the population is still growing, and a larger overall population requires more food and energy production and distribution, with all other factors held unchanged. Because energy and food expenditures per GDP bottomed out around 2000, this makes it more costly to maintain this larger population.



Further, as populations slow their growth rates, they get older. UN projections indicate that 2010 is characterized by a minimum in the *dependency ratio,* an estimate of the non-working fraction of the population divided by the working fraction of the population. Thus, the smaller the dependency ratio, the easier it is for workers to support non-workers (those too young or too old to work). Since the 1960s, worldwide the number of working-age people has been growing faster than the number of dependent persons. Going forward from 2010, the opposite trend will hold. In the 1990s Japan was the first industrialized nation to struggle with this change in demographic trend. Europe and the United States are experiencing the change now.

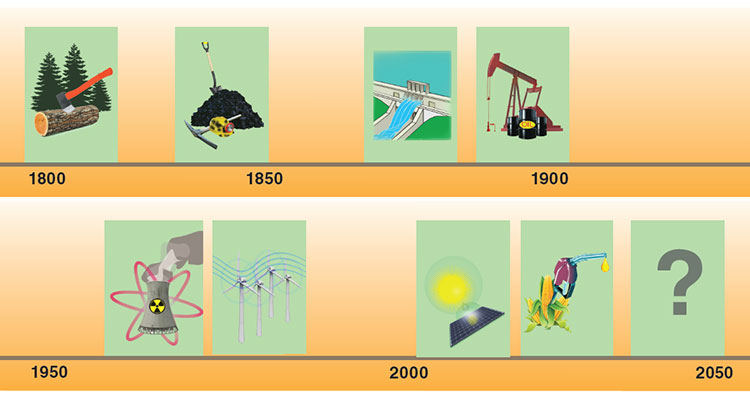
Just like with population, as we have slowed the expansion of our energy infrastructure, it has also become older. I have calculated a *dependency ratio* for U.S. electric generation equal to the fraction of total capacity that is older than a certain age (for instance, 40 years) divided by the fraction of total capacity younger than that same age. We have never had an older fleet of power generation assets than today. Since the late 1970s, we have relied more and more on older power plants.



The Energy Information Administration’s projection for new power plant installations indicates that the U.S. power plant fleet is expected to continue to get older. Power plants do not last forever, and they require maintenance. If we want to have more total generation capacity, we have to install new capacity faster than the existing capacity retires. Increasingly, maintaining and replacing power plants just to keep total capacity at the same level takes resources that have historically been allocated to accumulating more capacity in total.

In addition to having an older power generation fleet, the U.S. is no longer consuming more electricity. Just like the diminishing returns to increasing the population, we have diminishing returns to increasing electricity consumption and generation capacity. Because overall U.S. demand for electricity is constant (in some states demand is declining, fewer states increasing), the incentive for installing new power plants is small. The solutions then become to invest in smaller rather than larger increments. Hence recent investments have focused on energy efficiency, demand response, and smaller capacity natural gas, wind, and photovoltaic plants instead of larger coal-fired and nuclear power plants.

# Spending Energy to Make Energy

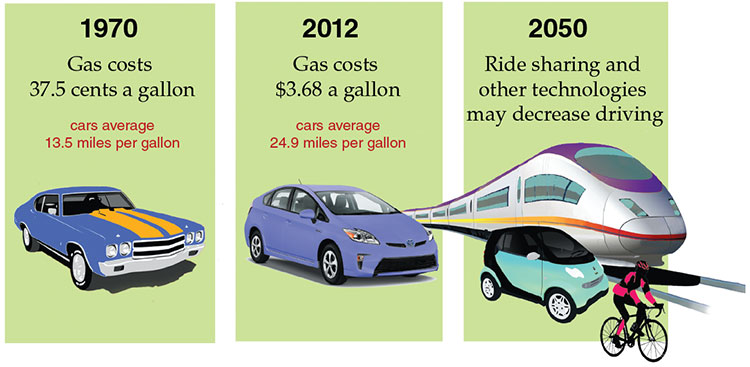


Although an older energy infrastructure requires more repair, maintaining the energy infrastructure and producing energy requires energy itself as an input. Because we’re spending more on energy overall since around 2000, this balancing act presents a conundrum. Our marginal energy supplies themselves are becoming more expensive, so we increasingly need more energy input to produce the same energy output from new resources.

As an example, consider the oil sands in Canada. During the past decade this resource became an economically viable energy reserve. Oil sands are significantly more expensive to produce than conventional oil, in that a lot of energy must be used to create steam that is injected underground to extract the bitumen. For every unit of energy input into oil sands production, less than 6 units of energy come out in the extracted bitumen. The U.S. oil and gas industry historically produced 10 to 20 units of energy relative to a unit of energy input. Considering the additional energy inputs for refining the oil to products such as gasoline and jet fuel, oil sands deliver less than 3 units of energy, whereas historically gasoline delivers between 5 and 10.

The lower this energy input/output ratio, the higher the energy cost. And this equation also largely governs which energy sources can be produced economically. Right now, sources such as the kerogen oil shale of the Piceance Basin in Colorado have a ratio too low for production. Unfortunately, many biofuels also have ratios that are too low (aside from southeastern Brazilian sugarcane for ethanol and electricity), and all suffer from limitations in productive land and climates. But can we become more efficient to enable consumption of such higher cost fuels?

# Efficiency and Consumption



One general response to increased costs is to become more efficient in the use of resources, both in terms of energy and capital. But in 1865, British economist William Stanley Jevons noted that technological improvements that increased efficiencies of energy use often caused industries to raise their energy consumption. Because of this rebound effect, also called the Jevons paradox, efficiency can help to promote growth that would otherwise not occur. So efficiency is a good cure for lack of growth.

Consider car fuel efficiency standards. In 1970 Americans drove their cars (with an average fuel use of 13.5 miles per gallon) and trucks (10 miles per gallon) for 1,035 billion miles, consuming 80 billion gallons of fuel. With gasoline at an average of 37.5 cents per gallon at the time, fuel costs were $27 billion, or 2.7 percent of GDP. In 2012 the numbers were 24.9 and 18.5 miles per gallon for cars and trucks, respectively, collectively driving 2,665 billion miles to consume 124 billion gallons of fuel. With gasoline at $3.68 per gallon, fuel costs were $457 billion or 2.8 percent of GDP. It is not a coincidence that fuel costs were practically the same, relative to GDP, in 1970 and 2012: Consumers adjust their habits to available technology and energy prices. If car fuel economy had not increased, Americans certainly could have afforded to drive only a fraction of the 2.7 trillion miles driven in 2012.

Today, the full cost of car ownership (payments, fuel, parking, and so on) is increasingly beyond, or unnecessary for, the urban Millennial generation, who will soon reach the peak driving ages of 35 to 54. Millennials have already influenced the 16 to 34 age demographic, driving 23 percent fewer miles from 2001 to 2009 than previous generations had done. Overall demographics are additionally pointing to less driving (older people drive less, and our population is aging). Student debt, crowded cities, and social media, amongst other factors, collect into “complex adaptive” changes within the U.S. socioeconomic system that lead to reduced driving. As the U.S. PIRG Education Fund reported in 2014, these changes indicate most driving forecasts are overly optimistic.

Millennials appear to be increasingly turning to car and ride sharing, examples of disruptive combinations of technology that can get around socioeconomic limitations. The services provide less transportation convenience than owning your own car and garage, but at significantly reduced costs and more efficient use of existing car capital. Thus, they are attractive services with enough grassroots support that it is too difficult for politicians to halt them on behalf of vested interests in the status quo (such as taxi services).

# Unequal Distribution

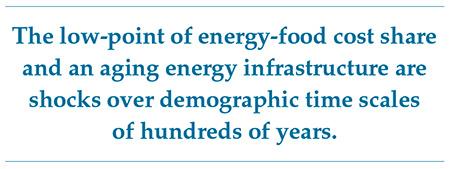
An additional factor in the distribution of consumption relating to energy is inequality, both within and between countries. The oil crises of the 1970s forced the developed Western economies to react, for the first time, to the fact that they do not fully control Earth’s finite resources. Other populations could make decisions affecting Western lifestyles. The United States no longer had increasing quantities of cheap oil of its own to pay down debts (such as from the Vietnam War) and provide a middle-class lifestyle.

Income and wealth inequality have become central topics since the Great Recession and Financial Crisis that began in late 2007. Per-capita income and energy consumption largely go hand in hand. A person who has more income consumes more energy both directly (fuel and electricity) and embedded in products (consumer purchases). From 1950 to 1980 the United States and Western Europe achieved historically unprecedented high levels of income equality. Cheap energy and distributive policies gave the American middle class easy living. French economist Thomas Piketty puts into perspective the wealth equality in the several decades after World War II, pointing out that it was uniquely high because so much wealth was destroyed in the wars. In other words, rich people got poorer; poor people did not get richer.

The developed economies have become decidedly less equal in income and wealth distribution since 1980 because of changes in domestic policies (such as lower taxes on capital and less benefits for labor) and globalization forces. Physicist Victor Yakovenko at the University of Maryland has calculated that from 1980 to 2010, the distribution in power consumption per capita between countries has shown increased equality. The same holds for income. Developing countries benefitted from declining equality in developed countries as manufacturing globalized. Americans now need two-income households to maintain the incomes from the 1970s, but Asians obtain higher incomes from working in new manufacturing and services jobs. Considering developing countries specifically, economist Martin Ravallion at the World Bank recently showed that total inequality (adding inequality between countries to inequality within countries) decreased from 1980 to 2005. Perhaps not coincidentally, developing country inequality then increased from 2005 to 2010 along with food and energy prices.

# The Debt Option

If inequality in developing countries is no longer decreasing, and developed economy households have had increasing income inequality for the past several decades, then how can consumption increase? Maybe we can just borrow to increase consumption. As economists Carmen M. Reinhart and Kenneth Rogoff state in their 2009 book titled *This Time is Different: Eight Centuries of Financial Folly,* “Financial crises seldom occur in a vacuum.” The global financial crisis that started in 2007 was no exception. It occurred in an atmosphere of economic ignorance about the influence of debt and the dependence of the economy on biophysical resources within the environment.



Reinhart and Rogoff point out that usually a real system shock occurs and then financial feedbacks react to and amplify the situation. Although not viewed as a “shock” as typically defined by economists, both the low-point of energy-food cost share and the dependency ratio for an aging energy infrastructure are shocks over demographic time scales of hundreds of years.

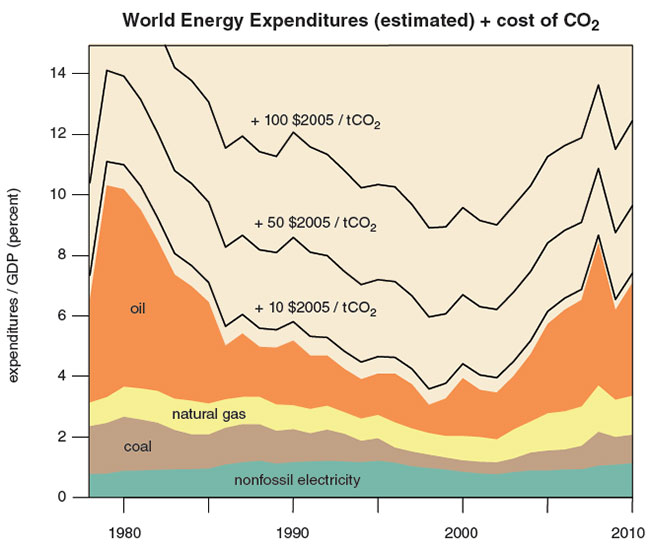
From 2000 to 2007 global debt increased from 246 percent to 269 percent of GDP, primarily due to household and financial sector debt, according to a 2015 McKinsey Global Institute study. In the early 2000s economic expectations were high based upon globalization and the Internet, both leveraged on cheap energy and food. As a result, Americans acquired home mortgages and borrowed against expected future rises in housing prices. The banks knew the mortgages were unaffordable but they were incentivized to pocket lending fees as long as the party lasted. It only became apparent to the developed world in 2007 that China’s pressure on increasingly scarce natural resources had increased prices to such an extent that it trumped the developed world’s debt-financed expectations.

Then from 2007 to 2014, global debt increased from 269 percent to 286 percent of GDP, a slower rate than the previous seven years, but this time driven by increases in public debt, as governments have attempted to come to the rescue by buying losing assets from private investment banks and insurers. Unfortunately, such monetary policy measures do not affect the real economy with biophysical constraints, which is where food and energy prices exist, and global debt continues to grow faster than GDP.

Lowering interest rates is the major tool of the central banks to try to entice economic growth by making it cheaper to borrow money. Countries have had high debts and energy prices before, but today central bank interest rates are lower than at any time in the history of central banking. Central bank rates historically average about 5 percent. However, the rates of the Federal Reserve, the Bank of England, and the Bank of Canada have been less than 1 percent since 2009. The rate at the Bank of Japan has been below 1 percent since 1996.

Interest rates near zero leave no room to maneuver downward, and the Central Banks then began a policy called *quantitative easing,* where they buy government bonds from the banks, to reduce the risk from banks holding poor quality assets. The theory holds that the banks will then be more willing to make new loans. The problem with this approach is that the process actually works in the opposite direction. Banks make loans, creating money, when businesses are confident that consumers can buy their products. Inequality and consumer debt have become so high that the average consumer doesn’t have enough money to buy much more of anything. Thus, even though borrowing money is cheaper than any time in the modern industrial era, present expectations about future growth are too low and uncertain for businesses and consumers to borrow anew. But many believe now is the perfect time for investments with a new purpose.

# The Carbon Market



To many the answer is clear: We should borrow the cheap money today to create the low-carbon economy of tomorrow. Decarbonizing our energy system is controversial for a multitude of reasons, but they boil down to disagreement on the costs versus the benefits. Internalizing CO2emissions from fossil fuel combustion increases the direct cost we pay for energy. That is to say it makes fossil energy more expensive; it doesn’t make renewable energy cheaper. For electricity generation, a price or tax on CO2 emissions directly raises the cost of natural gas and coal power but only to a much lesser extent (and indirectly) for nuclear, wind, and solar power that generate no CO2emissions during operation.

Consider that major recessions have coincided with high energy expenditures relative to GDP (such as the 1970s and 2007–2009). Adding CO2 expenditures to energy only increases “energy + CO2” expenditures. If there is a limiting percentage of GDP that can be spent on “energy + CO2” before coinciding with and/or causing recession, then as energy expenditures rise, CO2 market prices, and thus expenditures, should fall. This outcome has been exactly the response in the European Trading System carbon price. European Union officials assumed that the economy would always grow such that the carbon emissions market price would rise to induce new low-carbon investments. An alternative scenario has emerged since 2008, in which the exact opposite has happened: A no/low-growth economy has induced a low carbon price instead of a high growth economy inducing a high carbon price.

This energy and CO2 tango raises a question of priorities: Will countries target the needed CO2 emissions reductions if their economies are already shrinking or stagnating? Many studies predict that an emissions penalty (in other words, a tax or price on emissions) of $50-$100 per ton of CO2 would incentivize transition to a low-carbon economy. However, even at the time of cheapest energy in history (1998–2002), such a price would have caused the world to spend about 7 to 10 percent of GDP on primary “energy + CO2” (not including food). The only comparable time period of the past 100 years with world energy expenditures at that level was 1979–1980, when OPEC production dropped by more than 8 million barrels of oil per day (13 percent of world production at the time) because of the Iranian revolution and subsequent conflicts. As a result, oil prices spiked and the developed world was plunged into recession. Thus history shows that there is great delicacy needed to balance economic growth and opportunity against the environmental benefits of decarbonization.

# A Finite Planet

First we provide energy for our own bodies, then once that need is fulfilled, we use any excess energy to operate and possibly grow what we call “the economy.” For 200 years we have increasingly used higher energy density and cheaper energy alternatives (and used them cleaner). Since around the year 2000, this trend has not happened. Energy technologies continue to advance (for example, photovoltaic solar panels, or hydraulic fracturing for oil and gas), yet for the past 15 or so years we have paid more, not less, for food and energy.

Because world primary energy consumption is still more than 80 percent fossil energy, the increase in energy expenditures since 2000 is largely from those sources. Even though 2015 has seen significantly lower oil prices than 2010–2014, expenditures remain higher than 1998–2002. In an increasing number of locations, the marginal installation of renewable electricity technologies such as solar and wind is now cheaper than fossil fuel options. Thus, some authors argue that we can easily and affordably substitute renewable energy technologies that extract energy flows (such as sunlight, wind, or waves) for ones that extract and convert fossil energy stocks. By no means have we yet come close to any engineering or resource limits of the integration of modern industrial renewable energy. But it is one thing to state that wind and solar are competitive today for installing the next power plant; it is another to state that a 100-percent renewable energy world will enable us to spend the same low fraction of GDP on energy and food while living our current developed world lifestyles.

The world is not flat, and it is not infinite, either, no matter how much various economic models and pundits might imply. The fraction of GDP spent on food and energy is a system-wide indicator that is itself a function of multiple feedbacks within our complex world. To date, human ingenuity in the use of fossil fuels has enabled us to fill the planet with ourselves and our wastes. We increasingly have to deal with the reality that we are naturally reaching diminishing returns to maintaining our populations, energy infrastructure, and our planet. We have, and we will, continue to develop innovations in our food and energy systems, but we must be humble in what we expect to achieve. If sustainability is defined as a three-legged stool—with one leg each of equity, economy, and environment—it is possible that the future world could be balanced on such a stool, but perhaps we’ll have to consider lowering the longest leg(s) in addition to raising the shortest.

# Bibliography

* Brandt, A. R., J. Englander, and S. Bharadwaj. 2013. The energy efficiency of oil sands extraction: Energy return ratios from 1970 to 2010. *Energy*55:693–702.
* Fouquet, R. 2014. Long-run demand for energy services: Income and price elasticities over two hundred years. *Review of Environmental Economics and Policy* 8:186-207.
* Dobbs, R., S. Lund, J. Woetzel, and M. Mutafchieva. 2015. Debt and (not much) deleveraging. Washington, DC: McKinsey Global Institute.<http://www.mckinsey.com/insights/economic_studies/debt_and_not_much_deleveraging>
* Hand, M. M., et al, eds. 2012. *Renewable Electricity Futures Study*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-52409.<http://www.nrel.gov/analysis/re_futures/>
* Jacobson, M. Z., et al. 2015. 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States.*Energy & Environmental Science* 8:2093–2117. DOI:10.1039/c5ee01283j
* King, C. W. 2010. Energy intensity ratios as net energy measures of United States energy production and expenditures, *Environmental Research Letters* 5:044006. <http://stacks.iop.org/1748-9326/5/044006>
* King, C. W., and C. A. S. Hall. 2011. Relating financial and energy return on investment. *Sustainability* 3:1810–1832.
* King, C.W., J. P. Maxwell, and A. Donovan. 2015 Comparing world economic and net energy metrics. *Energies* (in press).
* Lawrence, S., Q. Liu, and V. M. Yakovenko. 2013. Global inequality in energy consumption from 1980 to 2010. *Entropy* 15:5565–5579.
* Piketty, T. 2014. *Capital in the Twenty-First Century.* Cambridge, Mass.: The Belknap Press of Harvard University Press.
* Singer, S., et al. (eds). 2011. *The Energy Report: 100% Renewable Energy by 2050.* Gland, Switzerland: WWF International.<http://assets.panda.org/downloads/101223_energy_report_final_print_2.pdf>
* Stern, D. I., and A. Kander. 2012. The role of energy in the Industrial Revolution and modern economic growth. *The Energy Journal* 33:125–152.

American Scientist, [November-December 2015](http://www.americanscientist.org/issues/id.117/past.aspx), Volume 103, Number 6

Y a-t-il plus à espérer qu'à craindre de la technique ?

Le développement technique transforme-t-il les hommes ?

Serions-nous plus libres sans machines?

L'homme est-il chez lui dans la nature?

Establishing such social-sexual relationships cannot be accomplished by indexical communication alone, that is, by systems of animal calls, postures, and display behaviors, no matter how sophisticated and complex. And yet, even extremely crude symbolic communication can serve this need. Only a few types of symbols and only a few classes of combinatorial relationships between them are necessary. But without symbols that refer publicly and unambiguously to certain abstract social relationships and their future extension, including reciprocal obligations and prohibitions, hominids could not have taken advantage of the critical resource available to habitual hunters. The need to mark these reciprocally altruistic (and reciprocally selfish) relationships arose as an adaptation to the extreme evolutionary instability of the combination of group hunting/scavenging and male provisioning of mates and offspring. This was the question for which symbolization was the only viable answer. Symbolic culture was a response to a reproductive problem that only symbols could solve: the imperative of representing a social contract. [...]

In conclusion, then, the theory of symbolic origins I have outlined is not just a new twist on Rousseau's "social contract" theory. It is not a theory of the origins of social behavior, but of the translation of social behavior into symbolic form. More important, it is not a scenario for how our intelligence triumphed over our reproductive competition, but rather how unique demands of reproductive competition and cooperation created the conditions that led to our unique form of intelligence. By answering the evolutionary question of how to take advantage of a new foraging trick, our ancestors unwittingly turned the tables of natural selection so that social evolution could reshape the brain in its own image. We reflect on this from the other end of an extensive co-evolutionary process, where the indispensable uses of symbolic communication as a social organizing tool were long ago relegated to being only one among a multitude of selection pressures mutually converging on making this communication more and more efficient. Two and a half million years of sustained selection in an unprecedented socioecological niche, maintained by unprecedented communicational and cognitive tricks have taken us far from these beginnings in both the physical changes in the brain that resulted and in the mental and cultural world that coevolved with them. [...]

La conscience de l’individu n’est-elle que le reflet de la société à laquelle il appartient?

Faire usage du langage est-ce renoncer à la violence ?

Est-il nécessaire de parler pour être compris ?

*The Symbolic Species: The Co-evolution of Language and the Brain*. Terrence W. Deacon. 527 pp. W. W. Norton & Co., 1997

Computer Vision and Computer Hallucinations

A peek inside an artificial neural network reveals some pretty freaky images.

[...]

Learning to See

The neurons of an artificial neural network are simple signal-processing units. Thousands or millions of them are arranged in layers, with signals flowing from one layer to the next.

A neural network for classifying images has an input layer at the bottom with one neuron for each pixel (or three neurons per pixel for color images.) At the top of the stack is a layer with one output neuron for each possible category of image. Between the input and output layers are “hidden” layers, where features that distinguish one class from another are somehow extracted and stored.

A newly constructed neural network is a blank slate; before it can recognize anything, it must be trained. An image is presented to the input layer, and the network proposes a label. If the choice is incorrect, an error signal propagates backward through the layers, reducing the activation of the wrongly chosen output neuron. The training process does not alter the wiring diagram of the network or the internal operations of the individual neurons. Instead, it adjusts the weight, or strength, of the connections between one neuron and the next. The discovery of an efficient “backpropagation” algorithm, which quickly identifies the weights that most need adjusting, was the key to making neural networks a practical tool.

Early neural networks had just one hidden layer, because deeper networks were too difficult to train. In the past 10 years this problem has been overcome by a combination of algorithmic innovation, faster hardware, and larger training sets. Networks with more than a dozen layers are now commonplace.

Some networks are fully connected: Every neuron in a layer receives input from every neuron in the layer below. The new image-recognition networks are built on a different plan. In most of the layers each neuron receives inputs from only a small region of the layer below—perhaps a 3×3 or 5×5 square. All of these patches share the same set of weights, and so they detect the same motifs, regardless of position in the image plane. The result of applying such position-independent filters is known as *convolution*, and image-processing systems built in this way are called *convolutional neural networks*, or *convnets*.

The convnet architecture creates a natural hierarchy of image structures. In the lower layers of the network each neuron sees a neighborhood of only a few pixels, but as information propagates upward it diffuses over wider areas. Thus small-scale features (eyes, nose, mouth) later become elements of a coherent whole (a face).

An annual contest called the ImageNet Large Scale Visual Recognition Challenge has become a benchmark for progress in computer vision. Contestants are given a training set of 1.2 million images sorted into 1,000 categories. Then the trained programs must classify another 100,000 images, trying to match the labels suggested by human viewers. Some of the categories are fairly broad (restaurant, barn), others much more specific (Welsh springer spaniel, steel arch bridge).

For the past three years the contest has been dominated by convnets. The 2014 winner was a system called GoogLeNet, developed by Christian Szegedy of Google and eight colleagues. The network is a 22-layer convnet with some 60 million parameters to be adjusted during training.

Seeing in Reverse

When a convnet learns to recognize a Welsh springer spaniel, what exactly has it learned? If a person performs the same task, we say that he or she has acquired a concept, or mental model, of what the dog breed looks like. Perhaps the same kind of model is encoded in the connection weights of GoogLeNet, but where should you look for it among those 60 million parameters?

One promising trick for sifting through the network’s knowledge is to reverse the layer-to-layer flow of information. Among the groups exploring this idea are Andrea Vedaldi and Andrew Zisserman of the University of Oxford and their colleagues. Given a specific target neuron in the upper layers of the network, they ask what input image would maximize the target neuron’s level of activation. A variation of the backpropagation algorithm can answer this question, producing an image that in some sense embodies the network’s vision of a flower or an automobile. (You might try the same exercise for yourself. When you summon to mind a category such as *measuring cup*, what images flash before your eyes?)

The reversal process can never be complete and unambiguous. Classification is a many-to-one mapping, which means the inverse mapping is one-to-many. Each class concept represents a potentially infinite collection of input images. Moreover, the network does not retain all of the pixels for *any* of these images, and so it cannot show us representative examples. As members of the Oxford group write, “the network captures just a sketch of the objects.” All we can hope to recover is a murky and incomplete collage of features that the convnet found to be useful in classification. The dalmatian image has black and white spots, and the lemon image includes globular yellow objects, but many other details are missing or indecipherable. [...]

[Brian Hayes](http://www.americanscientist.org/authors/detail/brian-hayes), *American Scientist*, [November-December 2015](http://www.americanscientist.org/issues/id.117/past.aspx), Volume 103, Number 6

La perception peut-elle s’éduquer ?

Peut-on percevoir sans juger ?

Qu'est-ce qu'une idée ?

Les machines peuvent-elles penser ?

# The Nature of Scientific Proof in the Age of Simulations

Is numerical mimicry a third way of establishing truth?

Empiricism lies at the heart of the scientific method. It seeks to understand the world through experiment and experience. This cycle of formulating and testing falsifiable hypotheses has amalgamated with a modern form of rationalism—the use of reasoning, mathematics, and logic to understand nature. These schools of thought are couched in centuries of history and, until recently, remained largely distinct. Proponents of empiricism include the 18th-century Scottish philosopher David Hume, who believed in a subjective, sensory-based perception of the world. Rationalism is the belief that the use of reasoning alone is sufficient to understand the natural world, without any recourse to experiment. Its roots may be traced to the Greek philosophers Aristotle, Plato, and Pythagoras; its more modern proponents include Kant, Leibniz, and Descartes.

A clear example of both practices at work is in the field of astronomy and astrophysics. Astronomers discover, catalog, and attempt to make sense of the night sky using powerful telescopes. Astrophysicists mull over theoretical ideas, form hypotheses, make predictions for what one expects to observe, and attempt to discover organizing principles unifying astronomical phenomena. Frequently, researchers are practitioners of both subdisciplines.

Problems in astrophysics—and physics, in general—may often be rendered tractable by concentrating on the characteristic length, time, or velocity scales of interest. When trying to understand water as a fluid, it is useful to treat it as a continuous medium rather than as an enormous collection of molecules, because it makes it vastly easier to visualize (and compute) its macroscopic behavior. Although the Earth is evolving on geological time scales, its global climate is essentially invariant from one day to the next—hence the difficulty in explaining the urgency of climate change to the public. The planets of the Solar System do not orbit a static Sun, as it performs a ponderous wobble about its center of mass due to their collective gravitational tug, but it is often sufficient to visualize it as being so. Milankovitch cycles cause the eccentricity and obliquity of the Earth’s orbit to evolve over hundreds of thousands of years, but they are essentially constant over a human lifetime.

This separation of scales strips a problem down to its bare essence, allowing one to gain insight into the salient physics at the scale of interest.

Multiscale problems, on the other hand, do not lend themselves to such simplification. Small disturbances in a system might show up as big effects across myriad sizes and time scales. Structures on very large scales “talk” to features on very small scales and vice versa. For example, a grand challenge in astrophysics is understanding planet formation—being able to predict the diversity of exoplanets forming around a star, starting from a primordial cloud of gas and dust. Planet formation is an inherently multiscale problem: Uncertainties on microscopic scales, such as how turbulence and the seed particles of dust grains are created, hinder our ability to predict the outcome on celestial scales. Many real-life problems in biology, chemistry, physics, and the atmospheric and climate sciences are multiscale as well.

By necessity, a third, modern way of testing and establishing scientific truth—in addition to theory and experiment—is via simulations, the use of (often large) computers to mimic nature. It is a synthetic universe in a computer. One states an equation (or several) describing the physical system being studied, programs it into a computer, and marches the system forward in space and time. If all of the relevant physical laws are faithfully captured, then one ends up with an emulation—a perfect, *The* *Matrix*–like replication of the physical world in virtual reality.

[...]

From the 1990s to the present, the approach of using computer simulations for testing hypotheses flourished. As technology advanced, astronomical data sets became richer, motivating the need for more detailed theoretical predictions and interpretations. Computers became more prevalent and faster, alongside rapid advances in the algorithmic techniques developed by computational science. Inexorably, the calculations produced by large simulations evolved to resemble experimental data sets in size, detail, and complexity.

Computational astrophysicists now come in three variants: engineers to build the code, researchers to formulate hypotheses and design numerical experiments, and others to process and interpret the resulting massive output. Supercomputing centers function almost like astronomical observatories. For better or worse, this third way of establishing scientific truth appears to be here to stay.

[...]

In a series of lunchtime conversations with astrophysicist Piet Hut of the Institute for Advanced Study in Princeton, I discovered that we were both concerned about the implications of these ever-expanding simulations. Computational astrophysics has adopted some of the terminology and jargon traditionally associated with the experimental sciences. Simulations may legitimately be regarded as numerical experiments, along with the assumptions, caveats, and limitations associated with any traditional, laboratory-based experiment. Simulated results are often described as being empirical, a term usually reserved for natural phenomena rather than numerical mimicries of nature. Simulated data are referred to as *data sets*, seemingly placing them on an equal footing with observed natural phenomena.

It is not far-fetched to say that all theoretical studies of nature are approximations. There is no single equation that describes all physical phenomena in the universe—and even if we could write one down in principle, solving it would be prohibitive, if not downright impossible. The equations we study as theorists are merely approximations of nature. Schrödinger’s equation describes the quantum world in the absence of gravity. The Navier-Stokes equation is a macroscopic description of fluids. Newton’s equation describes gravity accurately under terrestrial conditions, superseded only by Einstein’s equations under less familiar conditions.

[...]

A fundamental limitation of any simulation is that there is a practical limit to how finely one may slice space and time in a computer such that the simulation completes within a reasonable amount of time (say, within the duration of one’s Ph.D. thesis). For multiscale problems, there will always be phenomena operating on scales smaller than the size of one’s simulation pixel. Astrophysicists call these *subgrid physics*—literally physics happening below the grid of the simulation. This difficulty of simulating phenomena from microscopic to macroscopic scales, across many, many orders of magnitude in size, is known as a *dynamic range problem*.

[...]

As terabytes upon terabytes of information are being churned out by ever more massive simulations, the gulf between information and knowledge is widening. We appear to be missing a set of guiding principles—a metacomputational astrophysics, for lack of a better term.

Questions for metacomputational astrophysics include: Is scientific truth more robustly represented by the simplest or the most complex model? (Many would say simplest, but this view is not universally accepted.) How may we judge when a simulation has successfully approximated reality in some way? (The visual inspection of a simulated image of, say, a galaxy versus one obtained with a telescope is sentimentally satisfying, but objectively unsatisfactory.) When is “bigger, better, faster” enough? Does one obtain an ever-better physical answer by simply ramping up the computational complexity?

An alternative approach is to construct a model hierarchy—a suite of models of varying complexity that develops understanding in steps, allowing each physical effect to be isolated. Model hierarchies are standard practice in climate science. Focused models of microprocesses (turbulence, cloud formation, and so on) buttress global simulations of how the atmosphere, hydrosphere, biosphere, cryosphere, and lithosphere interact.

[...]

With increasingly complex simulations, there are also questions surrounding the practice of science. It is not unheard of to encounter published papers in astrophysics where insufficient information is provided for the reproduction of simulated results. Frequently, the computer codes used to perform these simulations are proprietary and complex enough that it would take years and the dedicated efforts of a research team to completely re-create one of them. Scientific truth is monopolized by a few and dictated to the rest. Is it still science if the results are not readily reproducible? (Admittedly, “readily” has a subjective meaning.)

[...]

There are also groups and individuals who take the more modern approach of making their codes open source. This has the tremendous advantage that the task of scrutinizing, testing, validating, and debugging the code no longer rests on the shoulders of an individual, but of the entire community. Some believe this amounts to giving away trade secrets, but there are notable examples of researchers whose careers have blossomed partly because of influential computer codes they made freely available.

A related issue is falsifiability. If a physical system is perfectly understood, it comes with no freedom of specifying model inputs. Technically, astrophysicists call these *free parameters*. Quantifying how the sodium atom absorbs light provides a fine example—it is a triumph of quantum physics that such a calculation requires no free parameters. In large-scale simulations, there are always physical aspects that are poorly or incompletely understood and need to be mimicked by approximate models that specify free parameters. Often, these pseudomodels are not based on fundamental laws of physics but consist of ad hoc functions calibrated on experimental data or smaller-scale simulations, which may not be valid in all physical regimes.

[...]

A simulation that cannot be falsified can hardly be considered science.

[...]

Simulations as a third way of establishing scientific truth are here to stay. The challenge is for the astrophysical community to wield them as transparent, reproducible tools, thereby placing them on an equally credible footing with theory and experiment.

[...]

[Kevin Heng,](http://www.americanscientist.org/authors/detail/kevin-heng) *American Scientist*, [May-June 2014](http://www.americanscientist.org/issues/id.108/past.aspx), Volume 102, Number 3

L’expérience peut-elle démontrer quelque chose ?

Les principes de la raison sont-ils issus de l'expérience ?

A quoi peut-on reconnaître la vérité?

Y a-t-il d’autres moyens que la démonstration pour établir une vérité ?

Peut-on être sûr d'avoir raison?

Delving into Deep Learning

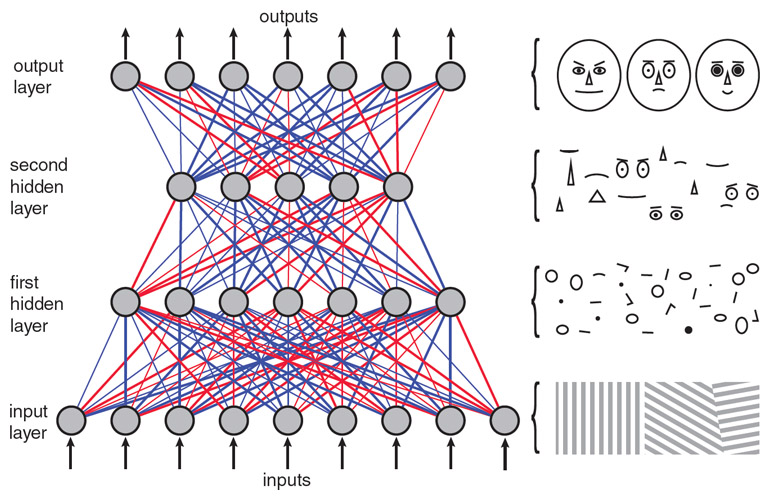
The latest neural networks learn to see and hear, and maybe even dream.

Endowing a computer with human perceptual skills, such as understanding spoken language or recognizing faces, has been on the agenda of computer science since the era of vacuum tubes and punch cards. For decades, progress was slow and successes were few. But now you can have a conversation with your cell phone about tomorrow’s weather or last night’s baseball scores. And Facebook and Google+ recognize faces well enough to suggest that you “tag” your friends in photos. [...]

How do the deep programs work? Oddly enough, no one can answer this question in full detail. A distinctive feature of neural networks is that the designer or programmer does not directly specify all the particulars of a computation. Instead, the neural net is “trained” by exposure to thousands of examples, and it adjusts its internal parameters to maximize its own success. When the training is complete, we have a machine that can answer questions, but we don’t necessarily know how it computes the answers. I find this situation mildly frustrating. On the other hand, it’s a predicament I am familiar with at the most intimate level. I, too, understand speech and recognize faces—and I can’t explain how I do it. [...]

Among all the ideas that animate the deep learning movement, the one I find most evocative comes from Hinton. He suggests that the networks must not only perceive and reason but also sleep and dream. The dreaming allows the system to augment its own training set.

Underlying this metaphor is the idea that the layers of a neural network represent information at progressively higher levels of abstraction. In face recognition the bottom level holds the raw input data—an array of pixels. The lower neural layers capture simple, local features of the image, such as oriented edges or corners. Activity in the higher levels represents larger and more complex features. At some point we encounter eyes and noses, and establish spatial relations between them. At the top is the concept of the face itself. In the artificial network as in the human mind, something suddenly clicks and the identification tumbles out: Aunt Em.



In people, this process also works in reverse. The mere thought of Aunt Em conjures up a vision of her face. Hinton devised a mechanism by which neural networks could also have visions and fantasies. All it requires is making the connections between layers bidirectional. In the conventional phase of the training process, information moves from bottom to top, assembling higher-level abstractions out of the bits and pieces found in the lower layers. In dreaming, the higher-level representations are projected downward through the layers, creating lower-level realizations of each concept. Connection weights are interpreted as probabilities to guide the process. At the bottom of the stack is an imaginary portrait. Generating such faux images contributes to learning in the same way that analyzing real images does. Hinton refers to the two-phase training regime as the sleep-wake cycle. [...]

These triumphs of neural networks might seem to be the definitive answer to the Minsky-Papert critique of perceptrons. Yet some of the questions raised 50 years ago have not gone away.

The foundation of the neural network methods is almost entirely empirical; there’s not much deep theory to direct deep learning. At best we have heuristic guidelines for choosing the number of layers, the number of neurons, the initial weights, the learning protocol. The impressive series of contests won by Hinton and his colleagues testifies to the effectiveness of their methods, but it also suggests that newcomers may have a hard time mastering those methods.

An immense space of network architectures remains to be explored, with a multitude of variations in topology, circuitry, and learning rules. Trial and error is not a promising tactic for finding the best of those alternatives.

Or is it? Trial and error certainly had a major role in building the most successful of all neural networks—those in our heads. And the long dialogue between biological and engineered approaches has been fascinating if not always fruitful. The biological model suggests ways to build better connectionist computers; the successes and failures of computational models inform our efforts to understand the brain. [...]

Brian Hayes, American Scientist, [May-June 2014](http://www.americanscientist.org/issues/id.108/past.aspx), Volume 102, Number 3

La perception peut-elle s’éduquer ?

Peut-on distinguer le rêve de la réalité ?

Une connaissance scientifique du vivant est-elle possible ?

Les principes de la raison sont-ils issus de l'expérience ?

Les machines peuvent-elles penser ?