Introduction

The great advances in Science are often described as those that have been mathematized as universal laws. In Physics, we have Kepler's laws, Newton's laws, conservation laws, the second law of thermodynamics, Maxwell's equations, relativity, quantum mechanics formulas, symmetry principles, standard model Lagrangian, etc. To appreciate these, you have to accept the universality of mathematical truths and be receptive to the idea that we live in a clockwork universe where nature behaves in an orderly way.

Where do we get these ideas? You could say we get 2+2=4 from experience, but we also need differential equations to have definite meanings that cannot be disputed. We get that from mathematical proofs. Mathematics provides us with a system of getting certain truths. We may be unsure about the weather tomorrow, but when we have a mathematical proof of a theorem, there can be no doubt about its validity.

Why would we think that mathematically precise formulas apply to the real world? If an ancient scientist tried to use formulas to predict the next year's rainfall or a volcanic eruption, he will not have much luck.

The hard sciences depend on formulas. They are called *hard* because of their rigidity, not difficulty. The soft sciences do not necessarily use mathematical formulas for definite numerical predictions.

Some ancient astronomers watched the sky and discovered that the heavens did operate with mathematical precision. Europeans did eventually come to see the world as an orderly place, subject to universal laws.

The circumstances leading to that conclusion seem like accidents of history to me. I discuss how those accidents happened and how Science might have been different otherwise.

Greek Mathematics

The ancient Greeks discovered axiomatic Mathematics. This was the idea that mathematical systems, like arithmetic and geometry, can be axiomatized, with theorems proved from those axioms. The culmination was Euclid's Elements. It not only stated the Pythagorean Theorem, it gave a rigorous proof.

This meant that mathematicians achieve truths like no one else. A theorem can be proved in a finite number of logical steps, and then we can be certain that it is the absolute truth.

There is a common misconception that Kurt Goedel undermined the axiomatic method, but he actually did the opposite. He showed that Mathematics could be axiomatized as set theory, and that a statement can be logically proved if it is true in every model. He did famously find a subtle logic paradox, but it is not relevant to this essay.

Truths are also obtainable by the scientific method, but they are provisional truths. Scientific theories might have to be modified or rejected based on future observations or experiments. Mathematical truths are forever. Once a theorem is proved, there is no need to test it, or expend any effort to question it.

Greek Mathematics achieved a certainty that scientists have emulated ever since. Scientists sought laws that were universally true. They could find mathematical principles, built on a foundation of mathematical truth. Mathematical theorems are completely reliable.

General relativity teaches that spacetime is curved, and that might seem contrary to Euclid's theorems. But it is not. Those theorems are correct statements about flat space, and that math was used as the foundation for theorems about curved space that ultimately got applied to relativity.

No other civilization ever discovered mathematical axioms and proofs. Impressive methods and calculations were done by ancient Chinese, Indians, Babylonians, Persians, and even Mayans, but none of them had the concept of a mathematical proof. Today it is taught to every high school geometry student, but most do not truly grasp it. It is the most profound and important idea in history.

Had the Greeks not discovered mathematical proofs, or if Euclid's Elements had been lost, science would have been crippled.

Astronomy

Much of early science was inspired by Astronomy. Predicting the seasons was essential to farming. The apparent motions of the celestial objects suggested a mathematical regularity to the universe.

It did not have to be that way. The sky could have been opaque, and we would never see any stars. Maybe we could have gotten light from the Sun, but not been able to identify any objects in the sky.

The prediction of eclipses was the greatest accomplishment of ancient Astronomy. But the existence of eclipses is a scientific fluke. Earth has an unusually large Moon, which just happens to match the apparent size of the Sun for spectacular solar eclipses. Earth also has an umbral shadow that neatly matches the Moon for lunar eclipses. For all we know, Earth might be the only planet in the galaxy with such perfect eclipses.

Scientists achieved high status when they could predict eclipses. Nothing was more amazing to the ancient world. Even in the XX century, Philosopher Karl Popper's favorite example of a scientific prediction was the deflection of starlight during an eclipse.

What if we had no eclipses? And if the sky were cloudy all the time, we would have no Astronomy. No stars, no moon, no planets, and no celestial mechanics. Where would we even get the idea of a clockwork universe?

Isaac Newton developed differential calculus in order to explain planetary orbits. Deriving Kepler's laws from his law of gravitation was one of the outstanding scientific achievements of all time. But if the planets were not visible, what would he have done?

There would still be cyclic events, such as the annual flooding of the Nile river. But that does not occur with the regular precision of astronomical events, and scientists might not even look for mathematically precise laws.

Christianity

The role of Christianity in the development of science is hotly debated. In one view, the Popes stifled progress in the Dark Ages, causing Europe to fall behind the rest of the world. Then the Enlightenment came, intellectuals embraced rationality and rejected religion, and the scientific revolution was born.

That theory does not really explain how Europe leaped forward by millennia so fast.

My view is that Christianity planted the seeds of modernity in the European Dark Ages. That time saw the creation of universities and market economies. Clocks and many other crucial technologies were invented. The Church enforced policies that led to the nuclear family and to individualism. It drove out superstition and taught that the world was an orderly place. It taught free will, personal autonomy, and the pursuit of truth. It allowed secular governments and courts to progress.

Some of these effects were not obvious. Harvard Anthropology professor Joseph Henrich has amassed a lot of evidence showing that much of European success is attributable to the Catholic Church banning cousin marriage centuries earlier. That broke up clans, and created a high-trust and individualistic society. Strangers could cooperate with each other, and accomplish much more.

While Islam taught that knowledge was important, it sought to control politics, economy, and law. If Islam had conquered Europe as it had conquered the Middle East and North Africa, it is hard to see how modern science would develop.

Perhaps you disagree and say that European advancement was caused by navigable rivers, domesticated animals, lactose tolerance, imported silver and spice, or inherent superiority of the White race. I don't think any of those theories explain the Great Divergence of Europe from the rest of the world. Regardless, some set of factors put Europe way ahead, and it is easy to imagine a world where that did not happen.

Computers and Big Data

The study of Turing machines has shown computers can be built from just a few logic gates. It is inevitable that the technology for those gates would be discovered, and assembled into large computers.

The theory behind Turing machines and computability came from mathematical logic. John von Neumann was one of the early pioneers of computer architecture, and he was one of the world's experts on math and logic. Other computer pioneers were engineers trying to accelerate computation, and they also discovered that they could do very complex work by stringing together thousands of logic gates.

It seems inevitable that any civilization would eventually discover logic gates, combine them, and scale up to powerful computers. They could be built without anyone proving that the halting problem is undecidable.

It also seems inevitable that the field of Statistics would have to be developed in order to interpret data. Once you get beyond the simple examples, it is not obvious how to draw conclusions from a large set of measurements. Statistical tests need to be used.

Historically, Statistics was invented long after Euclidean geometry and other seemingly more advanced concepts. Bayes theorem was not discovered until 1763, and linear regression was after that. Arguably the legacy of Greek Mathematics left scholars demanding perfect truths and less willing to consider the uncertainties of probability and statistics.

The uncertainties of big data become essential once a civilization computerizes. While I can imagine an advanced civilization without axiomatic Mathematics, Astronomy, or Christianity, I cannot imagine one without computers, big data, and statistical measures.

Neural Nets

Neural nets have relatively simple components, so it seems inevitable that any civilization with powerful computers and vast training data will eventually develop something similar to today's large language models. They are not conceptually any more difficult than many things taught to high school students.

Today's neural nets are strikingly more successful than those of the 1980s. This success is not because of any tremendous theoretical advances. It is mostly a matter of faster processors, more memory, more extensive training data, incremental model improvements, and a larger investment of money and resources.

Large language models are improving so rapidly that no one knows how good they will get. They seem to be limited only by having sufficient training data and computer capacity. The next Einstein might be GPT-10.

These models, like ChatGPT, are amazing everyone with how good they are and also at how intelligent they appear without ever discovering the secret to intelligence. At a low level, they are just a lot of elementary functions. Their virtue is that they encode and efficiently utilize vast amounts of information.

The finitism and certainty of axiomatic mathematics are unnecessary for these models. Statistics and machine learning have ushered in an era of fuzzy thinking, where nothing is certain, and a low error rate is acceptable. Pills sometimes have adverse effects. Google searches sometimes give bad links. Tesla cars sometimes crash. And face recognition might confuse you for a dog.

A peculiarity of neural nets is that it is nearly impossible to figure out why they give the outputs they do. In a small neural net, maybe a neuron could be identified as decisive on a particular input, and perhaps you could figure out how that neuron was trained. But today's large neural nets can have a trillion parameters, and are far beyond human comprehension.

When neural nets misbehave, they cannot be directly fixed. Instead, they get retrained with additional training data until performance is acceptable. As a result, they seem to acquire their own mysterious personalities.

They are becoming useful scientific instruments. They are not precise and predictable instruments like telescopes and microscopes. They sometimes hallucinate and deliver results that cannot be easily replicated. Usually scientists hate such devices, but they are so useful that they encroach on all science areas. Scientists are learning to live with the idiosyncrasies.

Black box science

Today a lot of science is done without much theoretical underpinning. Especially medicine and soft sciences.

Computer scientists distinguish between *top-down* and *bottom-up* development. Darwinian evolution was top-down, describing life on Earth without understanding genetic mechanisms. The significant advances in Physics have been bottom-up in that they describe motion, energy, forces, and electrons before more complex phenomena.

The example of axiomatic Mathematics led physicists to believe that theories could be reduced to core fundamentals that are like axioms and built up from them. Without that example, maybe Physics could have developed in a more top-down manner.

Consider p-values. They were discovered in the 1920s by statisticians who wanted a test of statistical significance. The scientific method has morphed into the following: Collect some data. Formulate some hypotheses. Compute some p-values. If you find an excellent p-value, you have a publishable result. There is not necessarily any need to have an underlying theory for cause and effect.

What if Science had developed without reliable mathematics and a belief in universal laws? Scientists would busily collect data and publish. They would probably use p-values or some other such rule of thumb to decide what is publishable.

Eventually, they would get computers and neural nets and scale up to large language models. They would make science problem-solving engines where they would feed in data and get valuable predictions.

These engines would be just black boxes, and scientists would not know how they worked. They would have no scientific theories as we know them today.

They might even put atomic clocks in orbit and discover that the transmitted time data could be used for a global positioning system. They would not know how it worked. They would see that they could regularly re-synchronize the clocks in a particular way and train devices to convert the time signals to map coordinates. Another neural net would give people directions or provide directions to autonomous vehicles.

They may even get to the artificial intelligence singularity, and people might become slaves to super-intelligent robots that take over the world. The laws of physics would become implicit in the trillion-parameter models being used. The computers could deduce everything we can with our theories and much more, but the poor mortals would have no conceptual understanding of how the world works.

Conclusion

The history of Science on Earth was contingent on certain breakthroughs where huge amounts of progress were made in particular places and times. It might have been a lot different if conditions had been altered.

I have identified three things that seem like giant flukes in favor of scientific development. The Greek invention of mathematical logic and proof, the astronomy of orbits and especially eclipses, and medieval Christianity. Without these, it is hard to imagine discovering classical mechanics, Maxwell's electromagnetism, or XX century Physics.

Statistical measures like p-values and computer models like neural nets came much later. Still, I contend that they are conceptually more straightforward and more inevitably the consequence of advancing technology and big data. If we had gotten to large language models before classical mechanics, we might have developed a very different idea of science. Science would be all about feeding large datasets into black boxes for artificially intelligent predictions.