

# 21 Evolution of the Scientific Method

## Birth of the Scientific Method

*“By three methods we may learn wisdom: First, by reflection, which is noblest; Second, by imitation, which is easiest; and third by experience, which is the bitterest.”* Confucius (551–479 BC)

How has our search for understanding nature and the universe around us changed in 2,500 years? Confucius’ quote suggests the path to enlightenment is by reflection. Was this internally-focused path to knowledge restricted to Confucius, or shared by other sages in other places and other intellectual traditions? Changing continents to Greece, the birthplace of the Western scientific tradition, let’s look at Plato (427-347 BCE). Plato’s view is called **Anamnesis**.

(1) How is knowledge “acquired” via **Anamnesis**?

<http://plato.stanford.edu/entries/innateness-history/#PreEmpVsAna>

(Section 3 on Plato, 1<sup>st</sup> paragraph)

Answer

(2) But there were contemporaries of **Plato** who had other ideas. How did **Aristotle** (384-322 BCE) think knowledge is acquired?

<http://yourknowledge.hubpages.com/hub/Empiricism-Aristotle-the-First-Empiricist>

3<sup>rd</sup> Paragraph beginning “*Aristotle didn’t...*” 2<sup>nd</sup> sentence.

Answer

(3) Comparing **Aristotle** to **Confucius** and **Plato**, what would **Aristotle** argue is the *noblest* way to wisdom; reflection or experience?

Answer

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**Aristotle's** approach, called **empiricism** went on to dominate western science for 2000 years. In large part because **Aristotle** developed a methodology to formalize correct reasoning from observation and perception – Aristotle invented logic. Aristotle further subdivided logic into **Deductive** and **Inductive**.

(4) What is **Deductive** Logic?

[http://editthis.info/logic/Deductive\\_and\\_Inductive\\_Logic](http://editthis.info/logic/Deductive_and_Inductive_Logic)

*Answer*

(5) What is **Inductive** Logic?

[http://editthis.info/logic/Deductive\\_and\\_Inductive\\_Logic](http://editthis.info/logic/Deductive_and_Inductive_Logic)

*Answer*

(6) Which of the two logics, **Deductive** and **Inductive**, did Aristotle and many philosophers view as the **ideal kind**?

<http://johnmccaskey.com/Higgins.pdf>

page 1, 1<sup>st</sup> paragraph, in the sentence beginning with “Many philosophers...”

*Answer*

(7) Why did they view the other one as inferior?

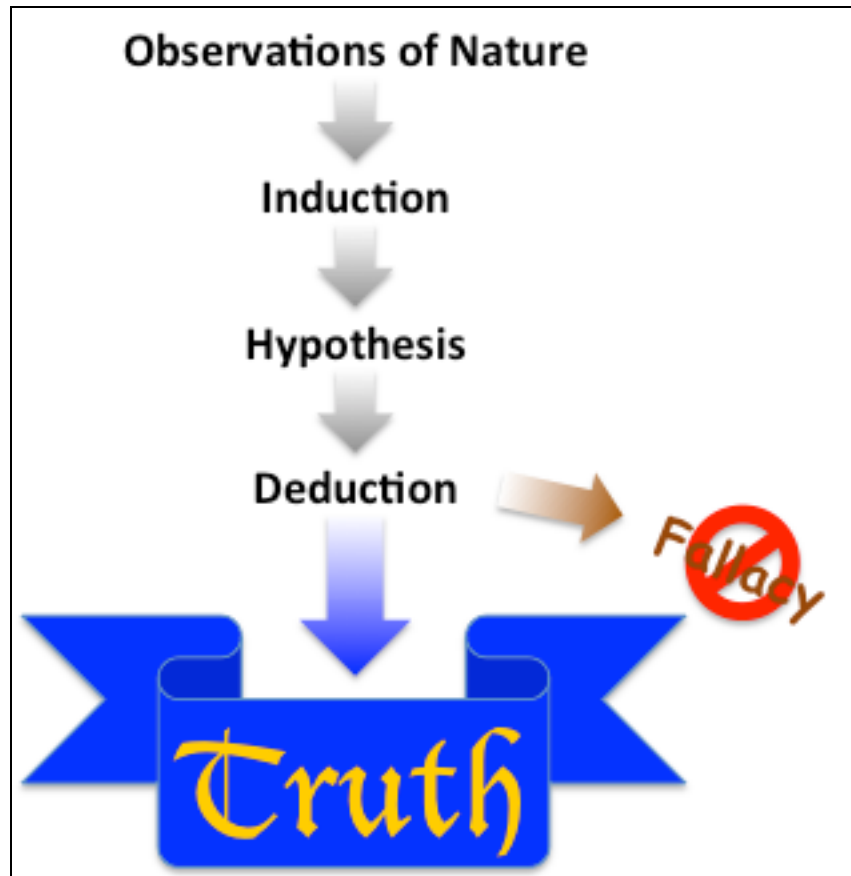
<http://johnmccaskey.com/Higgins.pdf>

page 1, 1<sup>st</sup> paragraph, in the sentence beginning with “Many philosophers...”

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Answer

Putting all this together, we arrive at Aristotle's scientific method **Empiricism** looking something like this.



Start at the top and reason, through the power of **Deductive Logic**, leads one to **TRUTH**.

**Empiricism** will rule science for almost 2000 years.

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## Aristotle's Cosmology

Applying **Empiricism**, Aristotle develops a cosmology that divided the universe into two realms, one **Celestial**, the other **Terrestrial**.

(8) How did Aristotle characterize each?

[http://people.wku.edu/jan.garrett/341/aristotle\\_big\\_picture.htm](http://people.wku.edu/jan.garrett/341/aristotle_big_picture.htm)

<b>Celestial Realm</b>	<b>Terrestrial Realm</b>
1)	1)
2)	2)
3)	3)
4)	4)

(9) And of what elements were they made?

<http://aether.lbl.gov/www/classes/p10/aristotle-physics.html>

<b>Celestial Realm</b>	<b>Terrestrial Realm</b>
1)	1)
	2)
	3)
	4)

(10) And lastly, what object in the sky, defines the boundary between the **Celestial** and **Terrestrial Realms**?

<http://aether.lbl.gov/www/classes/p10/aristotle-physics.html>

*Answer*

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## A Short Interlude

### Parallax

Parallax is the *only* direct way to measure distance to stars. The technique is intuitive, its how you get distance to the world around you. Your eyes pivot inwards as you focus on an object. Your brain measures the distance they pivot inwards and since it knows the distance between your eyes, it calculates the distance to the object.

- A) Have a partner measure the distance between your eyes in mm using the clear plastic ruler. Record that number below and divide it by 1000 to get the distance in meters..

Distance between eyes in mm \_\_\_\_\_ in meters \_\_\_\_\_

- B) Have partner position the nearby star at first post. Line it up with a background star (the double one) with one eye, then blink to the other eye to see how far it moved against the background stars. Record how far it moved in the table below and to parallax in degrees (the background stars are spaced  $\frac{1}{4}$  degree apart, so if it shifted two stars, the parallax would be  $\frac{1}{2}$  degree).

- C) Repeat step (B) for the subsequent posts for the foreground star.

- D) Convert the parallaxes you measure to distance using the value you measured for your eye spacing in the following equation:

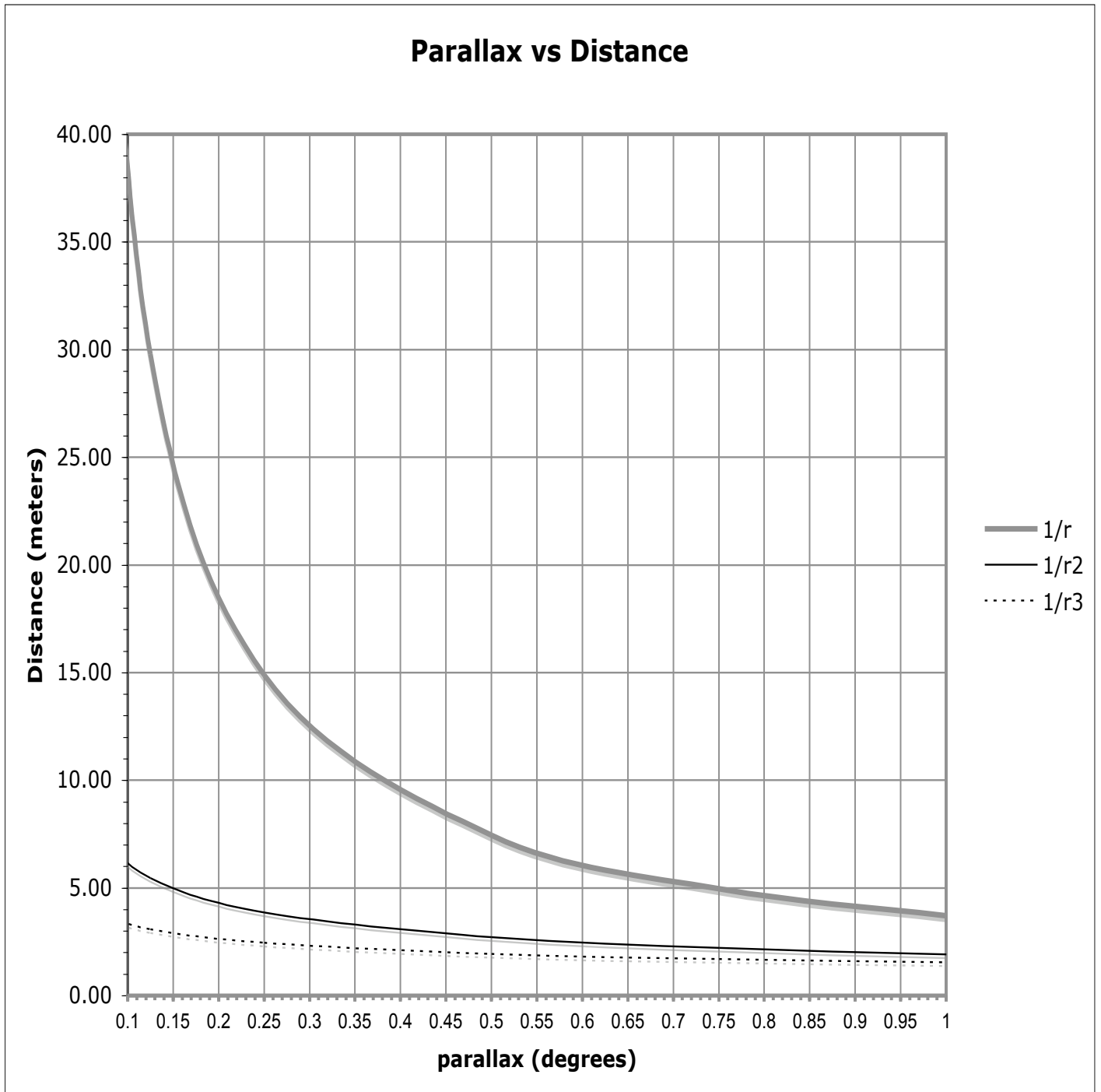
$$\text{Distance in meters} = 57 * (\text{your eye spacing in meters}) / (\text{parallax in degrees})$$

Table 1: Parallax & Distance

Post #	Parallax # of Stars	Parallax °	Distance meters
1			
2			
3			
4			
5			

- E) Plot your results on the graph below

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## Part A Questions

One word answers are not acceptable. Explain your answers in the space provided by referring to what you see in the graph

I) Does parallax get larger or smaller with distance?

*Answer*

II) How does parallax vary with distance? *Hint: Looking at your graph, did do your measurements vary inversely with distance ( $1/r$ ), inversely with the square of the distance ( $1/r^2$  curve) or inversely with the cube of the distance ( $1/r^3$ ) curve?*

*Answer*

III) How well do your measurements agree with the inverse relationship (the curve you selected in the graph)? Do you find yourself over- or under-estimating angular size at short or large distances? *Hint: If your points fall above the curve, your are overestimating distance, if below then you are underestimating the distance.*

*Answer*

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## Quibbling with Aristotle's Universe

Let's take a look at one characteristic of Aristotle's universe, circular motion: everything in Celestial Realm moves in uniform circular motion; Sun, Moon, Stars and Planets. Let's set up a deductive logic syllogism by which Aristotle might arrive at this conclusion.

### Planetary Motion Syllogism

Premise (1)      The Celestial Realm is perfect

Premise (2)      The circle is the perfect shape

Conclusion:      Planetary motion is circular

(11) How does Aristotle define perfection?

<http://en.wikipedia.org/wiki/Perfection>

The sentence beginning with "*The oldest definition...*"

<i>Answer</i>

(12) Why was the circle considered "perfect"?

<http://en.wikipedia.org/wiki/Perfection>

See section on **Aesthetics**, paragraphs beginning with "*Another early idea...*"

<i>Answer</i>

Note the answer to question (12) is found in the section on **Aesthetics**.

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(13) What is the definition of **Aesthetics**?

<http://dictionary.reference.com/browse/aesthetic>

*Answer*

(13) Does Aesthetics sound like Reason or Opinion?

<http://en.wikipedia.org/wiki/Perfection>

*Answer*

The Planetary Motion Syllogism appears to be a **false premise logical fallacy**.

(14) Why?

[http://en.wikipedia.org/wiki/False\\_premise](http://en.wikipedia.org/wiki/False_premise)

*Answer*

### Yet even Copernicus Clings to It!

(15) Why did Copernicus come to doubt the Aristotelian Cosmology as codified in the Ptolemaic Model?

<http://plato.stanford.edu/entries/copernicus/>

1<sup>st</sup> paragraph, 2<sup>nd</sup> sentence

*Answer*

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(16) What did Copernicus preserve from the Aristotelian Cosmology?

[http://en.wikipedia.org/wiki/Copernican\\_heliocentrism](http://en.wikipedia.org/wiki/Copernican_heliocentrism)

Section on **Copernican Theory**, 1<sup>st</sup> paragraph, last sentence

*Answer*

(17) But Copernicus still had to “fudge” to get (16) to work. What was his “fudge”?

[http://en.wikipedia.org/wiki/Copernican\\_heliocentrism](http://en.wikipedia.org/wiki/Copernican_heliocentrism)

Section on **Copernican Theory**, 1<sup>st</sup> paragraph, next to last sentence beginning with “But...”

*Answer*

Even Copernicus can't cut loose from Aristotle. Although philosophers are starting to quibble with Aristotle, they can't break free of his authority, because they can't break free of Aristotle's **Empiricism** as the path to **Truth**. Although Copernicus' book presenting his Heliocentric Cosmology is titled “*De revolutionibus orbium coelestium*” (On the Revolutions of the Heavenly Spheres), the real revolution comes with Bacon and Descartes.

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## Bacon, Descartes and Scientific Revolution

(18) Who was Bacon?

<http://www.britannica.com/EBchecked/topic/48177/Roger-Bacon>

*Answer*

(19) Who is Descartes?

<http://www.britannica.com/EBchecked/topic/158787/Rene-Descartes>

*Answer*

(20) Bacon contributes to the revision of **Empiricism** into something resembling the **Modern Scientific Method** based on 2 insights. What are they?

<http://kollarusonline.weebly.com/bacon-and-descartes-stumbleuponcom-account.html>

1<sup>st</sup> two on the list on left hand side

*Answer*

1)

2)

3)

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(21) Descartes contributes to the revision **Empiricism** into something resembling the **Modern Scientific Method** based on 2 insights. What are they?

<http://kollarusonline.weebly.com/bacon-and-descartes-stumbleuponcom-account.html>

1<sup>st</sup> two on the list on left hand side

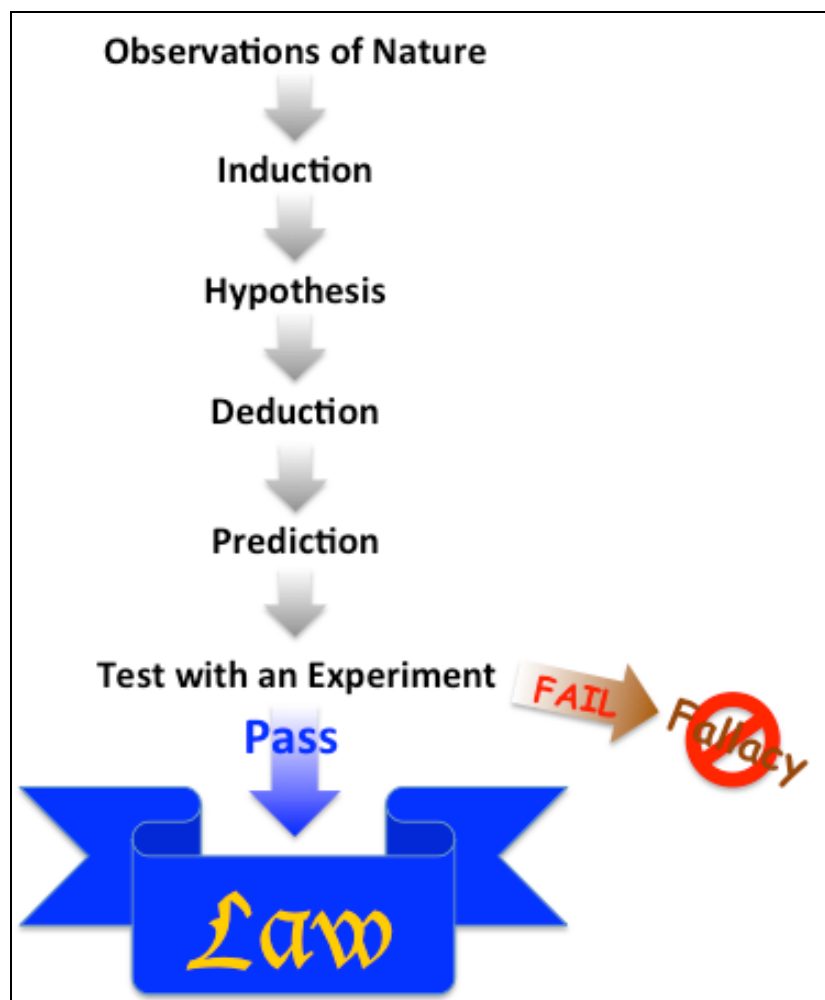
Answer

1)

2)

3)

### The Modern Scientific Method



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(22) Let's continue with quibbling with the Aristotelian Cosmology by looking at where **Aristotle** assigned those "harbingers of doom", **Comets**

<http://en.wikipedia.org/wiki/Comet>

Section on **History of Study**, 2nd paragraph

*Answer*

(23) **Aristotle** believes the answer to (17) because the synonym to **incorruptible** (see question 8) is the last word in this answer.

<http://en.wikipedia.org/wiki/Comet>

5<sup>th</sup> paragraph beginning with "*Aristotle's view* "

*Answer*

(24) And let's back up and review a bit. What object in the sky, defines the boundary between the **Celestial** and **Terrestrial Realms**?

*Answer from Question (10)*

(25) Tycho Brahe measured the distance to the moon. What was the method he used?

[http://books.google.com/books?id=fqBCAAAAIAAJ&pg=PA190&lpg=PA190&dq=tycho+brahe+lunar+parallax&source=bl&ots=lwAGnegNas&sig=KSk415t\\_Y2jWbl7bwJulQe6ZGRE&hl=en&sa=X&ei=vFg7VJ-tlMiTyATUIYDAAQ&ved=0CB0Q6AEwADgK#v=onepage&q=tycho%20brahe%20lunar%20parallax&f=false](http://books.google.com/books?id=fqBCAAAAIAAJ&pg=PA190&lpg=PA190&dq=tycho+brahe+lunar+parallax&source=bl&ots=lwAGnegNas&sig=KSk415t_Y2jWbl7bwJulQe6ZGRE&hl=en&sa=X&ei=vFg7VJ-tlMiTyATUIYDAAQ&ved=0CB0Q6AEwADgK#v=onepage&q=tycho%20brahe%20lunar%20parallax&f=false)

Page 190, 1<sup>st</sup> paragraph, Sentence beginning "*As Tycho has so often referred to the ....*"

*Answer*

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### Applying the Scientific Method to a Central Tenet of Aristotle's Cosmology

(26) So according to Aristotle (Answer to question 22) are Comets closer or further than the moon?

*Answer*

(27) So what experiment could you perform to "test" Aristotle's prediction?

*Answer*

(28) What observational technique would you use to make that experiment?

*Answer*

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## Breaking the Law

The preeminent example of the triumph of the Modern Scientific Method is Newton's Laws of Motion and Universal Law of Gravitation. So triumphant that Newton's replaced Aristotle as the supreme authority on physics. So dominant was Newton's reputation that Alexander Pope wrote;

“Nature and Nature's laws lay hid in night:  
God said, Let Newton be! and all was light.”

(29) But did Newton ever provided his Universal Law of Gravity Universally? For which celestial objects had he demonstrated its working?

<http://www.phy6.org/stargaze/Sgravity.htm>

3<sup>rd</sup> paragraph following light yellow box beginning “Newton went further and...”

*Answer*

But, never mind that. With Newton's triumph, the Modern Scientific Method (page 13) would hold sway until the opening years of the 20<sup>th</sup> century (you know, about 110 years ago) because it instilled deductive reasoning with rigorous mathematical reasoning (instead of aesthetics) and rigorous experimental testing to establish hard truth, to establish LAW.

But then a series of unfortunate events started happened :- ( Like the little inconsistency in Mercury's orbit, that it was precessing a mite more than Newton's Laws of Physics and Gravity could account for. Physicists tried to fix it by invoking another planet (Vulcan) inside of Mercury's orbit to no avail, since no one could find Vulcan! It required a new search for truth, by a guy named Einstein, the guy who developed the Theory of Relativity.

(30) But we're not here to learn relativity, but note the name is the **THEORY** of relativity, not the **LAW** of relativity. Why?

<http://www.newton.dep.anl.gov/askasci/phy00/phy00125.htm>

First reply, 1<sup>st</sup> paragraph beginning with “*Actually, it has...*”

*Answer*

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What breaks the LAW is if it can be falsified (proven wrong) then it's not a law. Here is introduced into the concept of "falsifiability", which is integrated into the Modern Scientific Method to bring it to it's present form.

(31) What is falsifiability?

<https://explorable.com/falsifiability>

Section beginning "**What is Falsifiability**" 1<sup>st</sup> sentence is good enough, but read the rest.

Answer

