The Long View of Science

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It is still taught that science began with Galileo, though this was disproven 50 years ago by Marshall Claggett who showed that Galileo was building on medieval predecessors, and we know they built on ancient philosophers. Hence physics (mechanics) runs through from antiquity to today. Acoustics, math, astronomy, and medicine also continue from antiquity.

Whom do we call a scientist? There was no distinction at first between wisdom of this type and other types of wisdom. For example the Book of Leviticus which is a mixture of commercial regulations (19:35-36) and public-health regulations (19:5-8). In antiquity scientists were called priests at first, then philosophers, then natural philosophers. Natural philosophers seek physical (Latin *natura*) explanations. “Scientist” was only adopted 140 years ago.

Recently (since the 1930s) the definition of science has itself been controversial. To be faithful to the historical context this lecture includes any serious attempts to understand and explain how the world works using physical explanations. Yes, under this definition astrology was a science because it rejected the notion that the planets were gods (if their movements can be perfectly predicted they have no free will so are not gods).

Where did Greek philosophy come from? From Asia, via the Persian empire, in the 6th century BC. Obvious Hindu influences such as belief in reincarnation and even transmigration of souls (Pythagoras). Later on there were Buddhist influences (Gnosticism, 2nd century AD) probably due to Buddhist missionaries coming west.

Greco-Roman Paganism and Hinduism are two branches of the same religion; they even share rituals. Both religions are animist, that is, they try to explain phenomena by positing spirits behind them. When the wind blows a wind-god is acting. When you put your hand in a stream, and the water forms an eddy, the eddy is the goddess of the stream welcoming you to use her waters (note that water normally flows downhill but one side of the eddy is flowing uphill so needs explanation). In the sky the planets wander wherever they want, indicating that they have free will; and they are at least thousands of years old (from Babylonian observations) so they must be gods.

What distinguished Greek philosophy from Asian philosophy?

1. **Greek philosophers took on practical questions.**

Thales (c. 624 – c. 546) wanted to show that philosophy was not just a hobby. He cornered the market in rental olive-presses, profiting greatly when the next olive harvest was abundant. He also tried to answer the question “what is everything made of?”. It didn't seem reasonable that every piece of wood was different stuff from every other piece of wood, even if they came from the same tree. Yet they don't look the same, they have different hardness, and so on. Thales posited that everything was a form of water, probably because water was the only common substance that occurred in all three forms of solid, liquid, and gas/cloud.

His pupils Anaximines (c. 585 – c. 528) and Anaxagoras (c. 610 – c. 546) continued this theme, but Anaximines argued that air is the real stuff of the universe, whereas Anaxagoras argued that we shouldn't call it by the name of one form it takes, but think of it as formless (*apeiron*).

2. **Early Greek philosophers acted like Hindu holy men…**

Pythagoras (c. 570 – c. 495 BC) led what can only be described as a cult. His followers had to live regimented lives in a dormitory. He imposed all kinds of arbitrary rules (like how to roll up a bed-roll) and also set them mathematical tasks. Although his cult seems to have been nutty, his followers did make important advances in mathematics.

Empedocles of Agrigentum (c. 490 – 430 BC), a.k.a. Emedocles of Akragas (the same city under a different name), claimed to have super-powers like being able to still the wind at will. Empedocles was the author of the four elements theory (air, earth, fire, and water) which supplanted the monism of Thales and his students. He also made some remarkable guesses, including an accurate description of the mechanism for the senses of smell and taste.

A consequence of this cultish behaviour was that ancient Greco-Romans expected philosophers to hold back the most important knowledge for their senior initiates. “I can't teach you the most powerful secrets until I have strengthened your brain”, that sort of thing.

By contrast Aristotle never had a cult and published lots of accessible books about philosophy, books which according to Cicero were very well-written. But when some notes were found in a basement a century or so after Aristotle died, even though the notes were in point form and might not have been Aristotle's own notes, everybody was eager for these notes to be published. So eager that now only the point-form notes survive and we have lost all of Aristotle's well-crafted books.

2a. But unlike holy men, Greek philosophers debated. The Greek public treated philosophy as a sport. Promoters staged prize-fights between philosophers, a debate which ended with the audience voting to decide which philosopher won the purse. This created a need for arguments that were irresistible, what we call **proof**.

Thales discovered **geometric proof**, though not in the modern style. The modern style of geometry – side-angle-side etc. – comes from Euclid (3rd century BC). His book Elements was used as a textbook until the 20th century. However it did not originally include any verbal description; it was assumed your math teacher would supply that. It was not until 700 years later (6th century AD) that Pappus added verbal descriptions to Euclid's textbook.

Aristotle discovered **verbal proof (logic)** in the 4th century BC**.** In early philosophy there was no way to look at sentences asserting claims (propositions) and prove that they were correct. On the contrary, as philosophers became better and better at arguing – as they developed general strategies for arguing – it seemed less and less like there really was such a thing as truth. Like beauty, it seemed truth was in the eye of the beholder. Even Socrates (469 - 399 BC), who championed the reality of truth, did not ask whether arguments were true but whether they were beautiful.

The Sophists were a subset of philosophers who specialized in argument technique. Socrates was trained by a Sophist and in fact Socrates was the best of the Sophists - his claim to fame was his ability to out-argue *almost* anybody else. But there was a subset of Sophists, the Skeptics, who believed that truth was a delusion. The skeptics believed that you could successfully argue any claim or its inverse. In fact some (notably Pyrrho the Skeptic) went around doing just that, arguing first for a claim and then against it and being thoroughly convincing both times. Socrates rejected Skepticism; he thought there had to be some actual, real truth and it should be possible to find it through argument. This crisis led to the reform of Greek philosophy.

The most famous student of Socrates was Plato (427 - 347 BC). Plato was not able to solve the problem of provable truth himself, but he did start what we might call the first real school of philosophy, where one could learn about the whole of philosophy and not just one man's ideas. His school was called the Academy.

Plato had a brilliant student named Aristotle (384 - 322 BC). After Aristotle finished all the courses he could take at Plato's school he stayed on doing research financed by Plato – today we would call it post-doc research. One of his research projects was called the “rhetoric project”. There is no more documentation about this project, but later when Aristotle taught at his own school his courses included two courses about language. The first course, Prior Analytics, was about grammar: parts of speech, verb forms, and so on. Today we call that syntax. The second course, Posterior Analytics, was about the content of sentences. Today we call that semantics. From his notes we know that this was the world's first course in deductive logic. For all the sophistication of Eastern philosophy, the Greeks were the first in the world to discover deductive logic.

Aristotelian logic deals in syllogisms: sets of two propositions and a single resulting conclusion. Aristotle did not prove that syllogisms work, he just claimed they did and nobody was able to show a counter-example. We are still in the same position today with respect to logic; we cannot use logic to prove logic works. (And logic does not always work, e.g. “this statement is false”.)

Note that before the discovery of proof knowledge was collected and blessed by tradition as wisdom. After the discovery of proof philosophers did not consider a statement wise unless it was provable. This is the root-stock of science: provable, hence reliable, knowledge.

3. **Greek philosophers discovered paradox through logic.** Parmenides (5th C. BC) argued that change was impossible because change involved something coming into existence that did not previously exist. But he argued that coming-into-existence is a reflexive verb, that is, for a thing to come into existence it has to act on itself. But how can it act on itself when it does not yet exist? So Parmenides denied the whole appearance and existence of the world we know as impossible.

Eventually other philosophers found ways around Parmenides, but to justify them they had to invent a rule that said natural philosophy must "preserve the appearances". This is the beginning of the modern distinction between science and mysticism, namely that if you are telling the universe that you know better than it does then you are a mystic and not a scientist.[1]

1 For example in 1906 there was a scientific meeting to consider special relativity. Both Einstein and Henri Poincaré (the other father of special relativity) were present. A member of the audience suggested that the effects of special relativity – clocks slowing, objects shrinking in the direction of motion, and so on – were really just optical illusions. Poincaré agreed, but Einstein rightly pointed out that special relativity is experienced by everything in the universe, every electron, every proton, every photon. Saying that it is an optical illusion is saying you know better than the universe, which is mysticism. Ever since physics has treated relativity as real, not illusory.

4. **Paradox led to atomism.** The problem of too many substances and the problem of the impossibility of change had a single solution, atomism. The atomists proposed that every substance is made up of a collection of atoms, which are themselves unchanging. When we see macroscopic change what we are seeing is atoms hooking up to other atoms or unhooking from them, and rearranging into different configurations. As it turns out there are more than four natural elements, and elements are themselves composed of a few types of sub-atomic particles, but the basic idea was correct.

5. **Ancient philosophers of science did perform experiments when possible.** A question at issue in the 4th century BC was whether air really exists as a substance when it is not moving. Strato the Physicist (fl. circa 287 BC) describes experiments involving immersing an upside-down empty dry cup in water, and then examining the cup. While underwater only part of the cup gets wet on the inside, so something must be holding back the water. He then goes on to describe drilling a hole in the bottom of the cup, again immersing it upside-down with a finger blocking the hole, then lifting the finger to see bubbles coming out of the hole. Afterward the cup is wet all over the inside. All of this proves that air is a thing.

The ancient philosophers did very well in **acoustics**, getting the whole picture right. They figured out that sound is vibration of air, that higher-pitched sounds vibrate faster, and even that for a given string the rate of vibration is proportional to the length of the string. They were able to do all this because they had a suitable test instrument: the single-stringed monochord, literally a musical instrument with a calibrated scale on the neck.[2] The monochord was invented by teachers of kithera-playing as a simplified hypothetical instrument for explaining the real instrument. Claudius Ptolemy (2nd century AD) built monchords for use in laboratory experiments and he even made multi-string monochords.[3] Ptolemy also performed other experiments, famously measuring the diameter of the Earth using the angle of a shadow and a surveyed distance.

Acoustics shows how far ancient science could go once a suitable laboratory instrument had been developed. The biggest thing holding back ancient science was lack of such instruments. For example they had no lenses[4], hence no microscopes or telescopes, and no thermometers, hence no thermodynamics.

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2 The kythera gained a neck around 300 BC. The word “kythera” has survived in ordinary usage as the English word “guitar”, passed down not by scholars but by ordinary folk. This is another, albeit non-scientific, example of the continuity of ancient culture into the modern world.

3 Not really monochords, were they?

4 There is some evidence suggesting that the Carthaginians knew how to make and use lenses. If so the knowledge was lost when the Romans destroyed Carthage and slaughtered most of the Carthaginians in 146 BC. Also the philosopher Diocles (fl. 190 – 180 BC) analyzed the behaviour of a parabolic mirror but only for reflecting heat which he thought was particles of fire (On Burning Mirrors); it did not occur to him, nor would the science of the time suggest, that light could reflect the same way. Alas history is full of such near-misses.

6. **Science began to change Greco-Roman society.** Philosophers did not plan to refute traditional beliefs but they ended up doing so. By the 3rd century BC philosophy of nature had explained the wind as hot air rising and cold air rushing in to replace it; eddies as resulting from the tendency of rotation to continue (what we now call rotational inertia); and shown that the planets were not gods because they had no free will, instead retracing the same paths over and over. By the 1st century BC many Romans converted to Judaism[5], and later Christianity, to escape the complicated and now-unnecessary animism of their ancestors.

Generally the Romans were very pious towards any alleged god. However by the 1st century AD there were lots of temples claiming to show off miracles on a regular basis. A mechanical engineer or scientist of mechanics calling himself Heron (English Hero) of Alexandria published a book called Pneumatics debunking lots of such miracles by describing mechanisms to produce the same effect. For example, he described how a jug could be rigged with an internal partition and vent-holes that could be covered by a thumb so that a fake holy man might fill the jug with water, say some mumbo-jumbo, and pour out wine. We don't know whether this book was published in the 1st century BC or the 1st century AD, but either way it leads us to believe that the miracle reported of Jesus at the wedding in Cana (John 2.1-11) was just the sort of thing expected of a holy man.

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5 From archaeological evidence, in 100 AD roughly one resident of the city of Rome out of nine was Jewish. It is impossible that so many Jews immigrated from the Middle East. Besides, we know that Jewish proselytizing annoyed both the Roman government and the poet Ovid.

Another example of impiety that would not previously have been tolerated was the behaviour of Titus, when his father was Emperor in Rome and had left Titus in charge in the Middle East. The Romans had a lot of trouble with Fanatics, a group of Israeli nationalists who were so extreme that when they lost a battle against Roman troops they murdered their own wives and children and then killed themselves. There were other, less extreme Israeli nationalists as well. However Titus found out that all Israeli nationalists believed the Temple of Solomon was essential to an Israeli state. Titus went to the temple and interrogated the chief priest. “What is that thing?” “Why, it's the Holy of Holies. The Ark of the Covenant is there.” “What would happen if I looked behind the curtain?” “Your face would melt! Only Jehovah's chief priest can look on the Ark of the Covenant without harm!” So Titus opened the curtain and looked…and his face failed to melt. He didn't even keel over dead. Whereupon Titus declared that the temple was fake and ordered it torn down. Thus did science triumph over superstition.[6]

6 If you are an ancient Roman don't try this for yourself unless your daddy is Emperor and you are the designated heir to the throne, otherwise you will get in rather a lot of trouble.

But it also worked the other way. The Hippocratics wanted to eliminate superstition from medical practise, so they rejected anything that sounded like a reference to animism. The idea that something invisible transferred from the sick to the well sounded to them like talk of possession by spirits, and as a result they rejected the very idea of infectious disease. In this regard they were scientifically regressive. Even Leviticus (4th century BC) talks about “defiling” (infectious) disease and preventing its spread by isolating the sick and burning their clothes.[7]

7. **The 5th century AD saw the political collapse of the Western Roman Empire, but Greco-Roman culture was not lost.** It continued for another thousand years in the Eastern Roman (Byzantine) Empire and in various cities of Northern Italy. Nor was learning completely lost in other parts of Latin Europe, rather it was taken over by the Catholic church. In the 11th century the church established a school system with parish schools at the bottom and universities[8] at the top. This system was modelled on Plato's Republic, with the word “philosopher” scratched out and “cleric” written in. All the teachers in the medieval universities were Dominican friars and they combined research with teaching as we now expect university professors to do.

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7 Leviticus 13.1-8, New International Edition.

8 Oxford, Cambridge, and the University of Paris were the three universities founded during that century. Two are in England, suggesting the whole project was the brainchild of Anselm (later Saint Anselm) who was regarded as the greatest scholar in Latin Europe and who at that time was the archbishop of Canterbury.

In the 13th century Chinese chemists discovered what we now call “gunpowder”, but at first it was used for fireworks. In less than a century the knowledge reached Europeans who turned gunpowder into a means for propelling projectiles, i.e. they invented the gun. That knowledge travelled back East, and was soon employed by the Mongol Empire among others. The bicontinental gunpowder revolution had other consequences; in 1453 Constantinople fell to Turkish cannon and refugee scholars from Constantinople helped to promote the Renaissance. Venice, which had been founded by refugees from Rome, continued as the last outpost of the Eastern Roman Empire for another three centuries.

During **Galileo**'s life (AD 1564–1642) the Renaissance was in full swing. Galileo was himself a university teacher and therefore a Dominican friar. Galileo defended Copernicus' proposal for geocentrism but he was unable to persuade the church because it seemed that such a movement would defy known physics. This was *not* church prejudice. Heliocentrism had been proposed in pre-Christian antiquity by **Aristarchus of Samos** (310 BC–circa 230 BC) but it had been rejected for the same reason.

Eventually Galileo invented a new physics of motion (later mathematized by Newton) which allowed for heliocentrism[9], and the church permitted him to publish (Discourses and Mathematical Demonstrations Relating to Two New Sciences) and teach it. In this text Galileo makes mention of several tough physics puzzles, such as predicting the path of a cannonball fired from a cannon pointed vertically in a smoothly sailing ship. In the 1970s Marshall Claggett proved that these puzzles came down to Galileo from medieval texts. In science questions are as important as answers, hence there was continuity in physics from antiquity right through to Galileo.

Medicine is another science that continued from antiquity to the modern era. Medical doctors continued circulating scientific literature in Latin and/or Greek right through the Middle Ages. Up until WWI medical schools still used textbooks written in antiquity by Celsus and Galen.

9 It required that the space between planets be empty, not filled with air. Newton showed that space must be empty, otherwise we would suffer intolerable atmospheric pressure. But the telescope already gave reason, because if space was filled with air the planets and stars would be blurred beyond recognition.

Chemistry is a special case. There were scientists doing chemistry right through the Middle Ages, but not in universities. However alchemy arrived in Greece about 100 AD. Alchemists were both mystics and practical bench chemists. They were disapproved of by the church but continued their work in private. Meanwhile the schoolmen did no experiments whatsoever but insisted on the four elements of Empedocles. Hence according to university professors of the day gold was not an element, therefore it was a compound and should have been sythesizable. Alchemy persisted because it attracted investors. Finally in the 18th century mainstream scientists including Newton and Lavoisier combined the praxis of alchemy with modern mathematical analysis to create what we now call quantitative chemistry. Although this case excludes the medieval schoolmen it still shows continuity, via private practice, from antiquity right through to the modern era.

8. **Ancient science was also held back by lack of certain mathematics.** Statistics were unknown in antiquity and could not be developed until after Pascal developed probability (really, gambling) theory in the 17th century AD. But one must not overstate the limitations upon ancient math. For example it has been said that Roman science was held back by the use of Roman numerals. Even if the supposed disadvantages of Roman numerals were true (which they are not), Greek astronomers relied upon records compiled using Babylonian numerals which were a place-value system. Babylonian numbers used base 60 and our system of measuring angles in degrees, minutes, and seconds is a direct crib from Babylonian.[10]

9. **Sometimes cultural assumptions still hold back science.** For example the first zoologist (Aristotle) had no trouble assuming that our species is just another type of animal. During the Middle Ages European culture came to assume that we are inherently different from other species. Even today Irene Pepperberg has spent her career proving that African grey parrots are capable of meaningful conversation, not just mimicry. Despite firm evidence her discovery has encountered a great deal of resistance, even from other scientists. Yet hardly anybody under 60 goes to church anymore, so it is not religious resistance, it is just lack of fluid thinking. It is hard for people to change their thinking and it often takes generations.

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10 The unit angle was a corner of an equilateral triangle, which they divided into 60 degrees. Then they divided a degree into 60 minutes, a minute into 60 seconds, a second into 60 thirds, and so on.