Galileo – the establisher of modern science

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In the 17th century a new outset of interest towards science started. One of the most well-known figures of this age was Galileo Galilei. For the historians of science Galileo's central role in developing the methods of modern science is obvious. Since he is considered to be one of the founders of scientific methodology, we examine how the certain elements of scientific method appear in his ouvre.

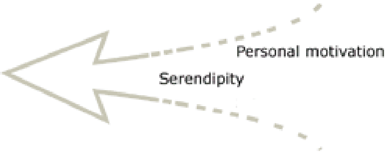
Through his life and works we can experience "how science works".

Portrait of Galileo Galilei. Oil on canvas by Justus Suttermans, 1636. (Galleria degli Uffizi, Firenze)

The Beginnings…

Interest towards science, motivation for learning more about nature or a scientific problem, curiosity, desire to discover something new – these are all elements of the personality of a person who is likely to become a scientist.

Due to his various interests and openness, Galileo got acquainted with several different fields of science. He did not choose just one specific profession. He was good at playing the lute and the organ, he could draw and paint well while becoming absorbed in the technique of scenography. He studied medicine, explored mathematics and he adored geometry, too. He was also interested in theology and he was the court mathematician and philosopher of the Duke. He enjoyed making experiments and trying and investigating everything around him. He was determined to show the phenomena of nature to the ordinary people.



All these characteristics enabled him to become a well-known scientist.

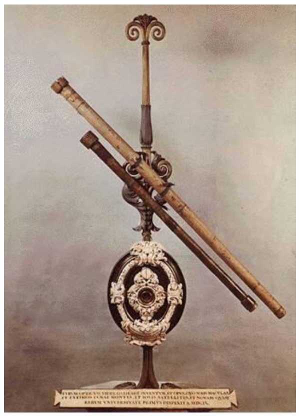
What kind of problem do we investigate?

Sometimes a scientist is affected by a certain phenomenon or problem and it especially arouses his interest. Others comes up with surprising scientific accomplishments and many other scientists go on investigating it. Often it is industry and technological development which raise questions to be solved. Finally there are some basic researches and theoretical investigations the benefit of which can not be experienced directly. However, in the history of science there were several theories which became the basis of how everyday appliances operate.

A scientist usually gets acquainted with several different fields of science and investigates a number of problems in the course of his life. This was especially true of the beginnings of scientific research. In our days so much scientific knowledge have we acquired that it is impossible for one person to learn all this information. Owing to this fact scientists nowadays get specialized in a certain field unlike scientists of the ancient times or the 17th century.

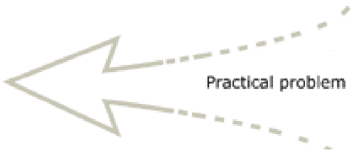
Galileo was occupied in several fields of physics and a number of motives determined his discoveries, inventions, and investigations. Here are some of these:

In the late summer of 1608, Europe was noisy with a **new invention** – the spyglass. These low power telescopes were probably made the best opticians and the very first was credited to Hans Lippershey from Holland. These initial telescopes only magnified the view only a few times bigger. Much like our modern times, the manufacturers were quick to corner the market with their invention, but Galileo's friends – being certain about Galileo's ability to improve the design - managed to convince his own government to wait. After Galileo had heard about this new optical instrument, he started engineering and making his own improved versions, with higher magnification. His first versions only improved the view to eighth power, but his telescope steadily improved. Within a few years he began grinding his own lenses and changing his arrays. Galileo's telescope was now capable of magnifying about ten times more than normal vision although it had a rather narrow field of view….



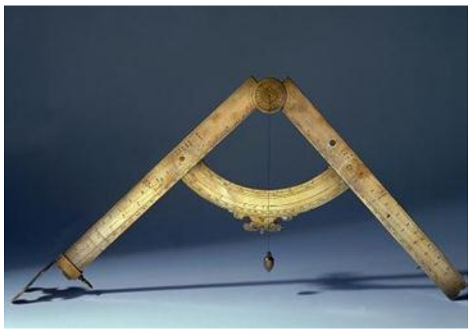
Galileo's telescopes (Istituto e Museo di Storia della Scienza, Firenze)

The appearance of this new technology urged Galileo to develop the instrument and use it for examining the sky. So were his astronomical result born such as the discovery of the mountains and craters of the Moon and the moons of the Jupiter's, the descriptions of the stages of the Venus, the drawings of the sunspots which all prove the heliocentric world concept.



In Galileo's time artillery used cannonballs which were indistinctively made of lead, iron, or other materials and had the same caliber (i.e., diameter), but different weight. Consequently, to standardize the range of the gunfire, the gunner had to adjust the explosive charge in relation to the cannonball utilized. The quantity of gunpowder had to be proportionally greater, in respect to the greater weight. Galileo's compass could be used as a gunner's gauge, because it established the relation between the weight and the volume of the different materials.

In the 17th century Italy was a region of independent states, each having its own particular monetary system. Exchanging currency was thus a daily problem for merchants, bankers and even simple travelers. It was essential to carry out laborious proportional calculations, which could be replaced with Galileo's compass in a few simple steps, using it as a real „currency converter".



Compass of Galileo's proportion (Istituto e Museo di Storia della Scienza, Firenze).

The compasses were designed to solve practical problems as was the thermoscope which was also designed by him.

Exploration and discovery

According to written records, two professors of the University of Pisa, namely Saviati and Galileo had a public debate about the question why ice floats on water. It is usual to raise questions before new theories are born.

Asking question

Why does ice float on the surface of water? Does the shape of the bodies determine their behavior when submerging?

We try to investigate what we can answer to this question, whether it has already been investigated by anyone and what hypothesis and theories we can find in the literature.

Galileo knew about Aristotle's principles about the relation between the behavior and the shape of the material and also knew about his experiments with different kinds of liquid.

This true debate inspired Brecht when he described the readers one episode of scientific process in The Life of Galileo.

„GALILEO: Why, according to Aristotle, does the ice not sink?

Exploring the literature

THE LITTLE MONK: Because it is broad and flat and so is unable to divide the water.

GALILEO: Nod. (He takes up a lump of ice and places it in the pail of water.) Now I press the ice forcibly down to the bottom of the vessel. I remove the pressure of my hands. And what happens?

Making observations

THE LITTLE MONK: It rises to the surface again.

GALILEO: Right. Apparently it can divide the water when rising. – Fulganzio!

THE LITTLE MONK: But then why does it float at all? It is heaviest than water because it is condensed water.

GALILEO; What if it were thinned water?

ANDREA: It must be lighter than water, otherwise it wouldn't float.

GALILEO: Aha!

Sharing data and ideas

ANDREA: Just as an iron needle won't float. Everything that's fighter than water floats, and everything that's heavier sinks. Quod erat demonstrandum.

GALILEO: Andrea, you must learn to think carefully. Give me the needle. A sheet of paper. Is iron heavier than water?

ANDREA: Yes.

Galileo lays the needle on the sheet of paper and then gently slides the needle on to the surface of the water. A pause.

GALILEO: What has happened?

FEDERZONI; The needle is floating! Holy Aristotle, they've never put him to the test! (They laugh.)

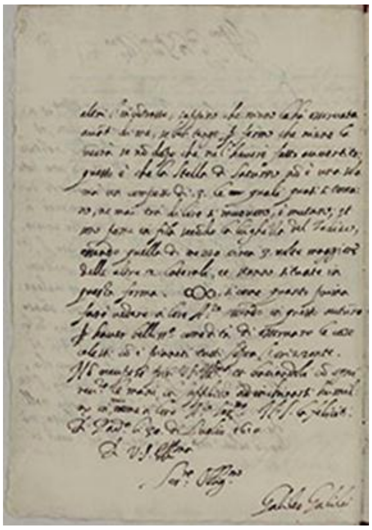
GALILEO: One of the chief causes of poverty in science is usually imaginary wealth. The aim of science is not to open a door to infinite wisdom, but to set a limit to infinite error. Make your notes." (Bertold Brecht: The Life of Galileo, translated by Wolfgang Sauerlander and Ralph Manheirn)

Community analysis and feedback

Publication

In Galileo's time there were no scientific journals but correspondence substituted for this to a certain extent. On the one hand it helped in spreading the new results, on the other hand it protected the discoverer against a possible theft. The Jesuits already used methods which are present today in scientific working. Namely, when a scientist discovered something or made progress in his analysis he wrote a letter about it to some of his friends who also transferred his results to the others. This way a lot of scientists were thinking hard on the new problems simultaneously. Obviously, working on a new problem was more effective.

After he had moved to Florence, Galileo established his scientific correspondence carefully. Nine of the twenty volumes of the National Issue contain his correspondence and eight and a half of it refer to the Florence years. We can literally learn about the whole scientific autobiography of Galileo day by day. His correspondence substituted for the scientific journals of later periods.



Three-bodied Saturn drawn by Galileo in a letter to Belisario Vinta dated July 30, 1610 (BNCF, Ms. Gal. 86, c. 42v).

It is essential for scientists to share their thoughts and observations. They reply to each other's works and also give feedback. Galileo corresponded with many other scientists. We highlight on one of these, namely the investigation of the nature of sunspots.

Signore Velsero, that is Marcus Welser, a rich tradesman and banker published his work entitled Three Letters about Sunspots, in which he published the letters by reverend Christopher Scheiner under the pseudo-name Apelles He also sent an issue to Galileo asking for his opinion. Galileo replied in a polite letter, formulating his letter in a humble way. Apelles received it as an honor.

Feedback and peer review

He drafted feedback in relation to the statements of the letters based on his own observations with telescope and on the interpretations.

In some of the questions he agreed with the author but he also formulated some disclaimers. We can find some of these in the chart.

Discussion with colleagues

He is right	I do not know	He is wrong
• The sunspots are real, they are not illusions. • They do	• Jupiter has several other moons besides the four known ones.	• The spots are dark (they are not, just darker than their surroundings) • The sunspots are permanent (they are not, they are growing

not originate from the atmosphere.		and changing their shape then disappear) • The spots cannot be on the surface of the Sun (they are, their movement can imply the rotation of the Sun)

He sent his letters to several friends of his, most of whom urged the continuation. He wrote another reply after three months, in which his aim was not to traverse Apelles's argument but the exact geometrical proof/verification of the fact that the spots can not be far from the Sun. He describes Benedetto Castelli's method that he made up for observing the sunspots, namely projection on paper.

Scientists and other people interested in science – as in our days – participated and co-operated in the investigations.

The Pirelli Circle (Padua)

The prominence of the University of Padua – besides its outstanding medical education – lay in the fact that it attracted both professors interested in science and enthusiastic non-professionals. Being a teacher at this university, Galileo had a good relationship with Girolamo Fabricio ab Acquapendente who taught anatomy and who discovered vein valves. Harvey was one of his students who became well-known for investigating the circulatory system. He was also in friendly terms with Girolamo Mercuriale, the founder of dietetics and with Santorre Santorio who carried on with Mercuriale's work. After Galileo had discovered that the time of the swing of the pendulum depends only on its length and not on its diversion, he prepared a sphygmograph with Santorio.

Galileo's wooden desk in the Sala dei Quaranta of Palazzo del Bo', site of the University of Padua.

Members of the scientific circle gathered in Giovanni Vincenzio Pinelli's house, where Galilei lived too. Pinelli was a humanist who was interested in several topics; an enthusiastic collector and expert of books, maps, instruments, antiquities, pictures, and sculptures. He modeled Sagredo, who represents critical sobriety in Galileo's two remarkable books, Dialogues and Mathematical Dissertations, of a real person, namely of Sagredo who was a nobleman from Venice and one of the most enthusiastic members of the Pinelli Circle. After Galileo had discovered the expansion of air when heated, Sagredo immediately prepared a thermometer. When some news arrived about Gilbert's magnetic investigations from the faraway England, Sagredo repeated the experiments together with Galileo. He was interested in optical researches, examined the mechanism of the eyesight and the eyes and enthusiastically followed Galileo in his mechanical experiments. Sarpi, who was a qualified theologian, was as good a friend of Galileo's as Sagredo. He called Galileo's attention to the „Dutch glasses" and he also paved the way for the success of his first telescopes. He undertook magnetic experiments with Sagredo with great eagerness and he must have had a role in the discovery of vein valves through Pinelli Circle.

Coming up with new ideas

The Pinelli Circle survived its host who died in 1601. Soon Galileo and his friends met in Antonio Querengo's house.

One of the most important dates of modern history of science is 1603, when six decades after Copernicus' discovery of the heliocentric worldview, Prince Federico Cesi established the intellectual workshop of the Accademia dei Lincei (The Academy of Lynxes), referring to telescopically sharp sight of the cautious predator. Only those could join the academy who had the sharp sight of a lynx, meaning those who recognized something in science and art which nobody else had ever recognized.

This was the first academic society of scientists ever, founded in Corsini Palace, in Rome.

Galileo and the Lynxes had a different view of the place and role of science than anyone else before. Until then science was restricted to an exclusive circle of experts. Even Bacon intended to gather those involved in science to a separated „house of Solomon" whereas Galileo wished to open the gates of knowledge wide and in this intention he was enthusiastically followed by the Lynxes – led by Prince Cesi and the young Cesarini.

build knowledge, satisfy curiosity

They were willing to accept anybody as a member who was deeply involved in a certain scientific field, regardless of profession, religion, or scientific principals. Their routine which determined their concepts as well as their policies about publishing was that they intended to forward the latest scientific results to everyone interested not only in science but also in other disciplines. They felt that the latest and the still controversial scientific results should spread not only among the exclusive group of experts but also among those interested in science as well as literature, knowledge about classic antiquity, arts, and the Holy Script.

Scientific method in the classic sense – Testing ideas

When people talk about scientific methods, they usually mean the simplified, linear method.

History of science attached the formation of this to Galileo. Let us have a closer look at some of the most important elements of it.

• *Defining mathematical principals and introducing them to describe quantities*

(e.g. time, distance, acceleration; speed = the measure of movement of the body/figure, acceleration = the measure of change of speed)

„…it seems that we have just recorded the definition of the steadily accelerating movement, which goes like this: We call a movement steadily accelerating when – starting from a standstill – when its circumstance increases equally at regular intervals.” (Galileo: Discorsi)

• *Determining the characteristics of the problem investigated, the mathematical description of the change in its characteristics*

• *Using the methods of mathematical logic and its previous result to formulate a hypothesis*

hypotheses

(a relation deriving from a mathematical deduction can be a hypothesis with regard to a certain natural phenomenon)

• *Planning and drawing up an experiment suitable for testing the hypothesis*

expected observations

Physics, just like other fields of science, intends to know, understand, and describe the natural phenomena as thoroughly as possible. The first step in this process is to observe the phenomena. There are some which happen automatically, without any intervention and they can be observed well – such as the illusory movement of the Sun in the sky. However, there are some which happen rarely and are difficult to perceive, like the interaction between the neutrinos and the substance.

In most cases spontaneous observation does not work. In these cases the experiments are carried out and studied by the experimenting scientist following the chosen conditions. This so-called experimenting is crucially important because the phenomena can be studied without any disturbing circumstances, and, if the circumstances are altered, the important regularities of the phenomena can be seen easier.

However, experimenting also has its dangers because, by altering the conditions, the experimenting scientist might strengthen features that can hardly or not at all perceived during spontaneous observation and do not belong to the essence of the phenomenon.

• *Experimentation, collecting numeric results*

actual observations

Galileo realized that the results of the measures which he had done several times are closer to reality. “Having done hundreds of investigations for several years, every contravention of laws usually settles and the measures are overwhelmed by the averages.”

(For the appearance of the formal concept of the average and the statistics scientists had to wait for another two hundred years, however, the concept of repeating the experiments and the concept of accuracy is also one of our scientific inheritance from Galileo.)

• *Negligence of the subsidiary effects during the experiments, investigation of the ideal marginal position.*

Galileo could not remove the air physically but he was able to draw logical conclusions concerning movement by the imaginary negligence of air resistance.

interpreting data

- *Evaluation of the results*

We compare the results and figures received with the expected results and investigate whether they support our hypothesis. If necessary, we change/alter our preliminary assumptions. It is also likely that after having the results we reject/refuse the hypothesis and draw up a new one.

Galilei also had some hypothesis that he rejected later: During free fall speed will change the same when taking the same distance.

The change of speed is directly proportional to time and not to the distance taken.

- *The validity of a theory*

During the development of science the validity of each theory could change. However, this does not mean that we should reject the whole theory. For a long time the laws of Newton were considered to give a detailed explanation of mechanical phenomena in every respect. The two completely different discoveries of the first decade of the 20th century revealed that these laws do not give a satisfactory explanation to either the phenomena of the micro-world, or the phenomena that occur in case of high speed. This fact limits the circle of utilization of the Newton laws, however, it does not question its utility for phenomena of our everyday lives.

Science or pseudoscience?

The knowledge of this new scientific method may help us get closer to the recognition of real science. If we want to refer to a certain investigation, theory or ideology as scientific, then they have to formulate statements based on correctly defined concepts. They support the statements and relations with/by experiments, which could be repeated by anyone.

Recently we can find several examples for problems which are referred to as scientific but in reality they are pseudoscientific concerning their methods.

This was the case in Galileo's time too. The two Padua Circles had conflicting opinions.

Besides the above mentioned Pinelli Circle, another circle existed as well, dealing with astrology, alchemy, and other secret professions. Its members met in Gioacomo Antonio Gromo's house.

Simon Mayr, the main astrologist of the Gromo Circle, was a German, who worked in Tycho Brahe's observatory in Prague before enrolling to the Medical Faculty of the University of Padua in 1601. These magicians were enthusiastic about the secrets of nature, like those scientists gathering at Pinelli's and after his death at Antonio Querengo's house. However, as opposed to the scientists, the magicians tried to search the secrets of nature somewhere else and with different methods.

The two Padua Circles strongly opposed each other.

The Pinelli Circle	The Gromo Circle
Galileo and other scientists observed the perceptible natural phenomena and tried to separate and give a detailed description of each phenomena – such as magnetism or movement. After that they planned and carried out exact experiments which could be repeated any time to explain each phenomenon applying quantity characteristics so that they could be verified by measures. They started from correctly defined concepts and tried to do the necessary negligence on the basis of fundamental principles and model each phenomenon.	Magicians intended to investigate the big relations/coherence of the Universe and observed every phenomenon in cosmic perspective. Their concepts were not always correctly defined and they did not support their philosophical statements with experiments. They emphasized labeling, external similarities, the logical and rhetorical turns and the secret harmony. For them numbers were symbols of mystical relations and secret harmonies, the meanings of which they tried to understand from the wisdom accumulated in previous ages.
scientific method	pseudoscientific method

Science checklist:
How scientific is it?

- [x] Focuses on the natural world
- [ ] Aims to explain the natural world
- [ ] Uses testable ideas
- [ ] Relies on evidence
- [ ] Involves the scientific community
- [ ] Leads to ongoing research
- [ ] Benefits from scientific behavior

Benefits and outcomes

This may be one of the most complex questions of all. What is the utility of scientific work – as often this is the condition for financial or moral support.

Which factors prove the effectiveness and usefulness of Galileo's work?

He solved everyday problems as he made a thermoscope. With the use of his compasses military problems could be solved, people could calculate compound interest or exchange different Italian currencies.

solve everyday problems

It is often difficult to tell how much a field of investigation helps to solve everyday problems. As for basic investigations, it may occur that a theoretical statement becomes the basis of our everyday utilities only after 50 or 100 years. Galileo's statements relating to the movement of pendulum prepared the way for Huygens to create the pendulum clock, which made it possible for average people to measure time.

His observations and explanations also contributed to the development of astrology. He proved the heliocentric world view.

He worked out and applied the method for scientific investigations in his own investigations. He neglects, sets up models and discusses each phenomenon by mathematical methods.

He tried to spread his works written in Italian to a wider audience, calling average people's attention to the importance of science.

build knowledge, satisfy curiosity

Several literary and literary interpretations prove that Galileo's life and work have raised several social questions.

address societal issues

May authorities (state or religious) have a word in the scientific observations, their fields of investigations and theses? Is it necessary for an average citizen to perceive the basics of science? Does science have to search for answers to everyday problems?

"But can we turn our backs on the people and still remain scientists? The movements of the heavenly bodies have become more comprehensible; but the movements of their rulers remain unpredictable to the people. The battle to measure the sky was won by doubt; but credulity still prevents the Roman housewife from winning her battle for milk. Science is involved in both battles." (Bertold Brecht, The Life of Galileo)

Through the life of Galileo we could have a glance at how complex scientific method is and we could experience what a creative, exciting, and dynamic process scientific research is. In Galileo's words:

"Philosophy is written in this grand book—I mean the universe—which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language and interpret the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures, without which it is humanly impossible to understand a single word of it." (Galileo Galilei, translated by Thomas Salusbury)

photos: Galileo Galilei's photo gallery, Museo Galileo - Institute and Museum of the History of Science · Florence · ITALY

WANT TO LEARN MORE? CHECK OUT THESE REFERENCES:

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