The History of Science

**See Peter Dear, Revolutionizing the Sciences, Introduction.*

The first question should be, "Why study what others thought, especially when we now know that what they thought was wrong.?"

First, was it wrong? Didn't they get some things right?
Secondly, when we know that their science was wrong, why study it?

The answer is both historical and philosophical.

Studying the science of a society answers many questions about their culture. Even when we know today that their science was wrong, it helps us understand their biases, their presumptions, the cultural ideas that influenced their worldview. We are not merely studying the science itself, we are studying the methodology that they used.

Science develops within a particular culture—therefore a "scientist" can only ask a question within the context of the culture. In other words, his questions are limited. By studying the limitations on his questions we can better understand the society in which the science developed.

> Mesopotamian science was based on an attempt to control the chaos around them.
>
> Egyptian science was intertwined with their view of the cyclical universe and the responsibility of the living to ensure the cycle of the dead.
>
> Greek science was concerned with a method for determining truth and based it largely on observable, quantifiable, facts.
>
> The Romans were more concerned with practical application, thus building and architecture.
>
> The Islamic world desired to preserve much of the Greek science, and thus, they preserved works that the Latin and even Byzantine societies tended to disregard. And they often improved upon it, but with a strong belief in Islamic ideas.
>
> The Medieval Europeans built their science on the rediscovery of Aristotle and their admiration of accomplishments of the Ancient cultures, as well as their strong belief in Christianity.
>
> The science of the high middle ages was challenged after the influence of the Renaissance in a period called the Scientific revolution, which was a transition to the birth of modern science.

So, science is not done in a vacuum because science cannot be separated from the culture that created it.

"The central goal of the history of science is to understand why particular people in the past believed the things they did about the world and pursued inquiries in the ways they did."[1]

So, the historian of science is not simply finding the grains of scientific truth in the past. In other words, we are not studying the things that they got right and ignoring the things that were wrong.

In fact, we do not study Copernicus's ideas about a moving earth because we now believe that the earth moves, but rather, because Copernicus believed it was true. There were *reasons* why he believed this. Just like there are reasons why Aristotle believed the things he believed, or why the Medieval Scholastics did not believe in a moving earth. The historian's job is to find out the various *reasons* why each of these believed what they did. Historians of science are not studying the science and determining its truth or validity, we are studying the arguments that were made.[2]

---

[1] Peter Dear, Revolutionizing the Sciences: European Knowledge and Its Ambitions, 1500-1700. Princeton, 2001, p. 2.

[2] Dear, 2.

Even if we now know the science is wrong, the argument tells us about the thought process. It tells us the assumptions that people make and those assumptions are built on their philosophy--their worldview.[3]

Thomas Kuhn and "paradigm shifts."

Thomas Kuhn wrote a book called *On the Structure of Scientific Revolutions*. (1962)

What is science?

Different cultures throughout history have defined science as different things. What was considered scientific 1,000 years ago would mostly be considered non-scientific today. What was considered scientific 200 years ago may now be regarded as pseudo-science. And what we consider scientific today may not be considered scientific in 200 years. (And that is why we study history and the history of science. It tells us not only about their culture, it helps us see ours more clearly).

Now, who defines science? Well, the scientific community of the day.

Scientists accept some questions as legitimate scientific inquiries and regard others as myth, philosophy, or pseudo-science. They are judging the validity of a question on the fact that the question fits within certain accepted rules, or within the paradigm that is accepted by the scientific community.

Scientists often do not even realize that they do this, but it is a fundamental part of science. This is the essence of studying the philosophy of science.

We often say that scientist are interested in truth.
What is truth? What is a fact? What is knowledge?

How do we know that we know things?
How do we know that the things we call truth are, in fact, true?
People of ancient mesopotamia *knew* that the world unpredictable and that the gods controlled everything and were vengeful. Ancient Egyptians *knew* that the man must ensure that the ma'at must be continued for the cycle to continue. Ancient Greeks *knew* that the world below the moon was composed of 4 elements. The Medieval thinkers *knew* that the earth was in the center of the universe. And of course, we say that we *know* sever things.

But scientists are truth seekers, right? They would not reject a question or answer that could lead to truth would they?

Well, that brings us back to Thomas Kuhn.

When Kuhn described the idea of paradigms in the history of science, he stated that since science can only be done within the framework of the prevailing paradigm, scientific advancement is a result of a paradigm shifts--movement from one paradigm to another. But replacing a paradigm is not easy.

The "Spider web" metaphor

Its more than just a conscious attempt to hold onto a certain belief, the person feels threatened because their world is centered or heavily built on the idea that is being attacked, an idea that they have held as absolute truth. If this "truth" falls then all "truths" built upon it will also collapse. Whereas the person woke up knowing how the world worked that there were certain ideas that were universally true and could be counted on, he would then, after the core of his worldview was broken, have to relearn everything that he one *knew* to be *true*.

When we begin to understand the problems in the conflict between the Ptolemaic and Copernican world views it help us understand the hostility toward the new ideas.

---

[3] Dear, 2.

What implication does this idea have for us today?

How we do science today.

Deduction—from a number of general observations or experiments one deduces a specific principle
Induction—building from smaller elements to produce a general rule

Observation—a key to science. The collection of data. Scientists observe the world around them. Scientists want to see repeatable things.
Experiment—a test to see if a prediction is true. It is am elimination of variables for repetition.

"Falsify-ability" vs. non-testable hypothesis

Scientists want to predict and control.

Pseudoscience

There are **observables** which are things you can see or (use any of the senses) (or measure) and develop "empirical laws"
There are **unobservables**—"theoretical laws"

Realists versus Instrumentalists

For both a theory must be predictable and Explanatory.

Instrumentalists only require that a picture (theory) explains and predicts.
For a realists what good is a picture (theory) of a phenomena if it is not real.

In conclusion

Science is done in a cultural atmosphere. By looking at the arguments made we can gain insight into the culture.

We will look at the science of early civilizations and then we will trace the scientific movements from the Greeks through, as close as we can in the time allotted, to our present day. We will focus primarily on the scientific revolution that occurred as a result of the renaissance.

Background (500 BC - 1500 AD)

<u>The Greeks</u>

These thinkers gave us our first "scientific" ideas of explanation.
Their ideas came from observation (which the Greeks were good at.)

Pythagoras—569-530 B.C. (from Italy)

Founded a religious group. Believed in reincarnation. The cosmos is full of living breath (or the breath of life), leading to an idea of the earth as an organism, and dependent on and connected to all other things, in a divine order.

If everything is connected then everyone should take care of each other. Implications of a warless, society (not very Greek).

<u>Aristotle</u>

Everything as an end or a purpose. Therefore a natural philosopher's job is to find the purpose of all things. The "final cause" of Aristotle's four causes.

In order to understand our modern view of science, we must understand the scientific revolution, or the science that emerged as a result of the renaissance. In order to understand that we must focus on Aristotle.

We are primarily focusing on the study of physics. What is Physics? At its most basic, its the study of motion. So, aristotle began to look at the universe and asked questions about motion and the nature of things.

<u>Aristotle's Universe- The Four Sublunar Elements and the Heavenly Element and their natural motion.</u>

* See Annible Fantoli, *For Copernicanism and for the Church*, p. 1-12.

Aristotle (384-321 B.C.) built on the idea of four elements and said that the universe was finite and had distinct parts--the heavenly bodies and the sub-lunar bodies. Sublunar things are made of four elements-Earth, Air fire and Water. These elements can be divided into two groups the heavy elements (Earth and Water), and the light elements (Air and Fire). Elements contained a natural rectilinear motion. The Heavy elements moved from high to low, and the light elements moved from low to high. It was this movement that distinguished the two categories. The place where the motion ceased was called the natural place of the element and each element with its natural motion sought its natural place.

This created a sphere with earth at the center with water on the outside then air and then fire. When fire would be released from something containing earth, the fire would move up and the earth would move down. There was such as thing as violent motion that would mess up the natural place of the elements but their natural rectilinear motion would begin to move them to their proper place.

This is something that can be proven logically with Aristotle's "experiment" with the four elements.

Aristotle's theory was a very grandiose theory and synthesized the movement of heavenly bodies with the movements on earth and contained elements of philosophy that both medieval Christian and Arabic thought embraced.

<u>Aristotle's system explained the motion that we see in the heavens with the motion that we experience on earth. One theory to explain all motion in the universe.</u>

Over time observations of the night sky began to reveal weaknesses in Aristotle's system. For example, throughout the year the brightness of the planets would change.
Greek astronomers such as Apollonius (262-190BC) and Hipparchus (c. 120 BC) began to modify Aristotle's theory.

Ptolemy

By about 130 AD a Greek Ruler of Egypt named Ptolemy wrote the first complete mathematical explanation of the heavenly motions. Ptolemy's book was the greatest astronomical work in the ancient world. It was called *Syntaxis* but named by the Arabs with its now more common name, the *Almagest.*

Ptolemaic system—was not a simple system.

Facts that Ptolemy accepted.

1. circular movement of the planets
2. the 4 elements are the only four and they are there.
3. The earth is spherical
4. The earth the center

When these certain facts are accepted all theories are made to fit within these "facts." The Ptolemaic system survives for nearly 1600 years.

With these facts in mind Ptolemy wrote about the movements of the heavens. (3 principles)

1) <u>The principle of eccentric motions.</u> The earth was not at the center of planetary motions but rather at a point just off center. This explained the changes in brightness of the planets and why the seasons were of unequal length.
2) <u>The Principle of Epicycles.</u> To explain the retrograde motion, and the occasional appearance of a stationary state, each planet was believed to revolve on a circle, the epicycle, whose center was traveling along a larger circle, the deferent, and some planets, required an additional larger circle for the deferent to travel on. (The result was called the epicycloid).
3) <u>The principle of the equant.</u> A difficult concept, but nonetheless, a final one that was needed to construct mathematical tables that would allow accurate predictions that coincided with the observations. (*The deferent's center was not with earth but rather with a point just off of earth and the angular velocity of the planet was not constant with the Center but to a point opposite of earth called the equant point).*

There were some Greek scholars who theorized that the earth was in motion and not stationary.

1) Philolaus (about 475BC)
2) A contemporary of Aristotle, Heraclides Ponticus (388-310? BC)
3) *Aristarcus of Samos (310-230 BC)*

[GREEK MEDICINE (5th-4th century)]

Roman Science

Medicine was thought as something for everyone to practice.

The Romans were not concerned with Hot Wet cold and Dry but about "Did it work?"

Roman technology—improved, windmills, aqueducts—to get fresh water, arches, etc…

The Impact of Christianity on Science

*See Nancy Pearcey, "Christianity as a science starter."

There is a strong desire to speak of the dark ages as dark because science was lacking. In fact, some would argue that science was put in a back seat since Christians saw the world as temporary anyway. In the 19th century, two historians John Drapper and Andrew White, developed what has become known as the Drapper-White thesis. This thesis, sometimes referred to as the "warfare thesis," argued that there was a war between Christianity and science. Between the Christian church and scientific advancement. They looked at medieval science and then the trial of Galileo in 1633. The warfare thesis tells us more about perceptions influenced by 19th century events more so than the events themselves. (In the 19th century, Darwin published origin of the species which described natural selection. Natural selection led to the theory of evolution, which was highly debated on both scientific and philosophical grounds. As christian sects began to way in on the debate, some like Drapper and White began to see a conflict.)

The warfare thesis is not one that any reputable historian of science buys into today. In fact, there has been a lot written on how Christianity actually helped built the modern idea of science.

The Science of Islam

Spain (Al-Andalus in Arabic) conquered by Islamic Empire from 711-1492.

Through all of the Muslim Conquests they set up schools of translation. They translated all of Galen's, Hippocrates, and other's works. The Romans had many of the works but disregarded much of it. The Muslim's did not disregard it, they wanted to learn it and so they translated it into Arabic. They translated Greek Medicine, Greek Astronomy, Philosophy. ….They were not necessarily interested in Greek Mythology or Greek Poetry.

Ibn Al-HAytham (Alhacen)
Al-Bitruji (Alpetragis)

Avicenno from Spain—(d. 1037)

Gerbert d'Aurillac—better known as Pope Sylvester II (The first French Pope), (became Pope in 999). He was a scholar, he traveled to spain and...

- He reintroduced the Abacus to the West
- Built it on Arabic numerals rather than Roman numerals

In 1189, Gerard of Cremona, went to Toledo, and found that the library was so much more extensive than anything that was in Latin. He decided to learn Arabic and translated many of the works into Latin.

Concepts and words from the Muslim world into the Western World:

Zero
Algebra (Means to balance (an equation))
Algorithm
Almanac
Zeniths

The knowledge base that was passed form the Muslims to the western world is the jumping off point of Western Science that lead to the Renaissance, Scientific Revolution etc… at the same time that the Muslim's were going in a different direction.

By the 13th Century—Aristotle becomes the foundation for all educated works.

<u>The Medieval Synthesis</u>

*See Annible Fantoli, *For Copernicanism and for the Church*, p.12-19

Medieval Scholasticism, which was the basis of intellectual inquiry during the High Middle Ages at the Universities, was based on creating a synthesis of various ideas. In the world of philosophy it was a combination of Greek scholarship, often with the overtones of these Arabic commentators, and the writings of Church fathers from the Roman Empire, through Early Medieval scholars.

In astronomy, it was the combination of the Aristotle, Ptolemy, and Christian principles.

The high point of Scholasticism was the writing of Sir Thomas Aquinas (1225-1274 AD).

The motionless universally centered earth made sense to the Christian scholars because (a) Aristotle's logic was solid, (b) Ptolemy's math provided the ability to predict motion and (c) When one based theology on the first two ideas, it made sense.

An example of the medieval synthesis was the replacement of Aristotle Prime mover with the Christian God, and the assertion that Aristotle's series of First movers being were angels. But on a deeper level, it was a combination of Christian philosophy with natural philosophy to the point that if either were wrong the other would be also. Remember, scholasticism was based on the synthesis of ideas to create a more accurate truth. The abandonment of Aristotle meant the reevaluation of Christian ideas, while the abandonment of Christian ideas meant that Aristotelian physics would break down. (It was for this very reason that Augustine, and later Galileo, would urge the Church to not base Biblical interpretation on scientific ideas since the scientific ideas may be proven incorrect in time.

Now, essentially for a Medieval philosopher the earth was in the center of the universe because that was the special place and the place than man had to be in God's creation. Again, the scholastics revered the Bible and Aristotle and used each to defend and "prove" the other.

<u>Medieval Universities</u>

**** William Ockham. Ockham's Razor was and idea, an idea that cut away the surplus of much speculative thought.***

Simply put it was ***"Do not multiply entities more than necessary"****. In other words, make your explanations as simple as will fit the facts.*

All things being equal the simplest explanation must be true.

We can note here both Copernicus' reasons for making the Sun the centre of the Universe, and the tendency in science always to look for the most simple explanation.

<u>Science and Magic</u>

"In practice science was not clearly distinct from magic. One of main motives for intellectuals throughout the Middle Ages and the Renaissance was to look back at the admired thinkers of the past (EMPHASISE) so along with logic and the art of the past, the rather large amount of magical and symbolic thought of the past was retrieved."

1. Alchemy

This involved trying to convert iron, lead or some other base (A metal that rusts easily) metal into gold (A noble metal) or to find some elixir of life. It was based on Greek science.

2. Astrology

This thought that events in the heavens effect events on Earth and was pre-Aristotelian, but Aristotle's idea of contiguous motion gave a scientific rationale to it. The idea of a Chain of Being is important here. It was fitted into a Christian worldview by saying that the stars affected the lower nature of people, while the higher parts still had free will.

3. Witchcraft

It is important to note that many of the figures we will study were very involved with magic, alchemy, and other pseudoscientific ideas. They were also surrounded by Religious ideas, specifically Christianity and most were devout in their own faith and used it as a guiding light. The scientific revolution cannot be understood as a break from these ideas but rather a part of the period as a whole.

[The cosmology of Aristotle led to the assumptions used in the math of Ptolemy. The Aristitolean-Ptolemic model gave way to the Medieval synthesis.]

And so, what we have covered is essentially what educated individuals knew to be the truth in 1500.

<u>Causes of the Scientific Revolution</u>

Trade and Expansion of Trade (age of exploration)

Navigational problems of sea voyages generated scientific research. Overseas specimens aroused peoples interest in different worlds.

Medieval Universities---As mentioned they were not as stifling as we sometimes attribute to them, there were many who had enquiring minds that were given the opportunity to study and find solutions to age old problems.

The Religious world,
The Church based many religious doctrines on the idea that the science was true, and thus the religion was true and thus the papal authority was true. However, The papal authority was being challenged and the church loosing power since the 14^{th} century and gaining much ground in the 16^{th} century. Thus, the church was very conscious of holding onto the slipping influence (and that is a better word than power) as the medieval world slipped away in the Renaissance, this helps explain both the world that fostered the scientific revolution and the world that challenged the new ideas.

Humanism
The belief that there are no limits to human accomplishment (Pico de Mirandola). This, rather than more medieval ideas, was the precursor of modern ways of thinking.

Reformation
The Reformation divided Europe. Science could go on in other countries when Catholic hierarchy opposed it.

Thus, the stage was set for new figures to challenge the old.

II. Nicholas Copernicus (1473-1543)

A Polish priest who studied canon law, mathematics, and medicine at Cracow, Bologna, Rome, Padua, and Ferrara. Copernicus became interested in astronomy and published an early description of his "heliocentric" model in 1512.

Copernicus's work gave a complete mathematical explanation of celestial motion and observation and was therefore incomparable to any other work before him, except Ptolemy.

Motivation for the Copernican System.

1. Tables that showed the time of eclipses and other phenomena were inaccurate.

2. The age of exploration sent sea captains out into uncharted waters with only the stars to guide them. It was very important to have accurate information and with the age of exploration the inaccuracies were becoming more and more apparent.

2. The Calendar that was begun by Julius Caesar in 44 BC (Julian Calendar) was not accurate. At the time of the Council of Nicea (325 AD) the equinox was on the 21st but by the 16th century had fallen to the 11th. Sine the Christian religious calendar depended on Easter and the Spring Equinox (Christian holidays counted from Easter) a discrepancy was a serious problem.

Copernicus was educated at Cracow and Bologna in a critical atmosphere that called for the reform of Ptolemaic astronomy and cosmology.

Renaissance Platonic-Pythagorean influences stressed unity, coherence, and harmony in the cosmos in addition to accounting for observed phenomena.

Copernicus sought to purify ancient astronomy…to simplify it. He was a neo-platonist mathematician, and with regards to "Early modern European history" he was a man with one foot in the modern but one foot in the early."

By the time of Copernicus the number of spheres had grown to 84. It was a very complicated system. According to Copernicus, the Greek idea of simplicity as beauty was important to him. He felt that God would create a more simple system and that the complicated system of Ptolemy did not suffice. In 1512 Copernicus published an account that hinted at a heliocentric model but did not state it outright.

He worked out his calculations and developed a full mathematical model that simplified the movement of the planets by switching the place of the Earth and the sun and hypothesized that that the earth moved and the Sun was stationary. However he was reluctant to publish his ideas.

In 1539 Copernicus took a man named Rheticus (1514-1574) on as a student. It was Rheticus's father was an alchemist, astrologer and magician who was beheaded for sorcery. It was Rheticus who encouraged Copernicus to publish his original work before Copernicus died.

In 1543 *De Revolutionibus Orbium Caelestium* On the Revolution of the Heavenly Orbs, was published.
In it, Copernicus introduced three motions:

1. Rotation of the Earth on its Axis (Day and Night—Movement of the Sun)
2. Revolution of the Earth and planets around the sun.
3. *A conical axial motion of earth to explain the fixed orientation of earth in space.*

Copernicus theory was based on very conservative maths and not on observation. Platontists' obsession with simplicity and perfection. It was simpler to explain heavenly motion if the Sun was at the center. Copernicus offered it as a hypothesis.

But it was not perfect. His way reduced the number of spheres from 80 to 34. He was still loyal to Ptolemy's system in many ways. He held onto (very tightly) many ideas, such as his obsession with perfect circular motion. Due to Platonic maths, he thought that planets moved in a perfect circle (not so), In this he is very much still a slave to the ancients, But the important thing was Copernicus' mental breakthrough. In this he was very modern. Ultimately, He was wrong but was the stimulus for future scientists to come up with something better.

And it even sparked a basis for arguments outside of Science--

Copernicus dedicated his book to Pope Pius III. Copernicus had enjoyed a long relationship with the Vatican that should not be thought of as hostile. He had been asked to serve on a council that discussed the problems with the calendar and was well respected.

However, since Copernicus waited until his deathbed to publish *De Revolutionibus*, one may assume that he was concerned with the reaction from the Church.

Should be noted, however, that the Church did not ban Copernicus's work until a century later when Galileo was at the center of controversy. For nearly a century Copernicus was not thought of as a threat to the Church's influence, nor a threat to the Christian worldview.

One reason was that Copernicus's work was designed for the professional. Most of *De Revolutionibus* was a technical mathematical work similarly to Ptolemy's *Almagest*.

In addition, a preface was added to *De Revolutoinibus* by a protestant reformer named Andreas Osiander (anonymously at the time). The preface stated that the theory put forth was only a mathematical theory that would help in the constructions of astronomers and was not to be taken as a literal explanation of the motion of the planets.

The reaction to *De Revolutionibus* was mixed. Most rejected the heliocentric idea, but also admired the mathematics. Copernicus had written the most complete and detailed astronomical work since Ptolemy. Many tried to take the mathematical constructions from De Revolutionibus and use them in Geocentric models. Erasmus Reinhold, who was a strict geocentrist, used Copernicus's mathematics to create a new set of astronomical tables (*The Prutenic Tables)* which came to be preferred due to their accuracy.

Thomas Diggs (1545-1595) was an early supporter of Coeprnicus. He translated large parts of Copernicus's Book I into English and included a drawing of the Copernican System set in an infinite Universe of stars.
But it took nearly a new generation to begin to accept and propose ideas based on Copernicus's hypothesis. There are a number of reasons for the delay.

First and foremost, the idea of a moving Earth seems, on the surface, to be absurd based on sensory perception.

The idea of a heliocentric universe was a mental breakthrough, but did not offer explanations for the other things, such as motion, that Aristotle's' view of the world did. This had been the reason Ptolemy rejected it.

Scientifically the difficulty with Copernicus is that his work contradicted the Aristitolean Physics and required a new understand of physics (or specifically a new physics) which had not yet been invented. To accept Copernicus meant abandoning Aristotle's physics.

The debate has often been portrayed as religious versus scientific acceptance. In reality, it was a debate between sciences. The abandonment of a millennium of understanding that began with Aristotle and the acceptance of a completely new understanding, one that would be developed between the 16^{th} and 17^{th} century, but one that was at the time of Copernicus was non existent.

III. Tycho Brahe (1546-1601) Danish Royal Astrologer/Astronomer.

Took detailed notes on celestial observation and helped prove the Copernican theory over the Ptolemaic.

Brahe set new standards in observation without a telescope.

He was sponsored by the Danish King Frederick II, (not the HRE from the 12th century), who built him a castle on an island for his observations, essentially creating the first observatory. (They also did alchemy research in the basement).

He disbelieved Copernicus because his observations showed that planets did not move in perfect circles.

In 1572-73 a new star appeared (it was actually a supernova) and in 1577 a new comet. *This went right through any supposed crystal spheres*. Neither event sat well with the idea of perfect unchangeable heavens, and it also proved that the Phenomenon was taking place well outside the sublunar world.

Brahe thus junked the idea of perfect circular motion, and the idea of fixed spheres in the heavens.

However, he created essentially a geoheliocentric model. Where the Sun goes around the Earth, and other planets go around the Sun.

Brahe hired a young Johannes Kepler to help sift through the vast amount of data.

IV. Johannes Kepler (1571-1630)

Student of maths and astronomy and a student of Brahe. His mother was tried for witchcraft, and Kepler himself was quite the believer in astrology.

He wanted access to Brahe's planetary tables in order to prove copernicus' theory.

He put Brahe's observations into order. His method was to test hypothesis after hypothesis until he came up with an answer that worked. Eventually he came up with the idea that planets move in ellipses.

Kepler was the first since the ancient Greeks to have a scientific law named after him, it helps illustrate the times. They felt that they were accomplishing feats that were equal or greater than the ancient thinkers.

His Three Laws of Planetary Motion corrected Copernicus in light of Brahe's observations. *Note also the beginning of the use of the idea of scientists discovering laws.*

Kepler's laws-- Kepler settled on the ellipse as an orbital path, that is, planetary orbits are elliptical (First Law).

Area Law: in equal time intervals a planet will sweep out equal areas (Second Law). (or the period of revolution around the sun is proportional to distance from the Sun.)

**Kepler had no explanation of why this was the case. In fact he was involved in number mysticism and explained it as part of the mystery of numbers.*

The old Aristotelian system was broken, but there was no new synthesis to replaces it. Constructing a new, equally persuasive synthesis was the achievement of the Scientific Revolution.

While Kepler was a contemporary of Galileo and died before him it took Copernicus's movement of the Earth to place the sun in the center, the data of Tycho Brahe, and the observations of Galileo which suggested that the heavenly bodies were not perfect, that led to the idea that their orbits were not perfect either.

Galileo Galilei (1564-1642)

Italian. He also studies at Padua, which was a hotbed of scientific discussion, on both the cause of motion and the scientific method. Galileo was also a mathematician, and was also keen on Archimedes (who was translated in 1543).

A. Astronomy

-**He used a telescope for better observation** c. 1609. He was not however the first to do so.

-This confirmed the heliocentric system. There were also surprises, like seeing the Moon with craters and mountains, and seeing sun spots. This was in a supposedly perfect heaven. The difference between Earth and the heavens was disappearing.

-What was really important was that he connected astronomy to motion on Earth, *which had also been the great achievement of Aristotle's system.*

Galileo's 'facts' differed from the traditional data of astronomy in that they were derived from qualitative telescopic observations.

Observational data obtained with the telescope:

a. Stellar 'population explosion' implying an expanded cosmos.
b. The topography of the moon was similar to, or more pronounced than, that of the earth; the earth-like moon moves around the earth--why can't the earth move around the sun?
c. The phases of Venus were inexplicable in terms of Ptolemaic cosmology; Ptolemaic scheme no longer viable.
d. The satellites of Jupiter, moving with, and approximately in the same plane as the planet, suggested more than one center of rotation in the solar system and, by analogy, the earth's rotation around the sun.
e. Sun spots implied that the heavens are not perfect (to reinforce the argument of the moon's topography); these data were obviously unknown to Aristotle or Ptolemy.

B. Motion on Earth

-Galileo also did experiments about motion on Earth.
Galileo's Scientific Method:

1. Galileo argued that theoretical conclusions required experimental verification even if the experimentation was mental rather than empirical.

2. He was a thinker about nature and thought in terms of ideal situations rather than the complexities of the sensate world.

3. Expressed confidence in deductive, reasoned conclusions: Archimedean mathematics applied to physical problems rather than extensive experimental programs. Recall Aristotle's' notion of contiguous motion.

-There is the story of Galileo dropping objects from the Leaning Tower of Pisa to see if heavy things really did fall faster as predicted by Aristotle. 1591. This is not true, it was actually a thought experiment. In fact a feather and a hammer will fall at different speeds (just like Aristotle would have predicted). *But Galileo did argue on the basis of tying two objects together and asking if they would fall more quickly.*

-There is also the story of him watching a pendulum swing in Siena Cathedral.

What Galileo did here was more important than the debate over astronomy.

HE IMAGINED MOTION WITHOUT ANY OF THE CONSTRAINTS IT FACES IN THE REAL WORLD - A THOUGHT EXPERIMENT WHICH BREAKS THE MOLD.

He based his theories on observation, but would go beyond observation to the truth, since he recognized the constraints on simple observation.

Notion of inertia - a body continues to move unless it is stopped - vital. Not fully developed by Galileo. He thought motion was naturally in a circular direction, rather than a straight line. Also he still had the old medieval idea of impetus in his head.

He did not offer a convincing explanation of heavenly motion.

His importance was that he attacked the whole Aristotelian system. He saw the need for an entirely new view.

Opposition from some Church authorities

Time line of the Galileo Affair.

In 1600, Giordano Bruno had been burnt at the stake for suggesting a plurality of worlds, and other heresies (some of which he based on Copernicus (and also Nicholas of Cusa)). This had led to an intensification of fear about Copernicus' ideas just before Galileo became active.

10 October 1604—A new star is observed at Pauda (actually a supernova)

January of 1605—3 Lectures at the University of Pauda on the new star suggesting that mathematical models (parallax) suggest that the star must be beyond the moon and therefore in the heavens, and therefore the heavens must change.

1608 Galileo is in Florence for the Wedding of Cosimo de Medici at the insistence of The granddutchess Christina

1609 Kepler published his laws of planetary motion

June 1609-Galileo built his telescope

7 January 1610 Galileo observes four satellites of Jupiter (calls them the Medician Stars) Kepler sends letter of Support of Galileo's observations

April 1611—Under the Direction of Cardinal Bellarmine, the Jesuits at the College of Rome, certify Galileo's discoveries, but do not necessisariy agree with his interpretation

December 1614—The Dominican Friar Tommaso Caccini, preached a sermon against Galileo and other mathematicians who believe in the Copernican view, which Caccini considers heritical. "*On December 20, 1614, Caccini issued a sermon at the Santa Maria Novella in Florence strongly opposing Galileo's support of Copernican theory.[1] While the exact text of the sermon is not clear, historians suggest that Caccini preached that mathematics and science were contrary to the word of the bible, and therefore, heretical.[6] Although Caccini* *appeared to have criticized math and science generally, he singled out Galileo and his followers. He made a point to utilize the biblical phrase "Ye Men of Galilee, why stand you gazing up in heaven?" The phrase can be found in Acts 1:11. The phrase refers to the inhabitants of Galilee who gazed into the sky expecting Jesus to return as he made his way to heaven. Caccini attempted to play on the words of the passage by starkly contrasting Galileo's allegedly heretical acts to the unwavering faith of the inhabitants of Galilee.[7]"*

"The reaction to Caccini's sermon ranged from vocal opposition to praise. Galileo himself is said to have described Caccini as an individual "of very great ignorance, no less a mind full of venom and devoid of charity."[8] Within the Church itself, there was substantial disagreement over how to address Caccini's scathing sermon. Matteo Caccini, Tommaso Caccini's own brother and former prior of a monastery in Cortona, was appalled by Caccini's sermon in Florence.[1] He stated "I am so angry that I could not be more...[Father Tommaso] revealed such dreadful plans I could scarcely control myself. In any event, I wash my hands of him forever and ever."[5] The preacher general of the Dominican order echoed Matteo Caccini's sentiments in a letter he issued to Galileo. Apologizing on behalf of the order, he lamented that "[he had] to answer for all the idiocies" that his fellow brothers perpetrated.[9]"

January 1615—Caccini's superior apologized to Galileo in writing.

Feb 1615—Another Friar Niccolo Lorini, filed a written complaint with the Inquisition against Galileo's Copernican views, and publishes a letter between Galileo and a student (Bendetto Castelli, who had defended Galileo to the Grand Duchess Christina of Lorraine,) Galleo's letter dealt with the relationship of science to scripture.

March 1615—another Friar (Paolo Antonio Foscarini) publishes a book that says the Copernican Theory is compatible to scripture.

April 1615—Bellarmine cautions Foscarini to treat copernicanism like a theory/hypothesis only.
Cardinal Bellarmine to
Paolo Antonio Foscarini
(April 12, 1615)

My Very Reverend Father,

I have read with interest the letter in Italian and the essay in Latin with Your [Reverence] sent me; I thank you for the one and for the other and confess that they are full of intelligence and erudition. You ask for my opinion and so I shall give it to you, but very briefly, since now you have little time for reading and I for writing.

First, . . . to want to affirm that in reality the sun is at the center of the world and only turns on itself without moving from east to west, and the earth . . . revolves with great speed about the sun . . . is a very dangerous thing, likely not only to irritate all scholastic philosophers and theologians, but also to harm the Holy Faith by rendering Holy Scripture false. For your [Reverence] has well shown many ways of interpreting Holy Scripture, but has not applied them to particular cases; without a doubt you would have encountered very great difficulties if you had wanted to interpret all those passages you yourself cited.

Second, I say that, as you know, the Council [of Trent] prohibits interpreting Scripture against the common consensus of the Holy Fathers; and if Your [Reverence] wants to read not only the Holy Fathers, but also the modern commentaries on genesis, the Psalms, Ecclesiastes, and Joshua, you will find all agreeing in the literal interpretation that the sun is in heaven and turns around the earth with great speed, and that the earth is very far from heaven and sits motionless at the center of the world. Consider now, with your sense of prudence, whether the Church can tolerate giving Scripture a meaning contrary to the Holy Fathers and to all the Greek and Latin commentators. Nor can one answer that this is not a matter of faith, since if it is not a matter of faith "as regards the topic," it is a matter of faith "as regards the speaker"; and so it would be heretical to say that Abraham did not have two children and Jacob twelve, as well as to say that Christ was not born of a virgin, because both are said by the Holy Spirit through the mouth of the prophets and the apostles.

Third, I say that if there were a true demonstration that the sun is at the center of the world and the earth in the third heaven, and that the sun does not circle the earth but the earth circles the sun, then one would have to proceed with great care in explaining the Scriptures that appear contrary, and say rather that we do not understand them than what is demonstrated is false. But I will not believe that there is such a demonstration, until it is shown to me . . . . and in case of doubt one must not abandon the Holy Scripture as interpreted by the Holy Fathers. I add that the one who wrote, "The sun also riseth, and the sun goeth down, and hasteth to his place where he arose," was Solomon, who not only spoke inspired by God, but was a man above all others wise and learned in the human sciences and in the knowledge of created things; he received all this wisdom from God; therefore it is not likely that he was affirming something that was contrary to truth already demonstrated or capable of being demonstrated.

Summer of 1615—Galileo sends a **letter to Christinia or Lorraine* (unpublished but widely circulated) http://faculty-staff.ou.edu/B/Peter.Barker-1/HSCI3013/lgc2.htm http://www.fordham.edu/halsall/mod/galileo-tuscany.html (and attached).

February 1616-- On orders of the Pope Paul V, Cardinal Bellarmine calls Galileo to his residence and administers a warning not to hold or defend the Copernican theory. An unsigned transcript in the Inquisition file, discovered in 1633, states that Galileo is also forbidden to discuss the theory orally or in writing.

In 1616, on the orders of the then pope, Paul V, Cardinal Bellarmine summoned Galileo Galilei, notified him of a forthcoming decree of the Congregation of the Index condemning the Copernican doctrine of the mobility of the Earth and the immobility of the Sun, and ordered him to abandon it.[2] Galileo agreed.[3] When Galileo later complained of rumors to the effect that he had been forced to abjure and do penance, Bellarmine wrote out a certificate denying the rumors, stating that Galileo had merely been notified of the decree and informed that, as a consequence of it, the Copernican doctrine could not be "defended or held".[4] Cardinal Bellarmine was himself ambiguous about heliocentrism, personally noting that further research had to be done to confirm or condemn it. (In 1633 Galileo would again be called before the Inquisition in this matter.)

March 1616—The Congregation of the Index suspends Copernicus's On the Revolutions until corrected and bans Foscarini's book entirely, Galileo is not mentioned in the decree. Galileo Has a meeting with the Pope.

May 1616—Cardinal Bellarmine writes a letter to Galileo certifying that Galileo had not been on trial or condemned by the Inquisition.

Statement (Affidavit) of Cardinal Bellarmine to Galileo
May 26, 1616
We, Roberto Cardinal Bellarmine, having heard that it is calumniously reported that Signor Gallileo Galilei has in our hand abjured and has also been punished with salutary penance, and being requested to state the truth as to this, declare that the said Galileo has not abjured, either in our hand, or the hand of any other person here in Rome, or anywhere else, so far as we know any opinion or doctrine held by him; neither has any statuary penance been imposed on him; but that only the declaration made by the Holy Father and published by the Sacred Congregation of the Index has been notified to him, wherein it is set forth that the doctrine attributed to Copernicus, that the Earth moves around the Sun, and that the Sun is stationary in the centre of the world and does not move from east to west, is contrary to the Holy Scriptures and therefore cannot be defended or held. In witness whereof we have written and subscribed these presents with our hand this twenty-sixth day of May, 1616.

Source: Arthur Koestler, Sleepwalkers (1959).

1618—three new comets appear lectures are given at the college of Rome on the Comets

January1619—Galileo's thoughts on the comets are requested by many..Galileo begins a critique of the lecure given at the Collegio Romano

May 1620—The Congregation of the Index issued correction to Copernicus's De Revolutionibus that must be made before it can be read.

April 1630—Galileo Finishes his book *Dialoge on two chief world systems.*

February 1632—After lengthy discussions with the Secretary of the Vatican, Galileo's book is published.

Sumer of 1632— Further distribution of the Dialogo is prohibited by Pope Urban VIII and a special commission is appointed to examine the book.

September-December 1632—Galileo is summoned to Rome to appear before the Inquisition… the Pope Himself leads the meeting that decides to call Galileo. …Galileo asks if the trial can be moved to Florence…he is told no.

13 February 1633 Galileo Arrives in Rome

12 April 1633—Galileo is formally interrogated by the Inquisition until April 30.

30 April 1633—after a plea bargain Galileo confesses that he may have made too strong of a case for Copernicanism, and pleads guilty to a lesser crime.

Galileo was sentenced to prison and threatened with torture (it is a controversial decision even among the inquisition as three of the 10 refused to sign the sentence.)

June 1633—Galileo formally recants his "errors" in a ceremony at the Church of Santa Maria

December 1633—Returns to his villa near Florence to remain under house arrest for the rest of his life.

1636—His letter to the granduchess is published (from 1616)

1638—Galileo looses the sight in his left eye and was now totally blind (right eye lost in 1637) petitions for freedom, but was denied, allowed to attend church on religious holidays.

8 January 1642—Galileo dies.

F. Reading Notes to Galileo Galilei

**1615 Letter to Grand Duchess of Tuscany (ruler of Florence). http://faculty-staff.ou.edu/B/Peter.Barker-1/HSCI3013/lgc2.htm http://www.fordham.edu/halsall/mod/galileo-tuscany.html (and attached)*

1. how does Galileo differentiate between the study of physical science and the study of theology? What differences does he see between them?

2. Did Galileo seem to believe in God? What view does he have of the Bible? Why might this view upset Church authorities?

3. From reading elsewhere, how does the Church now characterize its claim to infallibility? [ref. New Catholic Encyclopedia?]

4. Exactly why was Galileo condemned?

G. Was Galileo Totally Right?

There were real problems in the use of scriptures. This was especially true for Bellarmine. Galileo was persistent - he raised the ire of the curia. Some supported him, including Pope Urban VIII.

Francis Bacon (1561-1625) English Philosopher

It should be noted that he had an enthusiasm for the application of science; for Bacon science was power - He promoted the modern idea of progress.

1620 *Novum Organum* (New Tools) a challenge to Aristitollean syllogisms that he felt led to circular reasoning and not the empirical evidence that needed to used in science.

he used The Inductive Method; make a lot of observations and then generalize rules of nature. This leads to scientific observation as a method. He believed that one should discount all preconceived notions in order to not distort the truth.

Bacon's devotion to his method eventually led to his death as he caught pneumonia after trying to observe the impact that freezing has on meat.

Basically THERE IS NO LOGICAL REASON TO GO ARGUE FROM ANY AMOUNT OF EXPERIENCE TO A GENERAL LAW.

THIS IS THE "PROBLEM OF INDUCTION"

Bacon's Basic Assumption: The Simplicity of Nature.

1. Scientific progress is a matter of finding the correct method, that is, the correct method is equivalent to truth:

    a. If nature is approached in the appropriate manner, the truth can be found.

    b. Error is the result of defective methods.

2. The ultimate goal of science is practical utility for the benefit of mankind.

3. The method is the 'tool' of the intellect: it enables the mind to overcome its weaknesses, and can compensate for disparity of mental ability.

4. The function of method is to collect data from the natural world and refashion it (the bee)--it is not just empirical cataloguing (the ant) and it is not a matter of pure speculation (the spider).

Bacon believed in eliminating all possible causes of an observation leads to the truth, thus the final elimination is the crucial experiment. (Modern science does not hold to a crucial experiment).

Bacon and Mathematics

Bacon's great problem was that he never understood the importance of mathematics, which is deductive not inductive since it proceeds from theorems to axioms without empirical observation. Also, although experimentation became the watchword of science, a lot of the breakthroughs in the Scientific revolution were in astronomy and mechanics, and these were mental breakthroughs.

Rene Descartes (1596 - 1650) * *Discourse on Method (*abridged*) (see attached)*
http://www.wsu.edu/~wldciv/world_civ_reader/world_civ_reader_2/descartes.html

He had a quite lofty goal to replace Aristotle as the foremost philosopher.

Descartes was a great mathematician and philosopher for instance he showed the any algebraic formula could be plotted on a graph. This was a linking of algebra, which was Hindu and Arab maths, with Geometry, which was the great Greek contribution to maths. It was very important in the future methods of science.

Focused on Deductive reasoning, stating that deduction was a way to certain knowledge.

i. He began by asking how can I know that I know anything about anything.
–The past thought is not relevant, if senses are not to be trusted then that must be thrown out also.
So, Descartes threw out everything that had ever learned. He said that he could not trust something just because someone had once said it. He said that he could not trust he senses because his senses can be mistaken.

He wrote *Discourse on Method* in 1637 outlining his method for deducing truth and gaining knowledge.

ii. He began by asking if there was anything that one could know for certain.
   1. Cogito Ergo Sum (I think therefore I am)
   2. God exists because I as an imperfect being can contemplate perfection. God is there fore perfection and perfection does exist as imperfection would not exists without perfection (to measure against)
   3. The universe is made of matter and all one can know about matter is that it has height, width and depth. If that is all that can be known about mater then …
      a. The 4 elements are gone

b. Movement is gone
c. Knowing God exists is one thing but understanding God is another as he is not in the realm of matter, therefore one should not contemplate the “thinking stuff” but only the “matter”

He stressed Maths was a general science, applicable to all other sciences which were concerned with order and measurement. Note the Platonism here, the stress on Maths as away to knowledge.

This was “good” in that it stressed Mathematics in science, but “bad” in that it seemed to allow little room for testing ideas in the real world.

In fact, Descartes was not totally against observation, but his emphasis was different from Bacon.

Isaac Newton (1642-1727)

-Did mot of his work between 1665-1687

A professor at Cambridge.

Newton was quite possibly the greatest scientist who ever lived, and the genius of the Scientific revolution.

-He is one of the most influential people in all of history…we live in very much a newtonian world. Even sense Einstein most people still see the world in a Newtonian sense and not in an Einsteinian way.

i. Question of Newton—Why do the Planets move?
    1. After the Aristotelian view is dead the planets must have another reason to stay in place and move.
    2. He looked at magnetism and there things first.

1687 - Philosophiae Naturalis **Principia** Mathematica Mathematical Principles of Natural Philosophy

600 pages written in Latin published in 1687

It brought together Galileo's discoveries about motion on Earth, and Kepler's discoveries about motion in the heavens.

He also brought together the Baconian stress on generating laws by inductive arguing from experience and Descartes' stress on deducing new ideas from things known well.

To do this Newton had to invent calculus.

Newton provided an explanation for heavenly motion that was tied to observed properties of motion on Earth. (Galileo + Kepler)

And he generalized laws from these observations, but based laws based on mathematics. Newton had read Descartes and in fact attacked him, but uses his mathematical approach. (Bacon + Descartes)

<u>A Better Synthesis than Aristotle</u>

<u>So at last there was a synthesis better than that provided by Aristotle. Newton accounted for motion throughout the Universe.</u>

Newton's explanation was based on idea of Inertial Movement and Gravity.

All bodies moved as if every particle attracted every other particle with a force proportional to the product of the two masses and inversely proportional to the square of the distance between them.

NOTE THAT THIS IS NEVER THE CASE IN THE REAL WORLD. NEWTON'S GENIUS WAS TO IMAGINE MOTION OUTSIDE THE REAL WORLD OF IMPEDIMENTS TO MOTION, AND A WORLD OF VERY MANY PARTICLES, AND TO IMAGINE A UNIVERSE WITH ONLY TWO PARTICLES, BUT TO BASE THAT IMAGINATION ON OBSERVATION.

(Eg. in 1672 Jean Picard, a Frenchman observed Mars from Paris and Cayenne, and worked out its altitude. This helped Newton in his calculations.)

The Three Laws of Motion

* 1. A body moves in a straight line unless impeded. (Inertia) An object at rest will remain at rest, and an object in motion will remain in motion unless an external force acts upon it.
* 2. F=MA (Force = Mass x Acceleration)
* 3. Every action has equal and opposite reaction.

Newton’s Universal Law of Gravity
*Every body attracts every other body with a force proportional to the distance between.
every body in the universe attracts every other body with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Newton did have controversy with the Cartesians (Followers of Descartes)

Newton could explain what gravity does but cannot explain what gravity is.
To the Cartesians he re-instituted unknown (or as they were called—"occult") forces. In *Principia* he explains how gravity works but not why it works (a break from medieval to modern science).

Newton illustrated a world that was very mechanical.

II. The implications of Newtonian physics for the rest of history.

A. The universe is a machine and operates as such. The metaphor is that the universe is like a watch (in regards to God he may now be seen as a watchmaker who winds the watch and then lets it go.—a deist worldview) the mechanical worldview.

Newton himself still had room for God; and he was very pious.

Newton was not, of course, "right". Einstein and Quantum Mechanics in the last century have shown that, but his model was better than anything done before.

VIII. Other Sciences

A. Other Sciences than Physics and Astronomy

Other sciences were less on the cutting edge. They were less mathematical, but do exhibit a can-do attitude.

Chemistry did not show advances until a century later.

B. The Development of Instrumentation

-Clocks

-Galileo and Telescope

-Leeuwenheok - microscope

<u>*IX. Medicine*</u>

We saw it made little practical progress until late 1700s.

In Theory it carried a lot of baggage: the demonic view of illness.

The influence of Galen (2nd Cent. AD).

A. Vesalius

A doctor at Padua. In 1543 he began investigating anatomy.

B. William Harvey

Had studies at Padua.

1628 - On the Movement of the Heart and the Blood

Harvey explained notion of continual circulation of the blood. (da Vinci had know this but not published a century earlier).

C. Malpighi (Italian)

1661 discovered Capillaries

X. Practical Effects of the Scientific Revolution

There were few practical effects on technology. It is important to realize that the Industrial Revolution did not at first depend on this new scientific view of the world.

But new maths and science did effect navigation, map making and artillery.

-Better guns were another way Europeans came to dominate the world; they had better ways of using weapons and better ways of knowing where they were.

-Also the laws Newton discovered could be used to fire more accurately. This effect was felt soon after Newton.

- Science has innumerable practical ramifications: new guns, bigger armies, more taxes, social discontent.