The Scientific Paradigm

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Abstract

The *demarcation problem*[1], the debate over what is, and is not, science, was once a matter of interest only to philosophers and had little practical significance. But because science has assumed a more important role in the modern world, because there are financial and other reasons to describe an activity as science, distinguishing science from pseudoscience[2] has become an important issue in public policy.

This article shows that scientific fields are defined by the presence of *scientific theories*[3] – falsifiable, inductive generalizations that survive comparison with reality – and that those theories lead to *paradigms*[4], foundational principles based on empirical evidence that concisely summarize fields of knowledge and that produce consensus among a field's practitioners[*].

Also discussed is the central role played by mathematics in modern science, of two kinds – mathematics that quantifies experimental evidence, and mathematics that expresses theories.

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[*] This is not to suggest that a field's practitioners all accept the merit of a paradigm, only that they agree on the topic of conversation.

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1 Introduction

The basic premise of science is that our ideas about the world must be based on successful, dispassionate comparisons with reality.

1.1 Scientific Theory

Such ideas, formally called *scientific theories*, must possess a property called *falsifiability*[5]. On this basis, a scientific theory:

- Must be expressed with sufficient clarity that an unambiguous validating test can be conceived and executed.
- Must be empirically testable in practical experiments.
- Must be abandoned if tests fail to confirm the theory.

About this topic, Richard Feynman[6] said:

> In general we look for a new law by the following process. First we guess it. Then we compute the consequences of the guess to see what would be implied if this law that we guessed is right. Then we compare the result of the computation to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment it is wrong. In that simple statement is the key to science. It does not make any difference how beautiful your guess is. It does not make any difference how smart you are, who made the guess, or what his name is – if it disagrees with experiment it is wrong. That is all there is to it.[7]

1.1.1 Authority

Feynman's oft-quoted remark addresses the strong anti-authoritarian tradition in science – authority has no role, only evidence matters. To put this another way, the greatest amount of scientific *eminence* is trumped by the smallest amount of scientific *evidence*. Consistent with this tradition, the Royal Society[8], possibly the oldest scientific society in existence, chose as its motto *Nullius in verba*, or "Take nobody's word for it." The Royal Society explains its motto this way:

> It is an expression of the determination of Fellows to withstand the domination of authority and to verify all statements by an appeal to facts determined by experiment.[9]

1.1.2 Legal Rulings

Because of the increasing importance of science in modern life, and because of the income and status associated with a scientific standing, many individuals and organizations try to describe their work as scientific, often on questionable grounds. One example is religious movements like Creationism[10] that want to present their beliefs as science in public school classrooms. By means of the *establishment clause*[11] the U.S. Constitution prevents the presentation of religious teachings in state-funded schools, so over time religious groups have tried to recast their beliefs as science, through the simple act of redefining science.

In response to these efforts and with the support of expert testimony, the U.S. legal system has ruled that religious teachings aren't science and therefore cannot be presented as science. In order to make such a ruling, to say what science is not, courts are obliged to define what science is. One such court defined science this way[12]:

1. It is guided by natural law;
2. It has to be explanatory by reference to natural law;
3. It is testable against the empirical world[13];
4. Its conclusions are tentative, i.e. are not necessarily the final word; and
5. It is falsifiable[14].

1.1.3 Practicality

Not clearly addressed in Feynman's remark nor in the Royal Society's motto, but strongly suggested in the above legal ruling, is the issue of practicality – it must be possible to perform a practical, empirical experiment, and the experiment must be conclusive, meaning if the experiment fails, the theory is falsified.

There is a political dimension to this issue. There's plenty of support for rulings that prevent religious teachings from masquerading as science, but some pseudoscientific fields are accepted as science by the public, fields that fail the same legal test as Creationism, except that they aren't regarded in the same way as religious teachings. Psychology – discussed at length below – is an example of a pseudoscientific field with wide public support and acceptance.

1.2 Paradigms

Theories that survive comparison with reality, and that have sufficient generality, become *paradigms*, foundational precepts by which scientific fields are defined. Examples include General Relativity[15] and Quantum Mechanics[16] in physics, evolution by natural selection[17] in biology, and plate tectonics[18] in geology. Paradigms have these properties:

- They associate a scientific field (example biology) with a falsifiable scientific theory (example evolution by natural selection).
- They forge a consensus between researchers about the meaning of a field and the prevailing state of knowledge.
- They inspire research efforts meant to support, modify or contradict prevailing theories.

In the face of new empirical evidence, scientific fields sometimes replace one paradigm with another in what is known as a *paradigm shift*[19], but at any particular time all scientific fields are defined by paradigms, precepts supported by tested theories and evidence. If new evidence falsifies a field's paradigms, and if no replacement is found, that field ceases to be a science – example astrology.

1.3 Measuring Science

Based on the presence of falsifiable theories and of paradigms on which a field's practitioners agree, a given field may be shown to be a scientific one. Conversely, the absence of these properties may conclusively place a field in the pseudoscience category. Based on these evaluation criteria, the demarcation problem yields to the same discipline and careful reasoning that characterizes the best science.

2 Examples of Science

In this section we present examples drawn from the scientific literature in which reliable, falsifiable theories and paradigms unite apparently unrelated activities – examples that show the synergistic effect of inductive reasoning, shared theoretical principles and consensus.

2.1 Background Noise

2.1.1 Narrative

In 1964 Arno Penzias and Robert Wilson, working at Bell Labs, prepared a very sensitive microwave dish for satellite communication work. Even though their receiver's detector was cooled to near absolute zero, there was a noise in the receiver they couldn't identify. The men considered many possibilities – interference from terrestrial radio sources, bird droppings, electronic component failures. But they weren't able to solve the mystery.

Meanwhile, unknown to Penzias and Wilson, astrophysicists including Robert Dicke, working at nearby Princeton University, realized there might be a detectable present-day residue from the so-called Big Bang[20], the idea that the universe began in a cataclysmic explosion many billions of years ago. The astrophysicists reasoned that, because the universe had greatly expanded over time, the temperature of the initial explosion would have declined due to the expansion, and a sort of Big Bang "afterglow" might be detectable in the present – if only they had access to a microwave dish.

This is one of my favorite science stories. Two groups of researchers had unmet needs – the Bell Labs people had evidence but no theory, and the Princeton people had a theory but no evidence. Finally, the Bell Labs people realized they needed to ask an astrophysicist about possible cosmological noise sources, so they called Dicke at Princeton, described the noise, and asked what it might be. In a now-famous story, Dicke explained that the noise could well be the much-sought-after cosmological afterglow, put down the phone and said, "Boys, we've been scooped."[21] Penzias and Wilson received a Nobel Prize for their discovery[22], and (along with the evidence provided by cosmological redshift[23] and Olbers' Paradox[24]) the Big Bang idea became an empirically supported scientific theory.

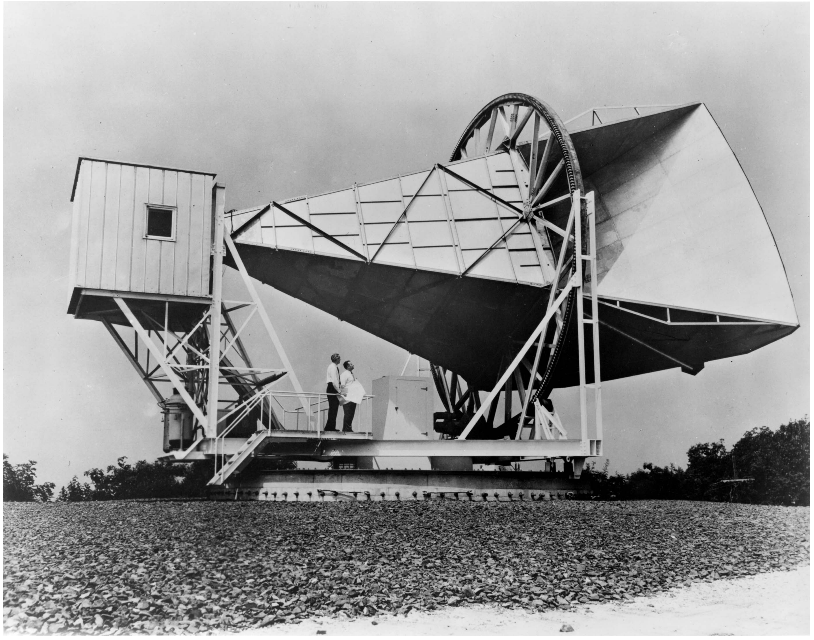

Figure 1: Penzias & Wilson's Microwave Dish

2.1.2 Analysis

In this narrative we see the role played by a shared theoretical foundation. For the astrophysicists, theories of cosmology and thermodynamics led to a prediction that a cosmological background temperature might be detectable as a microwave signal (representing a particular blackbody temperature[25]), in turn based on James Clerk Maxwell's electromagnetic equations[26]. In their conversations, the Bell Labs and Princeton people, trained in different disciplines, spoke a common technical language based on established scientific theories.

This is also an example of scientific cross-pollination. The Bell Labs people acquired an explanation for an unidentified signal that (we now know) represents an unavoidable background noise present everywhere in the universe, and the Princeton people acquired a measure of the universe's background temperature, the afterglow of its fiery birth. Because of this work, radio engineers know that, no matter how well-designed their antennas are, they cannot escape the 2.7 Kelvin cosmic microwave background[27] signal, and cosmologists know the Big Bang theory possesses empirical supporting evidence.

2.2 Darwin's Problem

2.2.1 Narrative

As Charles Darwin[28] shaped his theory of evolution by natural selection, he realized he had a problem – based on the diversity of species and the differences between them, it came to Darwin that there wasn't enough time for the observed variety of species and complexity of forms to have evolved by means of natural selection.

In Darwin's time the sun and earth were believed to be only millions of years old, not the billions of years we accept from a modern perspective. The reason for the earlier underestimate was a theory that presumed to explain the sun's heat energy – it was thought to arise from gravitational contraction. As it turns out, the heat released by gravitational contraction is a relatively short-duration effect that severely limits estimates of the earth's age. In his lifetime Darwin never resolved this problem, and because of it he regarded his theory as incomplete, without a satisfactory explanation for the variety of life forms we see around us.

Long after Darwin's passing, Einstein's Relativity Theories led to new ideas about energy, including the theory of nuclear fusion[29] in the sun. Einstein's famous energy equation[30] –

$$E = mc^2 \tag{2.1}$$

– tells us that mass possesses an enormous amount of potential energy. Subsequent work demonstrates that a sufficiently high pressure and temperature can ignite a thermonuclear mass-energy conversion process that allows a much older age for the sun and earth, resolves an unrelated mystery about the seemingly great age of geological deposits, and solves Darwin's problem.

2.2.2 Analysis

This is another example of theoretical cross-pollination. Biological theories about evolution, as well as the seeming great age of geological deposits, required more time than the 19th century explanation for the sun's energy could provide. The 20th century Relativity theories[31] neatly resolved these issues, and modern biological, geological and physical theories have become mutually supporting.

2.3 Conservation of Energy

2.3.1 Narrative

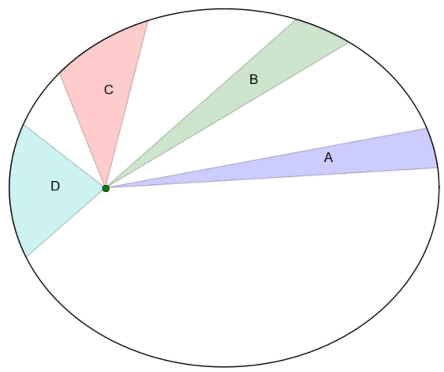

Figure 2: Computer-modeled elliptical orbit

In 1609 Johannes Kepler[32] studied earlier work on planetary orbits, decided it didn't agree with reality, and wrote three laws that have stood the test of time:

1. The orbit of a planet is an ellipse with the sun at one of two foci.
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time.
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit.

These laws agree very well with observation, but in Kepler's time no explanation was available. The modern explanation for Kepler's laws is that they support the principle of conservation of energy[33]. My readers may know that energy cannot be created or destroyed, only changed in form. Consistent with this principle, in an elliptical orbit without frictional losses, two kinds of energy are in perpetual and exact balance:

- Gravitational potential energy[34], which decreases as a mass moves toward the parent body.
- Kinetic energy[35], the energy associated with movement, which increases at higher velocities.

In Figure 2, created by a computer model (see the Energy Conservation appendix on page 20), there are four orbital sections that represent equal areas and equal amounts of time. In those sections closest to the parent planet (toward the left of Figure 2), the satellite's distance is small, which means less gravitational potential energy, but the satellite's velocity is higher, which means more kinetic energy. As it turns out, when a full analysis is performed, over time the two kinds of energy sum to a constant, which validates the principle of energy conservation.

2.3.2 Analysis

Kepler's second law says, "A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time." The law is exactly right, but it doesn't explain why. As it happens, the area of an orbital section (see the colored slices in Figure 2) remains constant because as the satellite approaches the parent planet, the section's height (representing the distance to the planet: gravitational potential energy) declines, but its width (representing the satellite's velocity: kinetic energy) increases. So the slice's area is correlated with total energy, and remains constant.

This example supports the idea that scientific theories based on mathematics are more rigorous and more conclusively falsifiable than theories without this property. A mathematical definition also makes it possible to show relationships between theories that might not otherwise be apparent – in this example, the theories of gravitation, potential and kinetic energy, and conservation of energy, are shown to be mutually supporting (a full treatment is provided in the Energy Conservation appendix on page 20).

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Kepler's work was important because it agreed with observations better than earlier efforts, at a time when the telescope was making its first appearance and astronomical observations were becoming more precise. But Kepler's laws only describe, they don't explain – *to be regarded as science, a testable explanation is needed.*

Let's examine that idea – for an observation be regarded as science, must there be a proposed, falsifiable explanation? To answer this question, I ask my readers to imagine the opposite – that any observation can be taken as science, no explanation required. If this idea were to be accepted, then:

- Because an astrologer's binary predictions (i.e. "You will/won't have a nice day") are right about half the time, astrologers could argue that they've produced a scientific statistical result – without offering a testable theory about the predictions.
- I could observe the many points of light in the night sky, then argue that, because the observation is replicated every clear night, therefore it's science – without bothering to theorize about what the points of light represent.
- I could shake a dried gourd over a common cold sufferer, wait several days, claim my treatment was the reason the cold abated, and call it science.

On this basis, mere observation is not enough – to be regarded as something more than accounting, science requires explanations – testable, falsifiable explanations. This rule applies strictly to all science – we know there's something called Dark Matter[36], we can measure its effect on galaxies, but until we offer a testable explanation, Dark Matter is just an anecdote.

2.4 Correlation versus Causation

2.4.1 Narrative

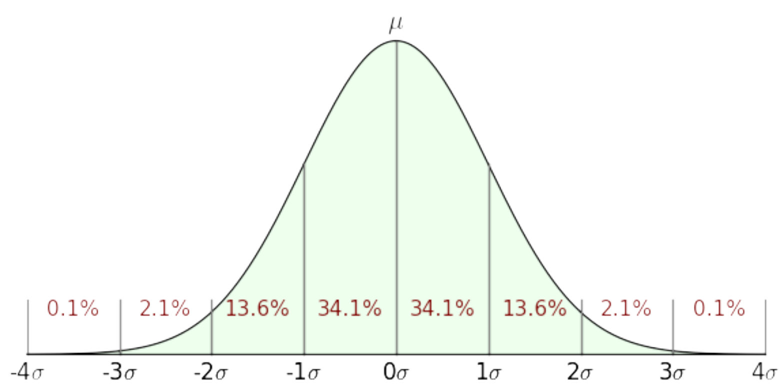

Figure 3: Normal Distribution

In the mid-1960s, a junior academic was delivering a lecture to a group of Israeli air force flight instructors on the advantages of positive reinforcement. The conventional wisdom in this field is that rewarding positive behavior works better than criticizing mistakes. In the midst of his lecture, one of the instructors raised his hand and objected – "I've often praised people warmly for beautifully executed maneuvers, and the next time they always do worse. And I've screamed at people for badly executed maneuvers, and by and large they improve. Don't tell me that reward works and punishment doesn't work. My experience contradicts it."[37]

At first glance, the flight instructor's personal experience could scarcely be faulted – his experience, and that of others in similar circumstances, might represent a valid statistical basis for doubting the idea that positive reinforcement works better than punishment. But this particular academic decided to think more deeply about the instructor's experience – even though behavioral improvement after criticism was an objective fact, maybe it didn't represent a cause-effect relationship.

After careful thought and some mathematical reasoning, the academic realized the instructor's report represented a statistical anomaly – even though the report represented a valid correlation and would likely hold up in a large survey, it didn't actually show a cause-effect relationship. Here's why:

- On a given day, a student's performance is likely to be average, i.e. likely to lie in the middle of a normal statistical distribution (Figure 3).
- Less probable are "outliers," performances outside the central region of the distribution curve – maybe better than average, maybe worse.
- After an "outlier" performance, the probability is high that subsequent performances will return toward the central, "average" region of the curve shown in Figure 3. This is called "regression toward the mean."[38] In the flight-instructor example it means that both above-average and below-average performances are likely to be followed by average performances, which would reinforce the misleading idea that criticism works better than praise.
- Regression toward the mean is a tendency driven by the mathematics of probability, it's not the result of praise or criticism, all appearances to the contrary.
- This means the instructor's experience was correlated with a natural and random statistical tendency for events to cluster around average values over time, but wasn't a cause-effect relationship resulting from either praise or criticism.

2.4.2 Analysis

This is an example where some knowledge of mathematics is essential to understanding the issues. It's also drawn from a field (psychology) where, because of multiple obstacles, it's difficult to do anything resembling science. And it shows that describing events and experiences without also trying to explain them represents a serious barrier to science.

A dispassionate observation of behavior without accompanying praise or criticism, a "control group," might have shown that both above-average and below-average "outlier" performances were likely to be followed by average ones, and this might have helped undermine the impression that the praise or criticism actually played a part in the outcome.

3 Mathematics in Science

As science has matured, the central role played by mathematics in expressing and evaluating scientific results has become apparent. The most reliable scientific theories are expressed mathematically, and the most trustworthy experimental results have a mathematical dimension as well.

Mathematics plays a central role in science because it expresses ideas in a precise and unambiguous way, one that compels agreement about meaning in a way that words cannot. Another reason is that theories which seem to be unrelated when expressed in words, turns out to be associated, sometimes even identical, when expressed using mathematics.

In 1960, physicist Eugene Wigner wrote a now-famous article entitled "The Unreasonable Effectiveness of Mathematics in the Natural Sciences"[39], an article that explains the many ways by which mathematics shows an uncanny ability to describe nature. In his article Wigner says:

> The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve. We should be grateful for it and hope that it will remain valid in future research and that it will extend, for better or for worse, to our pleasure, even though perhaps also to our bafflement, to wide branches of learning.

Physicist Max Tegmark and others have put forth the idea that the reason mathematics resonates so well with reality is because *reality is innately mathematical*[40]. This is an open question, but it's certainly true that, as our theories become more effective at describing reality, they also become more mathematical.

Next we compare the two primary kinds of mathematics in science – theoretical mathematics, which expresses scientific theories, and experimental mathematics, which analyzes and quantifies experimental results.

3.1 Theoretical Mathematics

3.1.1 Gravitation

Here's an example that compares a verbal description with a mathematical one. Without benefit of mathematics, about gravitation I might say, "Gravity causes masses to be attracted to each other." Experiments could be carried out based on this claim and the experiments would support the claim, but in a vague and non-quantitative way.

If instead I say[41] –

$$f = G\frac{m_1 m_2}{r^2} \tag{3.1}$$

– in other words, if I express the idea of gravitation mathematically, I might use such a precise statement to discover cases where observation contradicts it, something not possible if I limit myself to a verbal claim. For example, because of a discrepancy in the motion of galaxies that contradicts Equation 3.1, scientists have created the Dark Matter hypothesis[42]. To say this another way, when confronted with a quantitative exception to the mathematical theory of gravity, scientists had the choice of doubting the accuracy of a reliable, well-tested theory, or hypothesizing about a form of matter we hadn't observed before. Proceeding on the basis of Occam's razor[43] (of competing theories, the simplest is to be preferred), they chose the latter.

My point is that, if gravitation were expressed using words rather than equations, among many other examples the anomalous motion of galaxies would have escaped our attention, and our understanding of nature would be impoverished.

3.1.2 Antimatter

In 1928 Paul Dirac[44] published an equation[45] that reconciled Schrödinger's quantum wave equation[46] with Einstein's relativity theory[47]. Some of my readers may know that quantum and relativity theories are difficult to reconcile, so Dirac's equation was quite a breakthrough.

While writing his equation, Dirac noticed something peculiar – like the quadratic equations we learn in school, his equation had two solutions*. Dirac noticed this, but he regarded it as a mathematical oddity with no real-world significance – he didn't leap to the conclusion that there were two kinds of matter (i.e. matter and antimatter), simply to satisfy his equation. Shortly after Dirac published his equation, antimatter was detected and proved that his equation reflected reality more accurately than he had supposed. Later Dirac was asked why he hadn't simply predicted antimatter on his own. He replied, "Pure cowardice."

Mathematical theories are normally crafted to explain observations already made, but in this case Dirac's equation predicted something yet to be observed, an especially powerful kind of scientific confirmation, and one that supports Wigner's ideas about the uncanny power of mathematics in mapping out nature.

3.1.3 Mathematical Theories

The above are just examples of the mathematical nature of modern science. In fact, all of physics and parts of some other sciences are built on a foundation of mathematical theories, theories that express principles through equations rather than words. This has multiple advantages in scientific theory and practice – it allows quantitative predictions to be made about phenomena not yet observed, predictions that might reveal an unanticipated aspect of nature, or it might conclusively falsify a theory if observation disagrees. It also reveals connections between theories, as shown in the Conservation of Energy example on page 7.

It also allows *theoretical* science to play a part in *applied* science. Suppose I say, "If you put too much weight on that bridge, it will break." Is that sufficient guidance for a civil engineer charged with designing the bridge? Wouldn't he have the right to ask, "How much is too much? And define 'break' – is that different from 'bend'?" If instead I provide an equation that expresses the load-bearing capacity of bridge trusses and their breaking point, the engineer will have the best possible guidance from science. And because the theory is a mathematical one, if the bridge should fail, that might open a scientific process in which the theory that led to the equation would be revised, to prevent recurrences.

3.2 Experimental Mathematics

A lesser role for mathematics in the sciences is the task of analyzing observations and measuring their significance. The Correlation versus Causation example on page 8 shows how experimental mathematics can be used to assess the degree to which an effect results from a particular cause, and to sometimes contradict "common sense".

*For example, the equation $x^2 = 9$ has two solutions: $x = 3$ and $x = -3$

3.2.1 Stock Picking Genius

Here's an example where everyday perceptions can be contradicted by a dispassionate mathematical analysis. Suppose you heard a report that someone correctly predicted the direction of the future stock market (whether it will rise or fall) 20 times in an unbroken sequence – wouldn't that prove that he was an expert, a genius?

Not necessarily. First, for this example let's assume that the market is unpredictable, the thesis of the so-called Efficient-market Hypothesis[48], a thesis for which there is good evidence. If true, this means a person's ability to predict the market's direction should be no better than chance, or 50% per prediction if the market fluctuates up and down with equal probability.

If the chance for a correct guess is 50% per prediction (a probability of 0.5), then the probability for two correct sequential guesses is .5 x .5 = .25, for three it would be .5 x .5 x .5 = .125, and so forth. There's a simple mathematical equation that provides the probability p for n sequential correct up/down guesses in a random market:

$$p = 2^{-n} \tag{3.2}$$

This equation tells us that the probability for 20 sequential correct guesses is $2^{-20} = \frac{1}{1{,}048{,}576}$ or roughly a million to one. So without benefit of mathematics, everyday common sense tells us that someone who made 20 accurate, sequential stock market predictions must have special skills or some kind of market expertise.

But with some mathematical reasoning and a bit of healthy scientific skepticism, this seemingly remarkable performance can be easily explained. Let's say this remarkable predictive ability appeared in one person among a population of a million – what's the probability that any one of a million people will successfully make 20 binary (yes/no, up/down) predictions in an unbroken sequence? Well, the Binomial Theorem[49] tells us the probability is about 61%, or better than even. So the first question a scientist would ask is, "How many people are guessing the direction of the stock market?"*

3.2.2 Skepticism

The above exemplifies how a scientist thinks about experimental evidence – not "That's amazing!", but "What's the probability that this result arose by chance?" Relying on a precept called the *null hypothesis*[50], a scientist takes the default position that there's no association between measured phenomena, and relies on experimental evidence – and mathematics – to contradict that assumption.

3.2.3 Pseudoscience

Let me explain why a skeptical outlook toward claims is an essential component of science. There's a popular myth called "Bigfoot,"[51] a large, hairy creature said to occupy dense forested areas but one that leaves no physical evidence behind. Here is the contrast between how a scientist and a pseudoscientist† would investigate Bigfoot:

- A scientist investigating Bigfoot would rely on the null hypothesis, the assumption that Bigfoot doesn't exist, an assumption that can only be contradicted by positive evidence that he does, and the burden of evidence belongs to the scientist.
- A pseudoscientist investigating Bigfoot would rely on the opposite of the null hypothesis, the assumption that Bigfoot *does* exist, an assumption that can only be contradicted by negative proof (proof that Bigfoot doesn't exist), and the burden of evidence belongs to others.

The problem with the pseudoscientific outlook is that it relies on proof of a negative or an *argument from ignorance*[52], an impossible evidentiary burden as well as a logical error. In this example it would require a search of the entire universe to assure ourselves that Bigfoot isn't hiding under some rock on a faraway planet.

An interesting article[53] from Scientific American magazine aptly summarizes the distinction between science and pseudoscience. Quoting science philosopher Karl Popper, the article says, "The big difference Popper identifies between science and pseudo-science is a difference in attitude. While a pseudo-science is set up to look for evidence that supports its claims, Popper says, a science is set up to challenge its claims and look for evidence that might prove it false. In other words, *pseudo-science seeks confirmations and science seeks falsifications*."

The article emphasizes another distinction between science and pseudoscience – scientific claims are empirically testable and falsifiable, pseudoscientific claims aren't.

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*The answer is, "Far more than a million."

†A pseudoscientist is one who caricatures the external forms of science but without the skepticism and focus on objective evidence required for real science.

Most pseudoscience relies on an absence of mathematics, but in experimental work, a superficial kind of mathematics sometimes serves to conceal the unscientific nature of the work. One example is to state a result without adequate context, as in the 20 predictions example above – if that result relied on a single subject, not a population, it would be astronomically improbable instead of being a virtual certainty.

4 The Science Spectrum

This section ranks various scientific fields by comparing them to a careful definition of science derived from recent legal rulings and accepted principles from the philosophy of science.

4.1 Science Defined

As mentioned above, there was a time when defining science would have seemed pointless, on the ground that the demarcation between science and nonscience had no practical importance. Those days are past – in modern times science has a high value associated with its status and the validation it lends to ideas and activities thought to be scientific. On that basis, the modern world needs a clear definition of science. Beyond the legal definition given above, here are some requirements for science about which there is reasonable agreement:

4.1.1 Requirements

1. Scientific fields must be defined by unambiguous, falsifiable theories.
2. Science's theories must be based on empirical evidence, evidence derived from observations of nature.
3. Scientific evidence must be numerically quantifiable and objective, meaning the evidence must lead similarly equipped observers to agreement about its meaning.
4. Scientific theories must be open to falsification by new evidence, but cannot ever be proven true.
5. Studies within a given field must address the field's theories.

4.1.2 Discussion

Requirement 1 is essential to prevent pseudoscientific fields from springing up that aren't anchored to a specific evidence-based, falsifiable theory about nature.

Requirement 2 prevents supernatural agencies from being accepted as evidence. If this requirement were not present, as just one example, Creationists[54] could argue that their religious views on human evolution have the standing of science and should be included in public school science textbooks.

Requirement 3 creates consensus among researchers about the meaning of evidence. Without this requirement in force, scientific fields might disintegrate into countless disputing factions*.

Requirement 4 derives from the philosophy of science. It acknowledges that any scientific theory, however well-established, may be falsified by new evidence, as the Newtonian theory of gravity was falsified by Einstein's theory of relativity, and as pre-Darwinian biological theories were falsified by the theory of evolution by natural selection. This principle was perhaps best expressed by philosopher David Hume[57], who said, "No amount of observations of white swans can allow the inference that all swans are white, but the observation of a single black swan is sufficient to refute that conclusion."

Requirement 5 prevents an unscientific field from being validated by scientific work having no connection to the field's defining theories. Were this requirement not present, an astrologer could hire a statistician to divide his client population by astrological sign and on that basis claim that astrology was scientific.

I would like to have added a requirement that scientific theories be expressed as mathematical equations in all fields as they are in physics, but it's too soon in the history of science for that requirement. It will certainly be true in the future, but it's not true now.

4.1.3 Physics Envy

It's often said that practitioners of fields outside physics experience "physics envy"[58], a forlorn wish that their field's theories could be expressed in the mathematical, unambiguous way typical of modern physical theories. Physics envy

*For example, consider the American Psychological Association[55], now composed of 54 subdisciplines[56] and no unifying scientific theories.

should really be called math envy, because their mathematical expression is what distinguishes physical theories from theories in other fields.

Critics of this outlook argue that to try to convert all scientific theories into mathematics constitutes a pointless and sometimes distorting reductionism[59] in which the essential meaning of a theory is lost by forcing it into a mathematical form. One response to that criticism is to say that theories which cannot be expressed mathematically may not be defined clearly enough to have such an expression, or to produce consensus about its meaning among workers in the field that defines the theory, or to have a clearly defined basis for falsification.

Another relevant aspect to this topic is that, with respect to many present-day scientific theories, some can't be expressed mathematically only because the math doesn't yet exist. I say this because of the number of problems I've solved in my own work that were mathematical solutions, but that could only be expressed in algorithmic form, not in a widely recognizable and concise mathematical form.

To summarize this point, I expect that, at some future time, all scientific theories will be expressed mathematically, which will have the effect of making them more concise, easier to falsify if that's possible, and it will be easier to show common ground between theories, as was the case in the Conservation of Energy example on page 7 (and detailed in the Energy Conservation appendix on page 20). I also expect that, in the future when all scientific theories are required to have a mathematical expression, many theories presently thought to be scientific will be revealed to have been pseudoscience.

4.2 Physics

The fact that physical theories are expressed mathematically, and that they have copious confirming empirical evidence also expressible mathematically, makes physics the model for science. As discussed above, the degree to which physics is defined by mathematics supports the idea that reality is mathematical, and suggests the idea that true science reveals itself through an expression in equations that can be meaningfully compared to reality.

I emphasize that the mathematical nature of physical theories is more than simple aesthetics. Apart from being unambiguous in expression, mathematical theories provide a clear basis for their own falsification if they turn out not to reflect reality. Also, by virtue of their mathematical expression theories can be shown to complement one another, or to be in conflict with each other or with observation, in a way that non-mathematical theories cannot.

For example, the recent discoveries of Dark Matter and Dark Energy[60] resulted from quantitative comparisons of theory to observation, examples in which the clear predictions of mathematical theories were found not to reflect reality. And, consistent with a candid scientific perspective, when these phenomena were discovered physicists simply said, "We have no idea what these things are, but they're not explained by present theories."

4.3 Chemistry

Over time chemistry has come to be recognized as an extension of physics, on the ground that, from a modern perspective, chemistry is physics applied to atoms and molecules. This means chemistry's paradigms are derived from those of physics, in another example of theoretical unification by way of mathematics.

4.4 Biology

Unlike chemistry, biology has theories independent of physics, like evolution by natural selection, but unlike psychology and the social sciences, biology's primary theories can be expressed and validated mathematically, for example by the Logistic Function described on page 22, used to model biological populations faced with limited resources. By means of such theory-based mathematical tools, field measurements can be quantitatively compared to theory and on that basis the field's theories are falsifiable without ambiguity.

4.4.1 Antibiotics

In biology, politics sometimes trumps science. We now know that the widespread, undisciplined use of antibiotics, for example to fatten up cows and chickens, has caused bacteria to evolve resistance, with the result that there are now bacterial strains essentially immune to all available antibiotics. Based on well-established theory this outcome could have been anticipated, indeed many scientific warnings have been sounded over the years, but those warnings were ignored.

The situation is so bad that some researchers describe the present as the beginning of a post-antibiotic era[61], one in which antibiotics will simply stop working and scourges like tuberculosis, pneumonia, and others will resume their historical role as perpetual threats to public health. But in the midst of this crisis, low-level application of antibiotics in animal feed continues.

This discussion may seem to be a digression from the primary topic, but it shows how considerations other than scientific evidence sometimes influence public decision-making, in disciplines otherwise regarded as scientific.

4.5 Psychology

Human psychology (and its many branches – experimental psychology, clinical psychology, psychiatry, and scores of other recognized specialties) occupies a strange position among modern formal disciplines. On the one hand, because of the absence of empirically testable, falsifiable theories about the mind, psychology is clearly an unscientific enterprise. On the other hand its many loyal practitioners and followers desperately want it to represent a valid scientific field, some of whom argue that it is science, for a sufficiently relaxed definition of the term.

4.5.1 The Mind

First, to discover why psychology is unscientific, one need only look at its subject, the human mind. In a saying popularized by Marvin Minsky[62], "Minds are what brains do"[63]. Unfortunately for science, this is philosophy, not science, because the mind is not an empirically accessible part of nature.

4.5.2 Lying

To show why psychology isn't a science, let's assume the opposite and see where this leads us:

1. Psychology, the study of the human mind, is a science.
2. The human mind is a supernatural entity, a fact that would normally prevent its acceptance as a source of empirical evidence, except that its content and workings can be revealed by what human subjects say about it.
3. A primary and uncontroversial finding of human psychology is that people lie all the time, about everything.
4. Fact (3) prevents reliable collection of data about the mind.
5. Fact (4) contradicts claim (1).
6. Ergo, psychology is not a science.

An objection to point (3) above is that there are psychological measurement schemes that can circumvent the fact that people lie. Those schemes work unless the experimental subject is lying to himself, in which case the sincerity of the subject's self-deception will undermine any imaginable method to produce an objective measurement of the human mind.

4.5.3 Mind Theories

The above reasoning might be dismissed if psychologists could use other methods to produce reliable, falsifiable theories about the mind. For example, in the medical field, to earn public trust treatments must be consistent with medical and biological theories and validated in objective medical research in advance of their application to patients in a clinical setting. Using that model and for public safety, experimental psychologists are under a moral imperative to produce empirical scientific theories that validate some practices and falsify others, as a result of which clinicians would have a trustworthy scientific basis for their practice.

But psychologists have not done this, and given the seriousness of the issue, the only rational explanation for the absence of scientific psychological theories is that psychologists cannot produce them. Apart from allowing psychology's clinicians a dangerous amount of license to invent diseases (see the Psychological Pseudoscience appendix on page 19 for examples), science without empirically testable, falsifiable theories is not science.

4.5.4 No True Psychologist

In my copious correspondence with psychologists, I've heard the argument that the unscientific status of psychiatry and clinical psychology doesn't condemn all of human psychology – the damage is limited to undisciplined clinical specialties in an otherwise scientific field, an argument that's an example of the "No true Scotsman" fallacy[64]. This argument overlooks the fact that, in scientific fields, experimentally validated theories inform all research and practice. When a civil engineer builds a bridge, in the name of public safety the design must be consistent with current physical theories. When a doctor treats a patient, in the name of public safety the treatment must be consistent with current biological theories. In other words, where they exist, scientific theories (a) assure public safety and (b) unify research and practice.

The only reason this model doesn't apply to psychology is because there are no scientific psychological theories to apply.

4.6 Astrology

I include this entry only to make a point about the nature of scientific theory. Astrology is based on the theory that our lives are influenced by the position of the stars and planets at the moment of our birth and at the present moment. This theory has been conclusively falsified[65], which makes astrology a failed science – a theory is put forth, is tested, and is discovered not to reflect reality. In that limited sense, astrology is more scientific than psychology, only because psychologists have been prudent enough not to express their ideas in a way that could lead to a meaningful comparison with reality.

5 Pseudoscience

This section explores the role of pseudoscience in modern times – it explores why, in the midst of a world guided by science and reason, pseudoscience remains attractive to so many.

5.1 Authority

As explained above, a foundational precept of science is that authority must give way to evidence, to reality-testing. In this way science represents an extension of a basic human ability that is also an effective survival strategy – original thought.

5.1.1 Brain Power

The presence of a cerebral cortex[66] in human beings prepares us for autonomous behavior – behavior based on original thoughts, motivations and decisions. One of those decisions is self-referential, i.e. whether we choose to direct our own lives, or be told what to do by authorities.

The energy cost of the human brain is substantial – in a typical person, the brain accounts for only 2% of the body's mass but uses up 20% of its oxygen intake, and by implication, 20% of the body's available energy[67].

In the fierce competition between species, evolution rules, and natural selection wastes nothing. The fact that the brain burns a fifth of our available energy can only mean that creative thinking has survival value. But must the brain's energy budget equal creative thinking? Well, yes – if fixed ideas were an optimal survival strategy, they would become instinctive behaviors, inbred actions, with no expensive brain processing required. The human brain isn't a repository of fixed ideas, it's a way to create new ideas.

The above argues against authority as an optimal survival strategy, because, unlike social species like ants that do not, and cannot, function as individuals, species that have the ability to think for themselves are able to deal with rapid environmental changes that pose a threat to their existence, or design short-term strategies to exploit opportunities that might arise only once.

5.1.2 Adaptability

In a scientific analysis, arguments like the above must give way before evidence. This means we should observe nature – discover which species prevail and why – and draw a conclusion on that basis. In such observations we find that, if the environment never changes, social species like ants prevail, but if the environment does change, species able to craft original thoughts prevail. That in turn means a key factor in the comparative success of the human species is frequent environmental changes, changes that extinguish less adaptable species. As it happens, earth's environment undergoes frequent change – plate tectonics gives rise to volcanoes and earthquakes, heat energy moves between oceans and atmosphere in a complex and dynamic way, and periodic ice ages place demands on all species that only a few can meet. Humans adapt to new environmental challenges by changing our minds, not our bodies – this explains our success.

By focusing on dispassionate observation and the demotion of authority, science is to the human mind what the human species is to nature – it represents a preference for reality-testing over dogma.

5.2 Religion

It's important to say that, even though science is much more effective than an authoritative, dogmatic approach to sorting out reality, it requires more energy and more brain power. This means that, in the calm interludes between natural and unnatural catastrophes, fixed ideas seem more efficient.

The above explains religion's appeal. At times when nature seems to be on our side, an intellectual competition between hundreds of ideas seems wasteful. Maybe ten ideas would serve our needs better. Or one idea. And one authority to dispense the single idea – after all, if there's only one idea, individual thinking seems wasteful and divisive.

5.2.1 Galileo

Much has been written about the trial of Galileo[68], indeed it may be looked on as the archetype of all modern conflicts between science and religion. Briefly, based on observations of nature, Galileo published ideas about the universe that were in conflict with those presented as dogma by the Catholic Church (hereafter "the Church"), and the Church responded by placing Galileo before the Inquisition[69]. About thirty years prior to the Galileo affair, the Church had responded to Giordano Bruno's[70] heretical views by burning him at the stake. That action reflected the Church's power – or so it seemed. As it happens, the Church's authority was in rapid decline before a trend of increased respect for open inquiry, and by the time of the Galileo affair, the Church had lost the ability to dispose of Galileo as they had Bruno[*].

In hindsight one may see that the Church's handling of Bruno and Galileo reflected a severe misjudgment of prevailing public sentiment, and it may further be said that the Church never recovered from its mistake. But this is not to say that religion itself gave way before reason and a scientific outlook – religion remains a strong, though declining, force in modern society.

5.2.2 Science Substitutes

In the face of overwhelming evidence, most educated people recognize that science produces results that religion cannot – modern medicine, improved public health and well-being, technical wonders, and some understanding of nature. These advances have contributed to a widespread disenchantment[71] with religion and mysticism and a search for replacements.

For many people who intend to abandon religion, the chasm between religion and science is too great a distance to be bridged. Among other alarming properties, it replaces perfect certainty with perfect uncertainty – as Richard Feynman famously remarked, "Science is the organized skepticism in the reliability of expert opinion[72]." But some people find that a superficial resemblance to science may be an acceptable substitute for the real thing, and in some cases even the word science is enough, as religious sects like Christian Science[73] demonstrate. This unmet need sets the stage for pseudoscience – disciplines that resemble science, that posture as modern intellectual pursuits, but from which something essential is missing.

5.3 Requirements for Pseudoscience

My readers may wonder whether pseudoscience actually has requirements – isn't it just undisciplined sham science? But to prevail and win public support, pseudoscience must avoid certain things that could expose it as wishful thinking. At the top of the list are testable, falsifiable claims – as astrology shows, just one falsifiable claim is enough to destroy the illusion of science[†].

In modern times, another requirement for pseudoscience is that its technical publications contain all the trappings of science – observations, statistical analyses, conclusions – everything but the expression of theories that can be empirically compared to nature and possibly falsified, theories that might show a connection with other scientific fields.

5.4 Connections

The significance of theoretical connections between scientific fields can't be overemphasized. Here's an example that shows theoretical links between biology, chemistry and particle physics:

- **Biologists** observe that a Gecko[74], a kind of lizard, can climb vertically on a pane of glass. Investigation shows there are no everyday explanations – no glue or oil or other substances that might explain the ability.
- Study reveals that the Gecko is supported by what is called the Van Der Waals[75] force from **physical chemistry**.
- The Van Der Waals force is in turn explained by forces at the atomic level including quantum dynamics[76], a theory from **particle physics**.

[*] Galileo was forbidden from publishing his ideas and placed under house arrest.

[†] Astrology's claim is that the position of the stars and planets at our birth and on any given day influences our lives, a claim that's easily falsified, therefore astrology is bunk.

The value of connections between scientific theories is that a falsification or logical error anywhere in the chain might cause the entire structure to collapse. To a nonscientist this possibility might seem to be a reason to avoid making the connections. But to a scientist, who only cares about getting it right, this openness to falsification *strengthens* the theoretical structure, it doesn't weaken it. As explained earlier, a pseudoscientist seeks confirmations of prevailing beliefs, while a scientist seeks falsifications. Based on these preferences, which structure is likely to become stronger over time?

5.5 Theory

As shown above, the presence or absence of testable, empirically falsifiable theories can be used to distinguish science from pseudoscience. Testable theories unify and strengthen intellectual efforts, compare abstract models to reality, expand the scope of ideas into new domains, reveal connections between different scientific fields, and increase the breadth of our understanding of nature. For these reasons and others, the absence of testable theories marks a field as pseudoscience.

5.6 Psychology

Many pseudoscientific fields have appeared and expired over the decades, and only a few remain, primarily by learning how to survive – not unlike a biological species, by evolving toward a more resilient form. Psychology is the most successful example, for these and other reasons:

1. It meets a strong public demand for something resembling religion (replacing "sin" with dysfunctions, syndromes and ill-defined mental illnesses, and contrasting these with the unachievable ideal of "normal behavior") but without certain medieval trappings (like direct appeal to an imaginary superbeing).
2. It attracts people disenchanted with religion but who need what religion provided, in particular counsel, confession, and conversation.
3. Its leaders know better than to try to publish empirically testable theories about psychology's metaphysical topic, the mind.
4. Although it poses as science, on substantive questions it relies on appeals to authority – on experts instead of evidence.
5. It bears a superficial resemblance to science, but without science's intellectual demands.
6. It has no quantifiable theoretical connections with scientific fields.

Item (6) above would normally disqualify the field (indeed, any field) from an association with science, but in this case, it saves psychology from certain destruction if an effort were to be made to show an association with fields that are actually scientific.

5.6.1 Ranking of Fields

To reiterate a point made earlier and on the topic of connections between fields, one may rank scientific fields by the degree to which they're connected to others. By being connected to all other fields either directly or indirectly, physics has the highest rank. Chemistry has a high rank also, sometimes referred to as the "central science". Biology has a somewhat lower rank, but examples like the Gecko[5.4] given above show that it has substantial theoretical connections.

By contrast, psychology lives in a separate metaphysical universe with essentially no connections to scientific fields. Psychology's isolation from science was recently dramatized by a high-level U.S. decision to abandon[77] psychology's "bible", the Diagnostic and Statistical Manual of Mental Disorders (DSM)[78], specifically because of the DSM's lack of scientific substance. Appropriately, this decision was made by a psychiatrist[79], the director of the National Institute of Mental Health[80].

5.6.2 Bias against Psychology

In spite of the above policy reversal and so far, psychology's tactics have worked – psychology is seen by uneducated people as a "soft science," it has a loyal following, and its advocates argue that it would be science if only science could be defined differently than it is[1.1] (an argument also made by Creationists[81]).

Psychology's defenders sometimes publish self-referential papers (i.e. papers about the field of psychology itself), papers that vaguely resemble science, except for the absence of science, and that are largely read by other psychologists. For example, in a recent paper[82] that compares opinions of neuroscientific versus psychological diagnostic methods, the authors claim that the public's greater trust in neuroscience over psychology springs from bias, not objective evidence.

In the study, the authors contrast subjects' reactions to two kinds of Alzheimer[83] diagnoses. One group of subjects evaluated an MRI scan[84] (a physical scan of the brain), while another group evaluated a psychological cognitive diagnosis, a diagnosis based on self-reporting. The authors found that the subjects preferred the neuroscience result over the psychological one, then concluded that their subjects were "biased" against psychology and in favor of neuroscience.

That the test subjects preferred neuroscience over psychology is an uncontroversial finding, but that this represents a "bias" against psychology is an opinion, not science, and the study cannot support it. Worse, overlooked issues fully support the subjects' preferences. For example, a skilled actor, trained to imitate the symptoms of Alzheimer's and interviewed by a psychologist, could acquire an Alzheimer diagnosis without having the condition[85], but that same subject, if brain-scanned, could not. This means the test subjects' preference for neuroscience over psychology isn't necessarily "bias," in this and similar cases it's more likely to result from a critical evaluation of available evidence.

In the conclusion of their paper, the authors say, "The need for the general public to accurately evaluate the scientific methods used by psychologists is especially relevant to real-world situations in which strongly held values, beliefs, or identification with specific groups renders people particularly likely to discount psychological evidence." I have another theory – people discount psychological evidence on the perfectly reasonable ground that *psychology is not a science* as science is defined[1.1], and that psychologists have a long track record of publishing opinion as science, including the above paper.

The above article shows a tendency, common in the psychological literature, to present a reliable statistical observation, then draw a conclusion that isn't remotely supported by the observation. In this example, test subjects were discovered to prefer neuroscience results to psychological results (easily supported by observation), therefore they must have been biased against psychology (an opinion with no evidentiary basis). Where is the list of all possible causes for the experimental outcome that a trained scientist would have felt honor-bound to include, including the possibility that the test subjects' preference sprang from a rational comparison of psychology and neuroscience?

As it happens, outside the field of psychology, there's no controversy about the advantages of MRI brain scans over psychological methods for diagnosing Alzheimer's. By measuring brain tissue volume[86] as well as by detecting plaques associated with the disease[87], a brain scan produces unambiguous diagnostic indicators and is not subject to the psychological self-reporting problem[88]. Indeed, the above-referenced social psychology paper, which describes the preferences of test subjects but doesn't acknowledge the objective, evidence-based ranking of neuroscientific over psychological diagnostic methods, can only serve to dramatize psychology's distance from objective, empirical science.

5.7 Neuroscience

Neuroscience is the scientific study of the human nervous system[89] including the brain. Because neuroscience's research topic is composed of matter, the field can produce empirical results that psychology (study of the mind) cannot. Because empirical evidence is required for science[3], this places neuroscience among the sciences.

This isn't to say that neuroscience is ready to step in and solve psychology's many problems – the human brain is very complex and we're just beginning to sort out its workings[90]. It may be many years before neuroscience finds causes and possibly cures for various brain ailments, but from the perspective of the present, one thing is clear – because most "mental illnesses" are actually neurological conditions with mental symptoms, psychology cannot produce definitive results by studying the mind.

My point is that public funds expended on psychology are largely wasted in a field with little scientific substance and a poor track record for reliability and consistency[91]. Psychology's favorable public standing springs largely from social inertia and public ignorance of science, not an objective evaluation of psychology's methods or results.

One can only hope programs that focus on neuroscience like the U.S. Brain Initiative[92] will, over time, reshape public perceptions and redirect research funding toward areas more promising than psychology. As things stand, there is widespread public confusion about where psychology ends and neuroscience begins, a confusion made worse by vague terms like "cognitive neuroscience[93]", an ill-defined specialty that's neither psychology nor neuroscience.

In the long term, in keeping with the history of science and because of its reliance on empirical evidence, neuroscience will replace psychology, in much the same way that astronomy replaced astrology, and for the same reason. This is not to suggest that psychology will disappear altogether. Just as there will always be a place for astrology among the uneducated, there will always be a place for psychology.

6 Appendices

6.1 Psychological Pseudoscience

Because psychologists cannot shape and test unifying empirical theories about the mind, this allows them to invent imaginary diseases and offer imaginary cures. Here are a few examples psychologists have dreamt up over the years, based on popular sentiment, prejudice, and social fads.

- **6.1.1 Drapetomania**

  An imaginary mental illness dating to before the U.S. Civil War, Drapetomania[94] presumed to explain why slaves ran away from their masters (apparently a desire for freedom wasn't a suitable explanation). There was no corresponding mental illness to explain why slave owners believed it was moral to own a human being, but the slave owners, not the slaves, paid the psychologists.
  Outcome: abandoned.

- **6.1.2 Prefrontal Lobotomy**

  A procedure developed during the 1930s, then popularized in the U.S. by Walter Freeman[95] and associates, Prefrontal Lobotomy[96] achieved its greatest popularity in the early 1950s, during which time Freeman drove about the U.S. in his "lobotomobile," performing icepick lobotomies at mental hospitals along the way. After a total of 100 of his patients died from the procedure, Freeman, who had no formal surgical training, was banned from performing any further procedures.
  The advantage of the lobotomy was that it rendered mental patients docile and manageable. The drawback was that it often left them without personalities or intelligence. In the U.S. about 40,000 people received the procedure before its terrible effects caused the procedure to be banned. One critic of the procedure remarked, "through lobotomy, an insane person is changed into an idiot."[97]
  Outcome: abandoned.

- **6.1.3 Homosexuality**

  When homophobia reached its peak in the mid-20th century, psychologists listed homosexuality as a mental illness[98] and offered nonsense "treatments"*. When public attitudes changed, homosexuality suddenly wasn't a mental illness any more and was removed from the diagnostic guide[99]. But because of the undisciplined and unscientific nature of psychology, society now finds it necessary to pass laws forbidding therapists from trying to force changes in people's sexual orientation[100].
  Outcome: abandoned.

- **6.1.4 Refrigerator Mother**

  Invented by a prominent psychiatrist, this widely accepted pseudoscientific diagnosis supposedly explained schizophrenia and autism as resulting from emotionally crippled mothers unable to bond with their children[101]. Relying on the imagined authority of a psychology expert and with no scientific evidence, this outrageous belief held responsible any number of innocent and caring parents for outcomes that actually arose in organic and genetic conditions outside psychology's purview.
  Outcome: abandoned.

- **6.1.5 Recovered Memory Therapy (RMT)**

  This dangerous, nonsense fad took hold in the 1990s. Therapists who practiced RMT[102] talked their clients into imaginary "memories" of (among other things) vile sex crimes. In some cases virgins, brainwashed by their unscrupulous therapists, reported copious details of imaginary rapes[103]. Many lives and families were destroyed before the stupidity of the claims became apparent. Psychology insiders now describe RMT as a "debacle"[104], but in the long term it's had little effect on the relationship between therapists and their naive clients.
  Outcome: abandoned.

*Treatments that drove computer pioneer Alan Turing to suicide.

- **6.1.6 Asperger Syndrome**

  Also known as "Asperger's", this diagnosis appealed to parents who believed their bright youngsters weren't "normal". Psychologists used the Asperger's[105] diagnostic criteria to misdiagnose bright youngsters as mentally ill, then offered therapies meant to "correct" behaviors that are normal for bright people[106]. After an epidemic of nonsense diagnoses of above-average youngsters, Asperger's lost public credibility and was removed from psychology's diagnostic manual[107]. But, just as with homosexuality, some psychologists still offer "treatments" for this discredited idea.
  Outcome: abandoned.

Some notes for the above list:

- It's hardly comprehensive – it only shows a few highlights in the history of modern psychology.
- As with all psychological ideas, each of them has been abandoned.
- On reviewing the list, with a little insight one can see it represents an evolutionary process, of learning by experience, and each new imaginary ailment shows more sophistication in appealing to public taste and prejudice.
- To date, by far the most successful imaginary ailment has been Asperger Syndrome, for these reasons:
  - It exploits a superficial association with an objectively real organic ailment with genetic roots (Autism[108]), that, because of its biological origins, lies outside psychology's purview.
  - Its diagnostic indicators are close enough to the normal behavior of intelligent people that the latter are assured of receiving the diagnosis if they want it (in a practice called "pathologizing normal behavior").
  - In a stroke of public relations genius, psychologists "diagnosed" a number of famous people, living and dead, with Asperger's, including Isaac Newton, Thomas Jefferson, Albert Einstein and Bill Gates. This has had the effect of making a mental illness diagnosis seem appealing, desirable, even a status symbol, for the first time.

Asperger's was as wildly successful as Recovered Memory Therapy was wildly unsuccessful, but Asperger's finally became a victim of its own success. So many people clamored to be allowed into the exclusive Aspie* club that even psychologists realized they had given birth to a monster. So to prevent further damage to psychology, they removed Asperger's from the DSM[109], psychology's "bible", only to discover that, like an undead zombie, Asperger's has taken on a life of its own.

In a perhaps unintended irony, those responsible for removing Asperger's from the diagnostic guide explained their decision by saying, "It's not an evidence-based term[107]," overlooking the fact that none of the DSM diagnoses are evidence-based (all rely on lists of symptoms, none rely on a knowledge of causes, i.e. science).

When reviewing psychology's history and the connection between wealth, power and what society chooses to describe as mental illness, it becomes clear that to predict the outcome of a mental health controversy one need only ask, "Who pays the psychologists?"

6.2 Energy Conservation

The principle of energy conservation states that energy cannot be created or destroyed, only changed in form. As it happens, with respect to an orbiting body three independent physical theories, each expressed mathematically, support a fourth theory (energy conservation), and in principle could falsify it.

The first theory is that of gravity, which (at relatively low velocities) has this mathematical expression[110]:

$$f = \frac{G m_1 m_2}{r^2} \tag{6.1}$$

f	Force, Newtons.
G	The universal gravitational constant[111], colloquially known as "Big G".
m_1	Mass of body 1, kilograms.
m_2	Mass of body 2, kilograms.
r	Distance between m_1 and m_2, meters.

When expressed as a time-dependent differential equation[112], the physics behind equation 6.1 causes an orbiting body to describe an elliptical orbit (Figure 2 on page 7), one easily confirmed by empirical observation.

*Aspie: one who has acquired an Asperger's diagnosis.

Moving forward, with respect to such an elliptical orbit and barring frictional losses, the principle of energy conservation means two kinds of energy, gravitational potential energy (theory two) and kinetic energy (theory three), should sum to a constant.

The second theory, gravitational potential energy E_p, has this expression:

$$E_p = \frac{-Gm_1m_2}{r} \tag{6.2}$$

With this additional definition:

E_p Gravitational potential energy, Joules.

The third theory, kinetic energy E_k, has this expression:

$$E_k = \frac{1}{2}mv^2 \tag{6.3}$$

Where:

E_k Kinetic energy, Joules.
m Mass of moving body, kilograms.
v Velocity of moving body, meters per second.

The combined equation for total orbital energy E_t is:

$$E_t = E_k + E_p = \frac{1}{2}mv^2 + \frac{-Gm_1m_2}{r} \tag{6.4}$$

The meaning of equation 6.4 for the present topic is that gravity, gravitational potential energy (E_p) and kinetic energy (E_k) represent three independent theories with excellent observational evidence, but when they're evaluated together, they confirm a fourth theory, conservation of energy (E_t). The reasoning that leads to this theoretical unification is only possible because the theories are expressed mathematically.

6.2.1 Computer Model

A computer orbital simulation model was created to draw Figure 2 on page 7, and to provide the quantitative results shown in Table 1. The model's results agree with theory within the accuracy limitations of computer floating-point processing.

Orbital Segment	Kinetic energy (E_k)	Potential energy (E_p)	Total energy (E_t)	Area m^2
A	$2.186\,810\,407 \times 10^8$	$-9.143\,857\,387 \times 10^8$	$-6.957\,046\,980 \times 10^8$	$1.340\,966\,475 \times 10^{21}$
B	$4.778\,249\,536 \times 10^8$	$-1.173\,529\,652 \times 10^9$	$-6.957\,046\,980 \times 10^8$	$1.340\,966\,475 \times 10^{21}$
C	$1.721\,929\,414 \times 10^9$	$-2.417\,634\,112 \times 10^9$	$-6.957\,046\,980 \times 10^8$	$1.340\,966\,475 \times 10^{21}$
D	$2.144\,985\,881 \times 10^9$	$-2.840\,690\,579 \times 10^9$	$-6.957\,046\,980 \times 10^8$	$1.340\,966\,475 \times 10^{21}$

Table 1: Kinetic and Potential Orbital Energies

The fourth column in Table 1, labeled "Area m^2", confirms Kepler's empirical "equal-area" law. The third column, labeled "Total energy (E_t)", is the sum of potential and kinetic energies and confirms the modern energy conservation theory.

• • •

This example demonstrates the power of mathematics to show a relationship between apparently unrelated scientific theories. As explained above, the theories of gravity, potential energy, kinetic energy, and conservation of energy can all be stated separately, but because of their mathematical expression, as shown in Table 1 the first three theories validate the fourth in a clear and objective way.

This is a model for science. The four theoretical claims are expressed using mathematical equations, easily compared to nature, quantitative, predictive, falsifiable, and mutually supporting. Only perfect theoretical consistency, and perpetual agreement with observation, allows the structure to remain standing. To a scientist, this counts as a strength.

6.3 Logistic Function

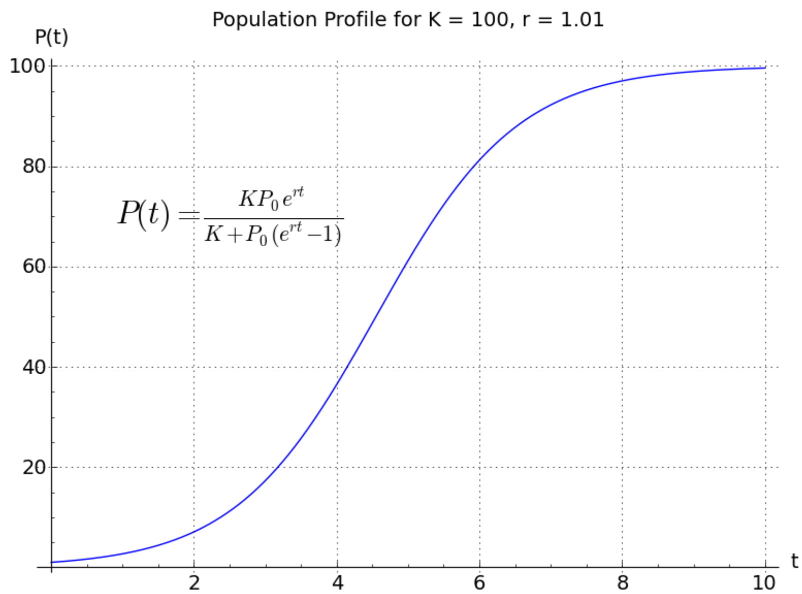

Figure 4: Logistic Function

The Logistic function[113], central to the study of biological populations, is the solution to a simple first-order nonlinear differential equation:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) \tag{6.5}$$

Where:

- t = Time.
- r = Population rate of change with respect to time.
- P = Population.
- K = Environmental carrying capacity.

Equation 6.5 has this solution:

$$P(t) = \frac{KP_0 e^{rt}}{K + P_0(e^{rt} - 1)} \tag{6.6}$$

With the additional variable:

- P_0 = Initial population size.

And with this corollary:

$$\lim_{t\to\infty} P(t) = K \tag{6.7}$$

That is to say, K represents an environmental population carrying capacity, brought about by natural limitations such as food or territory, and is never exceeded.

The theoretically-derived logistic function 6.6 allows experimental data to be compared with theory and possibly falsified, which places some parts of biology on a reliable theoretical basis.

References

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[3] Scientific theory
[4] Paradigm
[5] Falsifiability
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[16] Quantum mechanics
[17] Evolution
[18] Plate tectonics
[19] Paradigm shift
[20] Big Bang
[21] Detection of the cosmic microwave background
[22] Discovery of cosmic microwave background radiation
[23] Cosmological Redshift
[24] Olbers' paradox
[25] Black body
[26] Maxwell's equations
[27] Cosmic microwave background
[28] Charles Darwin
[29] Nuclear fusion
[30] Mass–energy equivalence
[31] Theory of relativity
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[33] Conservation of energy
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[45] Dirac equation
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[47] Theory of relativity
[48] Efficient-market hypothesis
[49] Binomial theorem
[50] Null hypothesis
[51] Bigfoot
[52] Argument from ignorance
[53] Drawing the line between science and pseudo-science
[54] Creationism
[55] American Psychological Association
[56] APA Divisions
[57] David Hume
[58] Physics envy
[59] Reductionism
[60] Dark energy
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[63] Nature of mind
[64] No true Scotsman
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[84]Magnetic resonance imaging
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[112]Differential equation
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