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Galileo's Epistemology

The question of epistemology – how true knowledge is obtained – has long concerned scientists and philosophers of science. The matter has at ranged from being a central question to an irrelevant sidelight, and remains unresolved – which has not stopped scientists from doing science, or even from doing science in a manner inconsistent with the particular epistemological theories they espouse. Although Galileo is often considered to be an empiricist, and often espouses empiricism, his work is imbued with a significant strain of rationalism.

The Contenders: Epistemological Theories

The major branches of epistemological theories include

- Rationalism: knowledge is obtained through reason and introspection. Ideas may be justified by sense experience, but if the senses and the intuition are in conflict the sensory evidence must be discarded.
- Empiricism: knowledge is obtained through observation and experiment. Models and theories may be used to organize this sensory experience, but if theories contradict experience they are wrong.
- Mysticism: knowledge is revealed through faith, emotion, or revelation. If observation or intuition contradict this revealed knowledge it is wrong.

Assertion: Galileo is a Rationalist

The History of Science as Presented by Physicists considers Aristotle a pure rationalist and considers Galileo, Newton, and the other fathers of modern science to be pure empiricists. The modern physicists' account holds 1) that Aristotle arrived at his ideas by reasoning out the noblest or most logical course of action for nature; 2) that Aristotle felt comparison to experience was unimportant or uninteresting; and 3) that Galileo was the first to systematically apply experimental rigor to the study of nature, and 4) was thus to refute many of Aristotle's wacky and unfounded assertions. Here is a typical account[1]:

> Even though Aristotle's system is quite simple, understandable, and even works in many cases, it does not stand up to experiments and testing. In his defense, Aristotle was not a scientist, but a philosopher, so he wasn't concerned about such nonsense. However, when Galileo came along (in the late 1500's and early 1600's A.D.), he would actually put many of Aristotle's ideas to test via experiments. This gave Galileo the lofty title of "the father of science." [Johnston]

This story is compelling but mostly wrong. Aristotle's ideas are not only well-grounded in experience, they often better agree with common experience than Galileo's ideas. He was quite upfront about the epistemological value of experience:

> From experience … originate the skill of the craftsman and the knowledge of the man of science. …[T]hese states of knowledge are neither innate in a determinate form, nor developed from other higher states of knowledge, but from sense-perception. [Aristotle, *Posterior Analytics* II.19]

[1] A representative example selected from the first page of Google results for the phrase "Aristotelian Physics"

Furthermore, Galileo based many of his theories on first principles even in the face of contradictory experimental evidence, and often gave intuition primacy over observation. We'll examine three theories of Aristotle that Galileo refuted, and see whether they show Galileo to be a rationalist or empiricist:

- The natural state of all objects is to be at rest
- Heavy objects fall faster than light objects
- The heavens are perfect, and are governed by fundamentally distinct laws than our terrestrial ones.

Galileo's Rationalism: Inertia vs. Final Causation

Aristotle states that objects have a final purpose, which for terrestrial objects is to be at rest. This is a perfectly empiricist standpoint: it is justified by and consistent with all quotidian experience. Aristotle surely considered other possibilities; for example, he states that heavenly bodies possess the property of perfect eternal motion. The reason we know that objects tend to rest is because that's what things *do*, not because that theory is nicer.

Galileo states instead that the natural state of terrestrial objects is to continue their motion unabated: if at rest, to continue at rest, and if in motion to continue with that constant motion. (I'll refer to this idea as inertia, although the term and concept were not properly formulated until Descartes) Galilean inertia:

> Salv: Now tell me what would happen to [a] movable body placed upon a surface with no slope upward or downward … if it were given an impetus in any direction?
> Simp: It must follow that it would move in that direction.
> Salv: But with what sort of movement? One continually accelerated, as on the downward plane, or increasingly retarded as on the upward one?
> Simp: I cannot see any cause for acceleration or deceleration, there being no slope upward or downward.
> Salv: Exactly so. But if there is no cause for the ball's retardation, there ought to be still less for its coming to rest; so how far would you have the ball continue to move?
> Simp: As far as the extension of the surface continued without rising or falling.
> Salv: Then if such a space were unbounded, the motion on it would likewise be boundless? That is, perpetual?
> Simp: It seems so to me. [Galileo, *Dialogue 2CWS* Day 2 p171]

This is a purely rationalist argument: if nothing exists to stop the motion, it will continue. No appeal is made to experience as indeed no such appeal can be made: this argument depends on "a perfectly round ball and a highly poished surface, in order to remove all external and accidental impediments. Similarly, … take away any impediment of the air caused by its resistance to separation, and all other accidental obstacles," as well as an "unbounded" space. Even today, with access to the marvels of modern engineering it is very hard to make a convincing yet direct and elementary demonstration of Galilean inertia. The foundations for this argument are clearly drawn from reason, not from experience: Galileo is a Rationalist.

Objection: Galileo is an Empiricist

Yet on the very first page of his *Dialogues Concerning Two New Sciences* Galileo states "At times also I have been put to confusion and driven to despair of ever explaining something for which I could not account, but which my senses told me to be true." [Galileo, *2NS* p399] This seems a clear statement of Empiricism – his "senses" tell him what is "true."

Galileo's Empiricism: Perfection of the Heavens

For example, Galileo seems to give experience primacy in his astronomical work. Aristotle holds that the material comprising and rules governing heavenly bodies are distinct and superior to those for terrestrial bodies. Galileo refuted this conception by appealing to not just observations, but *indirect* observations, made with a telescope. Aristotle's physics says that the heavens are held apart from the earth; they behave in a completely different fashion (move in

circles, never slow down) than terrestrial objects; they are unchanging, while terrestrial object grow, decay, and are in flux; and they correspond with ideal geometric forms (stars are points, the sun and the moon are discs or spheres). This may seem a rationalist argument but in fact is perfectly consistent with the observations available to the ancients. This theory was later augmented by the Thomists with the argument that, 1) God is in the heavens 2) God is perfect, supernatural, and eternal; 3) therefore the heavens must be perfect, distinct from our terrestrial existence, and unchanging. This is a rationalist proof based on mysticist axioms. Galileo strictly uses observation to carefully demolish this model.

Galileo laid out several ways in which the moon is like the earth. The moon is:

- Shaped like the earth: "It agrees with the earth in its shape, which is indubitably spherical. This follows necessarily form its disc being seen perfectly circular, and from the manner of its receiving light from the sun. For if its surface were flat, it would be covered with light all at once, and likewise would be deprived of light in an instant; not first the part directed toward the sun and then successively the following parts."
- Dark like the earth, not bright like the sun: "it is fitted to receive and reflect the light of the sun."
- Not smooth: "The unevenness of the major parts of its surface, evidenced by the many prominences and cavities revealed by the aid of the telescope. The prominences there are mainly very similar to our most riged and steepest mountains. …"
- Has land and sea: "I believe that the appearance of the earth illuminated by the sun would be very similar to [the appearance of the moon] fore one who could see it from the moon, … and that the surface of the seas would appear darker, and that of the land brighter." [Galileo *2CWS* p71-73]

This evidence stands up even against the argument that it is an illusion: Simplicio (representing the Thomists) says,

> "The appearances you speak of, the mountains, rocks, ridges, valleys, etc., are all illusions. … We see the same thing occur in … perfectly polished stones, where from the opacity of some parts and the transpancy of others various concavities and prominences appear to be present." The moon has "a polish and a luster superior to that of the smoothest mirror." [*2CWS* p80]

Galileo carefully counters with several perspicacious observations. The "reflection that comes from [a] wall diffuses itself over all the points opposite to it, while that from the mirror goes to a single place;" where the reflection from a mirror strikes, "the mirror appears very much brighter." Our sensory perception of the moon agrees with the diffuse reflectance expected of a rough ("an innumerable diversity of slopes" [*2CWS* p88]) and earthen substance, and not with the specular reflectance expected of a polished and perfect quintessence. Furthermore, we can be sure that the moon is rough because

> "You will see, in the darkened part, many illuminated summits separated from the already luminous portion. As the illumination becomes more elevated, you will see the shadows mentioned before diminish until they vanish entirely…; and then in reverse, as the light passes toward the other lunar hemisphere, you will recognize the same prominences observed before and see the projections of their shadows made in the opposite direction, and lengthening."

That is, the sunrise on the moon first illuminates the sunward sides of the mountains, and only later the valleys. This demonstrates that the moon is not perfect, but rather imperfect and like the earth.

Another component of Aristotelian physics is that the heavens were unchanging. However, Galileo observed sunspots appear and disappear on the surface of the sun. This was evidence of "generation and decay" in what was clearly the surface of the sun: sunspots appear only on the sun, and they "foreshorten, … necessary proof of their contiguity to the sun" [*2CWS* p63]. Furthermore, novae – new objects appearing in the heavens – were discovered during Galileo's lifetime. These new objects are not accounted for in Aristotle's theories or for that matter the Bible.

Galileo uses observation to refute the Aristotelian/Thomist model: the heavens are not perfect (the moon is rough, the sun is blemished), not unchanging (stars appear; sunspots grow and decay), and not distinct (the moon from the earth looks like the earth would from the moon). Therefore, Galileo is an Empiricist.

Galileo's Empiricism: Accelerated Motion

Galileo begins his discussion of accelerated natural motion by dissing Rationalism:

> "Anyone may invent an arbitrary type of motion and discuss its properties"

Pure thought may lead us to "imagine helices and conchoids as described by certain motions which are not met with in nature." He rejects such an approach and instead embraces experiment as a better guide to truth:

> "We have decided to consider the phenomena of bodies falling with an acceleration such as actually occurs in nature and to make this definition of accelerated motion exhibit the essential features of observed accelerated motions. … We are confirmed mainly by the consideration that experimental results are seen to agree with and exactly correspond with those properties which have been … demonstrated by us." [*2NS* p521]

In this also he appears to be an Empricist (however, more below).

Rebuttal: Galileo's Empiricism Takes a Back Seat

Galileo clearly admits experience and observation as viable sources of true knowledge. He just as clearly admits reason and intuition as viable sources. It is when those sources of knowledge come into conflict that he reveals himself to be a rationalist.

Rebuttal: Galileo's Theory of Accelerated Motion has Significant Rationalism

In the objection above, I quoted Galileo as justifying his theory of motion on empiricist grounds: "experimental results are seen to agree with and exactly correspond" with his model. However, he goes on to provide additional justification:

> "When, therefore, I observe a stone falling … and continually acquiring new increments of speed, why should I not believe that such increases take place in a manner which is exceedingly simple and rather obvious to everybody? If now we examine the matter carefully we find no addition or increment more simple than that which repeats itself always in the same manner."

In fact, almost all of the discussion that follows is rationalist: a highly mathematicized account that reasons from a few axiomatic foundations to a sweeping and coherent model. He even enumerates Propositions, Corollaries, and Theorems in a manner that pays homage to Euclid and Archimedes.

The appeal to experiment described above is surely more than lip service – he does perform a series of confirmatory experiments to demonstrate that his model corresponds to reality. However, these experiments necessarily diverge from the mathematical perfection of his theory. While discussing the motion of a physical object – a stone – he describes its motion but then specifies that this is only the path that it would "follow if there were no external impediments to disturb the motion of the stone; … but there [is] the inability of the … body to split the air." [*2CWS* p172-3] Furthermore, there is good reason to believe that some of Galileo's experimental data disagree with his claims: see the "History and Philosophy in the Classroom" handout from class[2].

If experience and intuition come into conflict, it is experience that is wrong. In his theory of pendulum motion he "grant [s] that these conclusions proved in the abstract will be different when applied in the concrete and will be fallacious to this extent." [*2NS* p592] But he goes on to account for these differences, and ascribe them to confounding factors outside of his mathematical model; for instance, air resistance: "As to the perturbation arising from the resistance of the medium

[2] From "History and Philosophy in the Classroom" handout: see Naylor 1974, 1980, 1989 and Ariotti 1968.

this is more considerable and does not submit to fixed laws and exact description." [*2NS* p593] Any inconsistency between experiment and theory was ascribed to such extraneous phenomena, not to a defect in the theory.

Rebuttal: Astronomical Observations are inferior to Rationalist Claims

He also admits that astronomical observations may be in error:

> "In taking a single polar elevation with the same instrument in the same place and by the same observer (who may have made it many times), there will be a variance of a minute or so, even of many minutes." [*2CWS* p337]

Contemporaneous astronomers measured the distance to the recently-discovered nova, to determine whether it lay within the sphere of the earth, of the moon, or among the fixed stars.

> "Astronomers and mathematicians have discovered infallible rules of geometry and arithmentic, by means of which … one may determine the distance of the most sublime bodies within one foot, whenever the said distance and angles are taken precisely."

This is a rationalist framework that draws on experiential inputs. However, the measurements were inconsistent; calculations based on the observations of various astronomers put the location anywhere from 1/48 to 42 earth radii, or even infinitely far away.

> "Of the various locations where the star is places, some are obviously impossible and others are possible. It is absolutely impossible that it was infinitely higher than the fixed stars… [or] went creeping along the surface of the earth, much less that is was inside the very body of the earth." [*2CWS* p338]

Galileo leaves no doubt which holds primacy: the model is to be trusted, not the contrary measurements:

> "whenever the calculations made from the observations of these astronomers do not agree in putting it in the same place, there must be errors in the observations" [*2CWS* p336]
>
> "if the rules depending upon geometry and arithmetic are correct, all the fallacies and errors that might arise … would have to depend upon improper measurement." [*2CWS* p333]
>
> "Salv: … there are a few which place the star in the same position, only these few can be free from error; the rest are certainly mistaken. Sagr: Then one would have to trust these few alone more than all the rest put together." [*2CWS* p336]

In fact, the model itself may be used to determine the degree of error:

> "Those observations must be called the more exact, or the less in error, which by the addition or subtraction of the fewest minutes restore the star to a possible position" [*2CWS* p341]

Conclusion: Galileo – Not Quite a Rationalist, Not Yet an Empiricist[3]

Galileo was primarily a rationalist. Although he admitted experiment and observation as sources of truth and as inputs to his models, in practice he resolved conflicts in favor of intuition and reason. His work is consistent with the philosophy that the world we live in is a projection of an ideal world governed by mathematical laws. When our experience deviates from the predictions of the ideal, it is due to the complexity of our world and to the presence of confounding factors. A good experiment, then, is one which is simple (controlled complexity) and free from bias (confounding factors are controlled, and quantitative bounds are placed on the magnitudes of their potential effects). Note that, though this viewpoint seems to blend rationalism and empiricism, rationalism holds primacy: if the results of a sensory experience deviate from the predictions of an accepted scientific model, it is our senses that are suspect. Only under extreme circumstances – after very careful and unassailable contrary evidence – do we reject our model in favor of experience.

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[3] Philosopher B. Spears confronts a similar existential debate in her seminal corpus "Britney" http://www.songfacts.com/detail.lasso?id=1595.

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