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Was ist Bewegung?

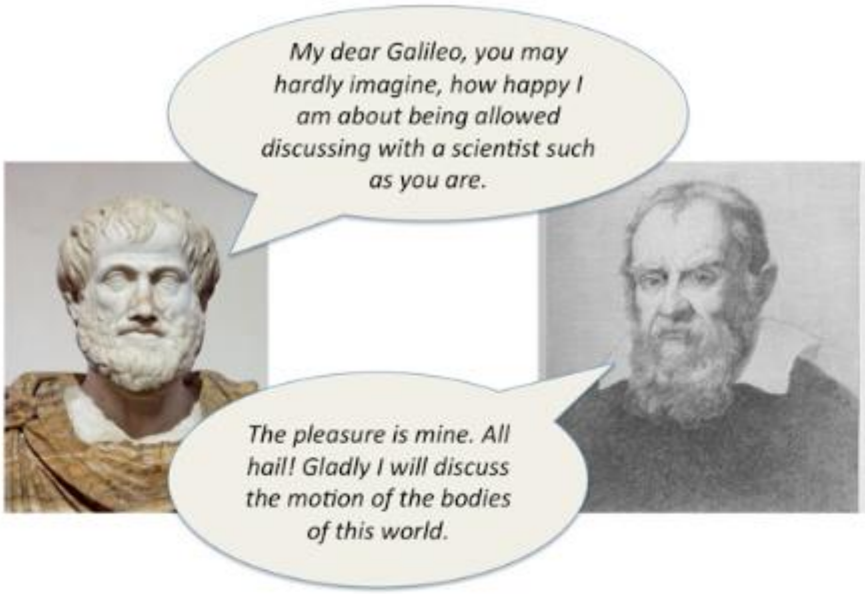
[Moving Bodies: Lessons from Aristole to Galilei about aspects of the nature of science].

Case study developed within the European project HIPST (History and Philosophy in Science Teaching),

https://www.ew.uni-hamburg.de/einrichtungen/ew5/didaktik-physik/projekte/projekte-abgeschlossen/hipst/casestudies/01-d-gilbert

Navigating through the case study

This case study is also available as a single file for your convenient download.



1-3 Introduction

1 Title and Keywords

Moving Bodies - An introduction to early and modern mechanics
mechanics, kinematics, law of inertia, idealization, mathematization of physics

2 Authors and Institutions

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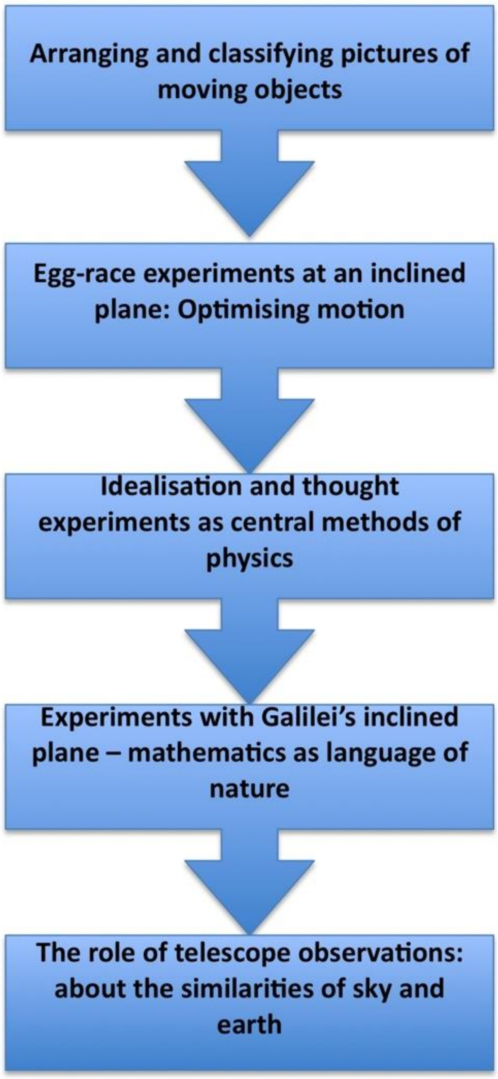
3 Abstract
The case study "moving bodies" is concerned with the contrast of two opposed scientific views on why bodies move. On the one side, the antique Aristotelean worldview is examined. It provides categories and beliefs, which are closly related to the beliefs of pupils about the process and cause of movement. This Aristotelean and teleological worldview is opposed to the idealistic as well as abstract and modern worldview of Galilei. Galilei represents the perspective of modern physics: Nature is determined by uniform principles, which can be identified by means of idealisation and abstraction. Mathematics is considred as the language of nature. Both worldviews are contrasted in the classroom. It shall be learned that the antique worldview comes close to one's own preconceptions and that it is useful for lifeworldly descriptions. At the same time the usefulness of idealisation, abstraction and mathematics for physics shall be experienced. This potential of achievement however, is accompanied by the loss of clearness and immediate acquisition of experience. The central educational objective is the devolpment of the concept of inertia as one of the central concepts of mechanics. Additionally, aspects of astronomy in the context of the development of the telescope are examined. Thereby, the relevance of the development of new technologies and the reciprocal interdependence of science and technology are highlighted.

4 Description of Case Study

The case study is designed in a methodically flexible and modularly way. The singel parts of the case study can either be worked on in class or in work-sharing group works.
Two physical concepts are examined and contrasted within the case study. With both concepts, mechanical movements can be described, classified and interpreted. The case study shows how the antique Aristotelian mechanics designs a system for the classification of bodies in motion and at rest. Parts of this system are loosely related to lifeworldly interpretations of students. Galilei's modern perspective, however, describes motion intentionally in an idealised way and abandons lifeworldly experiences.



Fictitious scenic dialogues between Aristotle and Galilei are an important methodical guideline of this case study. Apart from this, work assignments, experiments and other learner's activities are described. The *reflection corner* as method of explicit reflection on the nature of science plays an important role during the whole case study.
Pupils do not naturally raise the question about how movements are classified or interpreted. By **developing their own criteria guided classification system** based on several pictures of movements, they shall be introduced to the topic. Afterwards they are introduced to the two main characters Galilei and Aristotle. Their own developed classification system is then used as a reference for the classification of the different physical categorisations. Some pupils will develop classification systems, which are similar to the antique Aristotelian system. In this way, the Aristotelian view can be experienced as plausible and authentic, which makes it easier to contrast it with the idealistic view of Galilei.

The following lessons can be based on different **scenic conversations between Aristotle and Galilei**, which show the contrary views of the two main characters. Apart from this the pupils can also identify their different methods of scientific working. By comparing the different views the pupils shall be encouraged to critically reflect on their own beliefs and to develop them further into the direction of a more modern view.

Galilei's idea of idealization is contrasted to the Aristotelian view. An **egg-race like activity** is conducted as an introduction to Galilei's idea of inertia. The pupils are supposed to roll down a piece of plasticine from an inclined plane (e.g. made of cardboard) from certain heights. The piece of plasticine is supposed to roll as far as possible. In order to achieve this aim, the pupils can gradually optimize the experimental conditions. This process of optimization is reflected on afterwards. Another scenic dialogue shows that the optimization, if thought through, passes into a **process of idealization**, in which conditions are assumed, which do not exist in the real world (absence of friction etc.). These results require another reflection on the nature of science in the **reflection corner**, this time especially on the aspect of idealisation. In this context it is reasonable to make the function of **thought experiments** in physics a topic of discussion.

The case study is also concerned with the question, in how far **mathematics should be understood as the language of nature**. Galilei explicitly represented this belief by studying the motion of bodies left to gravity (free fall). To slow down the motion of a body and thus make it measurable, he conducted measurements with an inclined plane. He developed a law of free fall. This case study does not use a mathematic description of the law of gravity commonly found in schoolbooks. With the inclined plane, however, the pupils shall experience in own experiments that the path-increases of the down rolling ball in the same time units equal a sequence of odd numbers (1-3-5-7-9-...). This representation of the law of free fall is equivalent to the known correlation between paths and squares of time. Nevertheless the question about the mathematisation of processes of nature is raised in a suggestive way: can nature count?
Motion in the heavens and on earth is contrasted qualitatively within the limits of the Aristotelian mechanics. Galilei abandons this differentiation. Out of this context, Galilei's astronomic research gains importance. With numerous **telescope observations** Galilei showed that the heavenly objects are not the idealized bodies the heavens and its non-earthly physics were attributed with.

In this respect, moon observations are for example connected to the question about how motion in nature should generally be classified and interpreted. Here again scenic dialogues are used. Additionally the pupils can observe heavenly objects and compare them to Galilei's observation data.

5 Historical and Philosophical Background Including Nature of Science

5.1 Aristotle: life - work - thinking

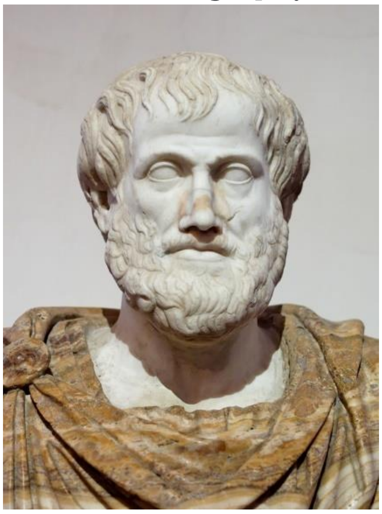
5.2 Galileo Galilei: life - work - thinking

5.3 Learning about the Natur of Science

5.1 Aristotle: life - work - thinking

Aristotle was intensively concerned with phenomena of movement. By observing and reflecting he tried to examine movements with reference to the question about their aim. A short scenic dialogue, which also can bei uese as material for pupils, serves as an introduction (see material 2).

5.1.1 Short biography of Aristotle



Aristotle (384-322 before our time) was born in the Macedonian city Stageira. Today still he is referred to being one of the most known and influential philosophers. At the age of 17 he accepted a considerable heritage of his father ensuring him earnings and a life free of paid work. He became a scholar of the philosopher Platon in Athens. At Platon’s academy he spent 20 years, which strongly influenced him and in which he only worked for his teacher. Only after Platon’s death (347 before our time) he left Athens and became the educator of the heir to the throne of Macedonia, Alexander (the Great) who then only was 14 years old. A few years later (332 before our time) he founded a centre for sciences and research in Athens, which was unusually big for his times. There, the different areas of the antique knowledge, of philosophy and its history, but also sciences, medicine, history, politics, economy and philology were studied. The scholars and followers of Aristotle then and up to the early modern times were called Peripatetics. The philosopher owned a great library and comprehensive collections of animals and plants, which Alexander had sent to him from his campaigns.

5.1.2 Aristotle's thinking

The religious/ philosophical worldview of his times highly influenced Aristotle’s thinking and therefore also his physical considerations: human beings and the earth were, in Aristotle’s opinion, not perfect and inferior to the perfect heavens. They had to be different in every respect, for there could be nothing on earth equalling the complete perfection of the heavens. Heavens also should consist of its own perfect element called the “quintessence“. Everything earthly was composed of the four elements air, fire, water and earth. In Aristotle’s opinion the pursuit of rest was the last and most natural principle on earth. Everything in nature was in the end aimed at this purpose. According to this, every motion could be categorized referring to whether it serves this purpose. Aristotle’s differentiation between the different kinds of motions also results from this approach (see above). For Aristotle, the meaning of the term motion was more general than it is for us today, for he associates every kind of change with it.

Aristotle suggested the idea of an *unmoved mover* as cause for motion. Motion can cause further motion, but if everything pursuits rest, there has to be a beginning and an origin of motion. This idea inspired Thomas of Aquinas in the Middle Ages to form an argument for the existence of God. The idea had a lasting influence on the view on the Christian God in the Middle Ages and thereafter. Since the middle of the 13th century, the Aristotelian philosophy has been compulsory at universities. His main treatises were available in Latin, the contemporary language of science. To the end of the Middle Ages, Aristotle had the status of being an indisputable authority.

According to Aristotle, nature-philosophical knowledge had to explain, why things happen without any *exception*. This approach implies that one can find, for example with physical phenomena, exactly the feature, which all of them have in common and without which those phenomena could not occur at all. Aristotle took his own observations of the world, which were analysed in a special way, as a basis for scientific knowledge.

Aristotle himself conducted only few planned experiments and he also did not believe they were important. This is not astonishing, for the experimental method was not established before the New Age and since then it is associated with names such as Bacon, Galilei or Newton. Aristotle was rather of the opinion that everything, which could be known about nature, could be learned of it, if it only behaved naturally. The function of a nature philosopher therefore was the observation of processes in nature and the establishing of principles. Aristotle believed that by suitably ordering and analyzing observations, principles could be found.

In his third book of physics, Aristotle differentiated even further between his categories. With the help of those categories, all motions (or more generally: changes) in the world should become seizable. Every science wanting to be called physical would have to deal with those categories and according to them, should organize the observations of the world.

Category: substance/ “WHAT?”
Development and stopping are differentiated

Category quantity/ “HOW MUCH?”
Amounts/ increase and decrease are differentiated

Category quality/ “HOW?”
Colours and other features are differentiated

Category place / “WHERE?”
Positions and relative positions are differentiated

According to Aristotle there was no benefit in the mathematical examination of the occurring phenomena. He even ascribed wrong assumptions of his teacher Platon to his affinity to mathematisation. Aristotle was of the opinion that all physical phenomena could be described by using one’s own perception and experience. Mathematics only had, at the most, the function of being an *ancillary science*.

Aristotle wrote a treatise about nature, which comprises eight books: “Physics”. It deals with the explanation of some basic terms used when describing observations of processes in nature as experienced in daily life.

The most important ones are: *space*, *time*, *motion* and *cause*. It is not a mathematical explanation of the main features of nature in a contemporary sense.

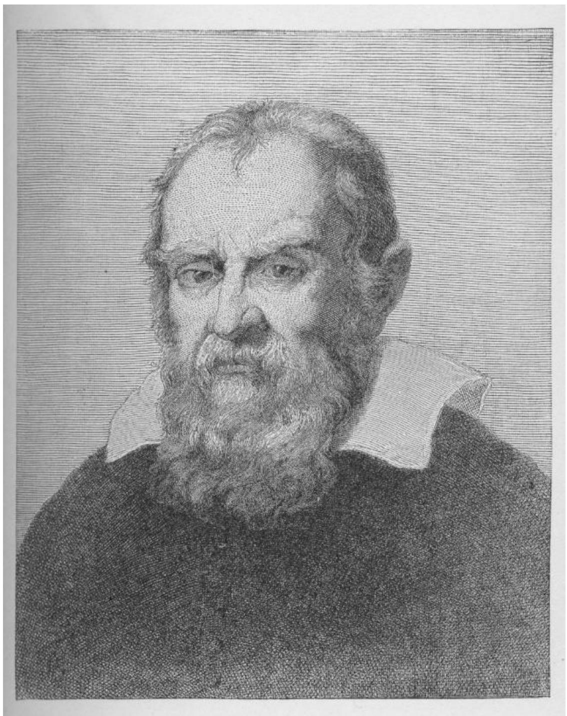
Aristotle’s statements referring to the movement of bodies can be summarised as listed below:

- The principles of movement of **heavens and bodies are entirely different**.
- In the heavens only **absolutely perfect circular motions** occur which last forever.
- On earth **motion ends** at some point – heavy bodies (such as stones), strive downwards, light ones (such as smoke) strive upwards.
- Earthly **motion is classified and ordered** according to natural motions (such as falling stones), natural self-motion (walking human beings, flying birds) and unnatural respectively forced movements (carriage drawn by a donkey). Unlike in Galilei-Newtonina mechanics, **rest is regarded as a special condition**, to which bodies in natural motions are striving to.
- The faster an unnatural movement, the greater the force activating and sustaining it has to be. **Without the application of force, every unnatural movement will finally come to an end.**
- Every left alone object has a **natural falling** (stone) or **rising** (smoke) **rate**, with which it therefore strives for its **natural place**. Heavy objects fall faster than lighter ones.
- Every earthly movement is influenced by **friction** – the lesser the friction, the faster the rate of fall.
- There is no vacuum and there also cannot be one, as there otherwise would be no friction working against motion. Objects would move with unlimited speed (**horror vacui**).

This system proves itself to be very comprehensive, for every statement determines another. If only one statement was falsified, the whole system could break down. On the other hand, the statements are closely related to life worldly experiences, although the latter are not usually systematised and thought through.

5.2 Galileo Galilei: life - work - thinking

5.2.1 Short biography of Galilei


GALILEO GALILEI.

In 1564 Galilei was born in Pisa as the son of a patrician family from Florence. His father, Vincenzio Galilei, was a musician in his heart, although he originally learned the respectable profession of a clothier. His father was, just like later also his son Galileo Galilei, a very good lutanist. As a result of the great dower of his mother and the respectable profession of his father, the family was financially well settled, when Galileo Galilei was born as their first son in Pisa. Due to his noble family background of a patrician family, he was treated with great respect.
Although Galilei has never been married, he could only live modestly. After all, he had to bring up high dowers for his sisters and he also had to again and again support his brother and his mother after the death of his father.

Galilei himself had three illegitimate children with his housekeeper Marina Gamba, a Venetian. He avowed himself to all of his children and paid child support for them, for them and their mother did not live in his house. While the girls, Maria, Celeste and Livia, were sent to a monastery guaranteeing illegitimate girls a stable accommodation early, he took his son Vincenzio into his house and legitimized him in 1613.

Galilei attended the traditional school of a Benedictine monastery close to Florence. When he wanted to become a monk, his father took him back home. In 1581 he started to study medicine at the University of Pisa. However, he soon discovered his passion for the physics lessons of motion, even though those were still taught according to Aristotle's views. When Galilei listened to a lecture about the Greek geometry of Euclid, he was so fascinated that he henceforth dedicated himself to studying this area intensively and absolutely neglected earning his medical degree.

His first position as lecturer for mathematics Galilei received from the University of Pisa in 1589. It was not well paid, but at least he only had to teach two hours per week. He was able to supplement his income with practical technical inventions, which had made him well known. A second extra income he earned with private lessons and the development of horoscopes, what was not unusual for a scientist in those times.

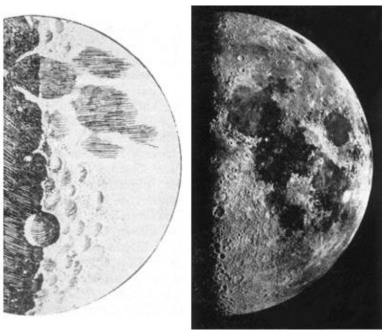
He published his first work about motion and the laws of falling bodies “De Motu” in Pisa, after he before had conducted his experiments with the inclined plane. Due to his growing criticism towards Aristotle’s lessons, Galilei became more and more unpopular with his colleagues from the traditional University of Pisa. Therefore, there was no prospect of extension of his employment. Thus, in 1592 he moved to Padua for another teaching position.

In Padua he heard of a new Dutch invention, the telescope. By cutting lenses he considerably contributed to the improvement of this instrument.

Indeed, Galilei is not necessarily thought of being the first to point a telescope towards the sky, but at least he was the first who made important observations for the benefit of scientific (and not only sciene). He discovered the four largest moons of Jupiter, the phases of Venus, that the milky way consists of single objects, spots on the surface of the sun, and that the surface of the moon is similar to that of the earth.

Referring to this, thorough drawings of mountains and craters survived being published, among other telescopic observations, in his treatise “Siderus Nuncius” (star messenger) in 1610.

One of Galilei's telescopes



Drawing of Galilei of half-moon


Sun spots obersved at observatory in Bochum (Germany) (http://wdrblog.de/teleskop/images/Junisonne.jpg)

Publicly he committed himself to the heliocentric worldview of Copernicus, what in those times absolutely invoked the danger of becoming a victim of the inquisition. A known example was the incineration of the Italian philosopher Giordano Bruno, who in 1600 was burned at the stake in Rome after spending several years in the dungeons. He represented the idea of an endless world, in which neither the earth nor the sun were a centre, and declared relentless antagonism to the Catholic Church.

In 1610 Galilei also received the well-paid position of a philosopher and mathematician at court in Florence. Not unimportant may have been the fact that he had named the Jupiter moons he discovered Medicean stars. What a great compliment to the dynasty in Florence. There he became responsible for the education of the Grand Duke Cosimo II.

Since his astronomic discoveries Galilei has always been anxious to support the Copernican lessons with his research. In 1616 this resulted in a decree of the inquisition according to which all Copernican lessons were declared wrong and whose distribution then was prohibited. As a consequence of his publishing the Dialogo (dialogue about the two main systems of the world) in the year 1632 also Galilei was publicly accused in an proceeding of the inquisition and was forced to entirely renounce the Copernican lessons. Only by this he escaped death and "only" was grounded for the rest of his life. Even an appointment with a physician he was not allowed to attend. During his house arrest he wrote another treatise in 1638, the "Discorsi" (discussions and mathematical demonstrations about two new disciplines referring to mechanics and the laws of falling bodies).

In his last years, Galileo suffered from various different physical discomforts. As a result of the intense impairment of his sight, he had an loyal assistant from 1638 on. Finally Galileo lost his sight completely. He has never been able to finish his "Discorsi". Galilei died, according to Viviani, on 8 January 1642 "after a long fever and heavy palpitation of the heart, which little by little had emaciated him for two months when he finally [...] died with philosophical and Christian continuance". Among Francis Bacon, René Descarts and Isaak Newton, Galilei today still is thought of as founder of the modern science based on experiments.

5.2.2 Galilei's views on sciences

In the antique Platonism heavenly movements have already been described with the help of mathematics. Galilei extended this model by also using those descriptions for the earth. He formulated a kind of *mathematic creation thought*: „*The great book of Nature lies ever open before our eyes and the true philosophy is written in it ... But we cannot read it unless we have first learned the language and the characters in which it is written .... It is written in mathematical language and the characters are triangles, circles, and other geometrical figures*" (Galilei 1623, p. 232, accoding to Forinash et al. 2000).

In his works, Galilei almost exclusively used the geometrical proof, which from today's point of view seems unusual or circumstantial. The geometrical mathematisation of the earthly nature replaces the pre-Galilei function of physics. The diversity of principles determining natural phenomena can only be discovered if one abandons instantaneous sensations. This basic idea still determines physical research today and became part of its success story.

As he often put mathematics in front of physics, Galilei was not *deluded* by contradictory sensations. He was able to do so by interpreting occurring discrepancies as perturbations blocking the view on the essential coherence working behind the instantaneous appearances.

Nevertheless the in reality conducted experiment does not form an unimportant or neglectable part of his examination. In Glailei's opinion the experiment rather had an important meaning for the "*methodological questioning of nature*". Galilei used the special language of geometrical mathematics with circles, curves and triangles for the presentation. The methodological questioning of nature was predominantly carried out with *demonstration experiments*, which had the purpose of *confirming* conclusions obtained in mathematical ways. According to this, Galilei believed that, before the actual experience, there already had to be a theory in mind

In his Dialogo one of his main characters announces: "*I am sure without even trying that the result is, as I tell you, for it has to be that way*" and "*I conducted an experiment, but before that the natural reason had caused me to definitely believe that the action had to proceed in exactly the way, it finally also proceeded in in reality.*"

Referring to his experiments, Galilei, in contrast to Aristotle, attached more importance to describing the processes of motioins than to studying their causes or purposes. In comparison to Aristotle, Galilei was not merely concerned with the question of <u>why</u> bodies move, but rather <u>how</u> they move. In the context of different experiments, he hence studied how bodies behave, if they fall undisturbed. To be able to examine the free fall, Galilei, amongst other things, worked with inclined planes. In doing so he implied that movements are indeed slower on an inclined plane, but that they are still determined by the same principles, a falling stone is determined by. The examination of a ball rolling down an inclined plane, which has to be as frictionless as possible, lasted long enough to be measurable with contemporary methods of time measurement (water clock, pulse beat).

Hidden relations could be, according to Galilei's opinion, identified by idealization and abstraction. Galilei knew that his idealized principals could only approximately describe complex, real phenomena. Galilei developed idealizations, which are today taught to learners of physics in an almost unreserved way, but which then represented a ground-breaking innovation. Assumptions about point mass, free fall in a vacuum and the absence of friction are parts of this.

To idealize, at first certain parameters have to be identified as perturbations and thereafter have to be characterized as neglectable. One cannot find a real counterpart to the idealized object – it only becomes real again after adding the perturbations. Today it can still be surprising that a physical principle, such as the one about the free fall, does not describe nature directly, but that especially here lies its usability.

To describe real processes and objects, the idealized principles have to be substantiated again. Motions of falling are for example described by adding a friction term depending on the rate of falling. The *art* of idealization is to be able to identify perturbations, which can be interpreted as divergence to the principal. In the end, the complexity of diverse natural phenomena is highly reduced. This opinion becomes obvious in the following quotation by Galilei: „*Referring to the resistance of a medium I admit that its disturbing influence will be more noticeable, and that it is, due to its manifold different compositions, hardly possible to apply definite rules to it [...] on all these endless different possibilities [...] no theory can be given.*" Consequently, to Galilei perturbations are a real part of nature, which surely will become physically measurable at some point, but which present too high a challenge at the moment.

5.3 Learning about the Nature of Science

5.3.1 Scientific controversies

Scenic dialogues between Aristotle and Galilei show exemplary how controversial science can be. Even though they did not live at the same time, Aristotle's successors presented the main stream philosophical position in Galilei's age. Scientific controversies are no accident or exceptional situation of science. They often even cannot be resolved by an improvement of the condition of empirical data, which a very naïve empiricist positioin would suggest. This is why Galilei cannot simply convince Aristotle in the scenic dialogues. Their basic ideas are just too different.

Galilei's way of studying science (idealization, mathematization and experimenting) are new for his times. The controversies Galilei had to fight against as well as he was able to do in the context of his times (accusation of heresy by the inquisition) were not simply an argument about the correctness of observations, but above all an argument about the premises science should be based upon.

5.3.2 The importance of thought experiments and idealizations

Thought experiments have their firm position in the history of science (Kühne, 2007). In this case study, two thought experiments of Galilei are examined in the form of scenic dialogues. In one of those thought experiments the idea of inertia under ideal, frictionless conditions is developed (material 4). The second thought experiment concerns Galilei's argumentation stating that heavy and light bodies should fall with the same velocity (material 5 and material 6). Both thought experiments do not substitute empiric experience. Thought experiments generally never substitute real measurements. They do however provide a theoretical change of perspective or framework. The concept of an inert motion, which would never ends without friction, as well as the idea that all bodies fall with the same rate, contradicts empirical experience. Real observable motion does come to an end and a stone just falls more quickly than a silk cloth. Aim of the thought experiment is therefore rather to question the premises working behind established interpretations. Hence Galilei's thought experiments do not serve to substitute empirical experiences, but rather to interpret them newly in the context of changed basic assumptions.

Physical school experiments with air cushion tracks and tables (to minimize friction) or with vacuum tubes (for experiments with falling bodies) optimize the experiment conditions (decrease of friction, see picture), to be closer to Galilei's thought experiment.

Air cushion track for reducing friction for teaching purposes - an example of optimization

The idealization of experiment conditions is therefore the same as a What-if-game. Impossibilities are accepted in order to identify a hidden principle operating behind the diversity of natural phenomena. Especially physics often seems remote from every day life for students and young adults. Therein, however, could also lie a key for its potential for explanations. Thought experiments are not unlike to thought games. In thought games children imagine themselves for example being invisible. They would only be able to communicate conditionally, but they would at the same time be in an extraordinary powerful position. An unrealistic situation is played through in an exciting What-if game. Thought games and thought experiments are, however, not similar referring to their aims, the consistency of the assumptions and the control of the imagined boundary conditions.

For the reflection on the importance of thought experiments the thought game can be a welcome inducement. The following questions can encourage a reflection on the nature of science:

- Do scientists conduct thought experiments because they are too lazy to performe real experiments?
- Should one take results of thought experiments seriously? They are, after all, still only thoughts?
- In thought experiments scientists ask the question: "What if…?"

Did you ever ask such a question?

Is there a difference between your What if-question and scientific thought experiments?

5.3.3 The role of mathematics for the interpretation of nature

Mathematics counts as the most important modeling tool of physics. On the other hand, it is not a science itself. Mathematical constructs are human products. It is therefore a miracle how well mathematics can be used to explain nature and how one can present physical principals in such an extraordinary well way. This fact was formulated by the American physicist Eugene P. Wigner in his talk in 1959:

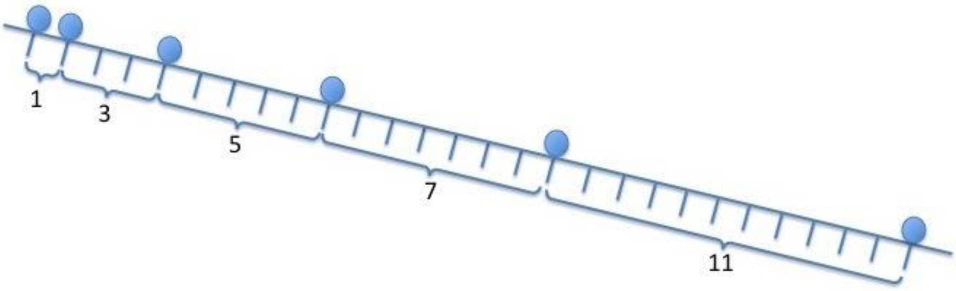
The first point is that the enormous usefulness of mathematics in the natural sciences is something bordering on the mysterious and that there is no rational explanation for it. Second, it is just this uncanny usefulness of mathematical concepts that raises the question of the uniqueness of our physical theories (Wigner,1960).

The possibility to describe nature by using mathematics is incredible, but only if one imagines scientific descriptions and explanations of nature to be completely independent from us human beings. Such a metaphysical realism is, however, indeed problematic. It seems rather that scientists reduce the diversity of natural phenomena depending on their matter of particular questions. Galilei does this with the method of idealization (see above).

"*We so to say divide the world into what we think is important about it and into what seems to result or hopefully results from those important things in a way we do not really understand, but which also does not really seem to interest us. The things seeming important to us we call 'natural laws', the rest we call ancillary and initial conditions*" (Hedrich, 1993, pp. 113f)".

In order to being able to use mathematics for describing and explaining nature, we have to idealize and reduce nature particularly. Arbitrariness is a part of this, although nature surely refrains from a lot of kinds of structuring. One should not forget that laws of nature are subject to restricted application (Allchin, 2007). The way physics interpret nature and nature itself only conform to a certain extend.

Within the case study, the principle of free fall can be examined by using a sequence of numbers. If a freely falling body in a first time unit has traversed a certain path, then after the end of the second time unit four times that path and after the end of the third time unit nine times that path will have been traversed. The differences of the paths then exactly correspond to a sequence of odd numbers.



In equally long time units the coped with section tracks add up according to a sequence of numbers consisting of odd numbers.

The material is also available in form of a PowerPoint Presentation.

t	1		2		3		4		5		6		7
s	1		4		9		16		25		36		49
Δs		**3**		**5**		**7**		**9**		**11**		**13**	

That a sequence of numbers is able to describe the free fall of a body can be presented as a curiosity: Can nature count? The question, whether nature could count (even if only with odd numbers), can be presented to pupils to encourage them to reflect epistemically. Do human beings just impose their consciousness, structured in numbers, on nature? Or is our consciousness, for we are beings of nature ourselves, suitable for identifying the principle-like structures of nature?

5.3.4 Technical innovations can advance science

In the year 1609 Galilei received the news of the invention of the telescope by the Dutch Jan Lipperhey. Galilei himself technically developed the telescope further, what was not only successful because of his access to masters of the production of glass grinding in Venice. In the same year Galilei achieved a ninefold magnification.

Galilei counts as the first to use the telescope for astronomical observations in a systematic way. As the lens systems only had a low quality compared to those of today, observations of the details of heavenly objects were not really important to Galilei's contemporaries. In astronomy the traditional interest in finding the exact position of the objects in heavens prevailed, but not to study their constitution. This epistemological interest corresponds to Aristotle's worldview: If a "separate physics" applies to the heavens according to which continuous motion of bodies along orbits is possible, then the restriction to the description of the motion of heavenly bodies is a reasonable desire.

One of Galilei's telescopes

Galilei instead observed that Venus has phases like the moon of the earth, that Saturn has a ring system around it and that there are mountain chains on the moon, which are similar to those on earth. Galilei's observations corresponded to his worldview, which did not follow Aristotle's differentiation between earthly and heavenly physics anymore. Galilei's heliocentric worldview was supported by a technical innovation. One must not imagine the observations made possible by contemporary telescopes as self-evident. In this way, Galilei in his first notes does not report rings of Saturn, but "ears" of Saturn (Teichmann & Höttecke, 2009). Observations and skill played a substantial role in the handling of a young technology such as the telescope, so that Galilei probably also observed with the **„sharpness of his intuition" (Giorgio Abetti, 1923, zitiert nach Teichmann & Höttecke, 2009).** Here the theory-loadedness of observations in science becomes obvious: theoretical presumptions influence what and how one observes in an uncircumventable way. Probably for this reason a lot of Galilei's contemporaries did not agree with his observations, for they had different presumptions.

6 Target Group, Curricular Relevance and Didactical Benefit

In the following paragraph, essential learners' prerequisites are briefly pointed out. Apart from that, also general educational objectives, each with reference to the areas of competence valid according to curricular standards (of Germany), are presented. As this is a case study especially concentrated on the nature of science (NoS), those educational objectives are presented separately.

6.1 Learners' prerequisites

This case study was designed for the use in regular classes of general education in the subject physics. It comprises about eight single lessons (each 45 minutes). The attached material has in parts already been used in year eight (age: about 13 to 14 years) of several schools in Lower Saxony. It is however also conceivable to use the case study for higher years, then, however, with considerably reduced assistance by the teacher.

The case study is especially suitable as an introduction to the topic of kinematics.

Experiences in experimenting are advantageous.

6.2 Competencies

Content Knowledge

The pupils shall…

… be able to reasonably classify the diversity of motions.

… develop an understanding of the principle of inertia by using the method of idealization.
… get to know a path-time-law of free falling.

… be able to explain an easy path of light in the Galilei telescope.

Scientific Methods and Gain of Knowledge
The pupils shall…

… enhance their experimental skills by independently planning and conducting experiments.
… compare their own experimental results with those of Galilei by critically reflecting on differences and similarities.

… qualitatively and quantitatively analyze measured data.

… critically reflect on their own experiments with reference to the scientific research.

Communication
The pupils shall…

… differentiate between colloquial language and scientific terminology.

… outline experimental settings and describe the used materials.

… name the occurring variables by using the correct terminology.

… present their results in an appropriate way as a whole group.

… independently identify relevant information in short historic text sources and fictious scenic dialogues.

… name own difficulties occurring while experimenting.

Judgement
The pupils shall…

… differentiate between classifications of motions oriented on their own preconceptions, Aristotle and Galilei.

… be able to judge the methods of idealization and thought experiment.

… realize the importance of abstraction of constraints, such as friction, as physical method.

7 Activities, Methods and Media for Learning

The following sequence of single units are not intended to be taught merely in a chronological order. Instead some parts of the case study (e.g. chapter 7.6 - 7.8) may be suitable for collaboration in teamwork.

7.1 Students develop their own classifications of bodies in motion

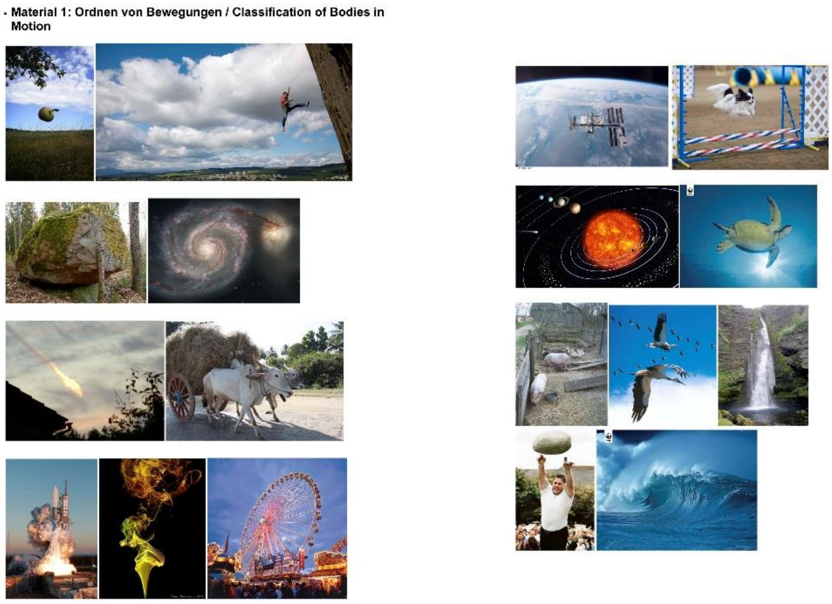
As an introduction to the case study and based on pictures. The pupils are assigned to develop a classification system of phenomena of motion. To do so, they work on the following activity (material 1):

The pictures show motions.

a) Cut out the pictures and sort them/ put them into the right order.

b) State your sorting criteria.

time: 10 minutes



Thumbnail-pictures of material 1

During the activity the pupils develop their own initial classification system of phenomena of motion and thus act to a certain extend analogously to Aristotle or Galilei. Later, in an explicit phase of reflection, it is illustrated that classifying and sorting are scientific methods. The resutls can later be compared. Here classification systems of pupils of year 8 of a gymnasium in Lower Saxony are exemplarily presented:

group 1	group 2	group 3	group 4	group 5
• quantity of rate • objects of nature • objects of technology	• unnatural motion • natural motion • human beings • animals • universe	• nature • “in one’s own right” • mechanical motion	• machines • motion in the air • motion on the ground	• means of transportation • sports • motion in space • motion in nature

The results of the pupils exemplify which kind of categories they develop. Some of the categories hardly can be interpreted in a reasonable way (e.g. what means mechanical motion in group 3). On the other hand, it also evident that the Aristotelian categories can be developed in approximately the same way. This becomes especially obvious in group 2 (Aristotle: natural, natural self-motion and forced motion, motion in heavens).

7.2 Development of a classification system of motion according to Aristotle

Now the protagonists Aristotle and Galilei can be introduced. They can be presented as two scientists concerning themselves with the problem of classifying and describing motion in nature. A short PowerPoint presented by the teacher might be useful, which includes facts about lives, works and also the *personal details* of both characters. Illustrated picture material can provide a high degree of presentiveness.

At this time, the method of scenic dialogues (Leisen, 1999) (here the fictive conversations between Aristotle and Galilei), which leads through the whole case study like a golden thread, can be introduced. In their conversations, Galilei and Aristotle discuss diverse physical problems and often represent different opinions. The first scenic dialogue [material 2] introduces Aristotle's classification system of motion. This introduces the pupils to the form of dialogue. They identify Aristotle's sorting and classification criteria in the text. For an extra assignment, the pupils could also do research on the Aristotelian lessons about the elements and on what one today refers to as (chemical) element.

In the following, Aristotle's classification criteria are summarized. The pupils are subsequently advised to sort the pictures according to Aristotle's classifications and then to compare them with their own, earlier developed criteria. Thus it can become clear that there are different ways of classifying. A close relation between the pupils' believes and Aristotle's ideas could perhaps be acknowledged. It especially should become obvious that classifying represents a scientific method. References to other scientific concepts of sorting and of classifying (genealogical trees in biology, periodic system of elements in chemistry, classification of elementary particles in physics etc.) suggest themselves.

The reflection corner arises as an appropriate method for reflecting scientific methods.

7.3 Confrontation of Galilei's and Aristotle's views on the problem of motion

This part of the case study is concerned with contrasting the two protagonists' different views on the problem of motion. It shall be understood that Aristotle follows the idea of classifying motions according to their purposes. Contrary to Aristotle, Galilei is interested in the process of motion itself. He therefore studies the course of motion.

The pupils are presented with a second scenic dialogue between Aristotle and Galilei: perspectives on the problem of motion (material 3).

The learners are told to identify the differences between Aristotle's and Galilei's view on different kinds of motions. After that the question why the two scientists cannot understand each other can be resolved. It becomes obvious that Aristotle's ways of thinking and working are very much determined by his teleological worldview. It however also becomes apparent that basic scientific approaches can change in the course of history. The question "what for?" was neither for Galilei nor for his successors an appropriate scientific question anymore.

Referring to pictures, the pupils can again explain the differences between the different approaches to the problem of motion. An alternative exercise could be the video-recording of more phenomena of motion, for example with the mobile phones of the pupils or camcorders and to afterwards interpret them according to Aristotle's or Galilei's perspective (what for? versus how?).

The premises based on the approaches of Aristotle's and Galilei can be pointed out in a reflection corner. The reflection now can be more closely focused on topics such as controversies and arguments among scientists and also on the possibilities of finding scientific truth (see chapter 5.3 -> scientific controversies).

7.4 Studying motion – an egg-race

The egg-race is originally a competition, in which a raw egg has to be transported, e.g with strange flying objects, without breaking it. This competition idea can be used for methodically designing a learning situation introducing the scientific method of optimizing experimental conditions and which leads over to Galilei's method of idealization. The pupils are now asked to study motions in little groups. In the sense of an egg-race, they shall let a piece of plasticine roll down a ramp. The competition is won by the group of pupils whose piece of plasticine rolls furthest. For that, only two experimental conditions are set: the height of the ramp (e.g. 40 cm) and the mass of the piece of plasticine (about 10 g) each group gets. The groups can freely choose the material for the ramp, its design and the form of the piece of plasticine.

In the context of this task, they use this liberty to optimize the experiment conditions according to the assignment. They will form their piece of plasticine into a ball which is as smooth as possible, choose the ramp so that the speed of the ball becomes maximal at the end of the ramp and they will make the rolling track of the ball as frictionless as possible. In this way, they will optimize the experimental conditions. Nevertheless the ball will roll more or less far, however, it will always stop moving.

At the end, the pupils shall tell each other as precisely as possible, which steps they took so that their piece of plasticine rolls as far as possible. Also they can contribute suggestions about what they would have to do to make the ball roll even further, if they had the liberty of changing the experiment conditions freely.

In the reflection corner, the pupils can reflect on their own methods. Here it should become especially clear that experimental methods in science very often require the process of optimization of experimental conditions. Furthermore experiences of school experiments of previous lessons can be contributed here.

7.5 From optimization to idealization

With another scenic dialogue the ideas about idealization and finally about inertia are introduced (material 4). This dialogue is highly related to a part of dialogue in Galilei's *Discorsi*. In the dialogue Galilei conducts a thought experiment to show that a ball has to move in uniform motion, if it is not influenced by friction. It behaves inertly. Every student of physics today knows this idea. From the perspective of our everyday experience however, it is barely believable.

The process of idealization suggested by Galilei is understandable to the pupils after the egg-race and their thereby developed strategies of optimization. After all, Galilei's suggestion is hardly different from what the pupils did themselves by optimizing the conditions in the ball competition, apart from the fact that this kind of optimization cannot be achieved in the real world. In thought experiments, experimental conditions can be changed in unrealistic ways; the phenomena are idealized. The idea of inertia itself, Galilei can only identify with the help of the process of idealization and thought experiment.

After reading the text, the scientific methods of optimization and idealization can be identified and defined. The reflection on nature of science here especially focuses on the status of idealizations and thought experiments (s. chapter. 5.3 -> The role of thought experiments and idealizations). In the context of the idea of idealization, the concept of inertia shall clearly be identified as gain of knowledge.

7.6 Free falling bodies

While for Aristotle the paradigmatic fall of motion is described by a body seeking rest, for Galilei it is the free fall of an uninfluenced body. According to Aristotle's physics, every body falls in its own individual way. Referring to this, a law of falling bodies expressing a proportionality of the rate of fall to the mass and force is revealed. Changes in rate are not considered. Heavy bodies should therefore fall faster than light ones.

Galilei however assumes a uniform law applying to all falling bodies. This is another example for the method of idealization of natural phenomena. After all, one indeed can observe that volume and form of a body have a considerable influence on its falling behavior. Galilei's law of falling bodies strictly speaking only applies, if forces of friction are not considered. The actual acceleration of a free falling body is composed of two terms. Thus, apart from a term for the free fall, it also contains a second term describing the friction of air (Stoke-friction for low rates). Our everyday experiences therefore do not immediately suggest Galilei's view and accordingly pupils (as well as physical layman in general) often favor Aristotle's views.

The topic of free fall can for example be introduced by giving the pupils the chance of presenting and explaining their own preconceptions about the motion of falling first. Impromptu falling experiments with differently shaped bodies can easily clarify that the form of a body is determining its falling time. If one lets a piece of paper fall down, scrunches it up afterwards and lets it fall again from the same height, this fact becomes clear based on the different falling times of the same body.

The different views of the two protagonists are again pointed out in a scenic dialogue (material 5). In the dialogue Galilei uses a thought experiment which today still is presented as extremely convincing by a lot of people: If the falling time of light bodies is higher than the one of heavy ones, then a light body ought to slow down a heavy one while falling, if one ties them together with a string. On the other hand the sum of the mass of the two tied together bodies is higher than the mass of the two separate ones. According to Aristotle, the tied body would have to fall fastest of all. A contradiction is revealed.

This contradiction however only develops, if one acknowledges Galilei's premise that the tied body does not differ from the two separate bodies it consists of, in entirely new qualities. Thus, Aristotle's is not simply convinced by Galilei's argumentation, but questions Galilei's prerequisites at the end of the scenic dialogue.

As an alternative material for efficient learner groups an original text by Galilei could be used (material 6), in which he presents his thought experiment in a contemporary style.

Now the question about whether the pupils are convinced by Galilei's argumentation can be discussed. After all, silk cloths fall considerably slower than for example stones. A light parachute actually slows down the falling motion of a skydiver! Based on this problem the pupils can discuss in small groups and develop a statement saying whether they are convinced of Galilei's idea.

The contradiction between everyday experience and Galilei's thought experiment can eventually only be solved, if it becomes very clear that here again Galilei's method of idealization is of central relevance for his argumentation. While the restraint of motion by friction belongs to the core elements of Aristotle's kinematics, Galilei wants to banish friction from the core area of his law of falling bodies by using idealizations ("*But if there were some accidental cause, such as, for example, the shape of the mobile, it must not be classified amongst the causes per se.*" see material 6).

The role of idealization already became clear in the scenic dialogue about idealization and inertia (material 4). What, however are accidental causes and what are causes per se? Galilei assumes a physical law working behind the phenomena, which only becomes identifiable by idealizaton. The differentiation between accidental and causes per se cannot be revealed by observing falling bodies, but is a result of physical theory development. The Reflection Corner can again support this realization methodically. Here, the very popular experiment with vacuum tubes, in which steel balls and feathers fall with the same rate in an evacuated tube, can underline that Galilei's assumption is superior to Aristotle's, but also that this superiority is only based on a highly optimized (intense vacuum) experiment. Also the topic of the role of thought experiments can be reflected on.

7.7 Experimental exploration of the law of falling bodies as a sequence of numbers

In activity the free fall is studied on an inclined plane. The inclined plane should be about 6 m long (-> historical picture material material 8-a). In our test lessons we worked with a replication of Galilei's original.

Replication of an inclined plane according to Galilei (replica and picture by W. *Engels, Oldenburg group)*

Galilei’s inclined plane is wrapped in silk to minimize friction. Alternatively one can work with aluminum v-profiles available from locksmith’s shops and do-it-yourself stores. It is important that the contact face of the down rolling ball is minimal.

With an inclined plane, the pupils themselves can explore the laws operating with the free fall. In this context also the law of falling bodies itself is introduced. It is however not presented as a formula (s=1/2*g*t2), but as a sequence of numbers (-> chap. 5.3.3). The presentation as sequence of numbers clarifies especially for younger pupils that the matching of mathematics and nature itself is a curiosity, which is indeed questionable. The degree of abstraction of the presentation is kept low. The epistemological problem of matching mathematics and nature is pointed out in this student-centered question:

Can nature count?
The following realizations could be used in class:

1.	The scenic dialogue about Galilei’s measurements with the inclined plane (material 7) serves the pupils as model for their own experiments. After reading the text the content is clarified. Possible assignments for securing the comprehension of time measurement: Describe the principle of time measurement with the water clock in your own words! What are the advantages and disadvantages of measuring with the water clock?

	Is it always necessary to measure times in the common units such as seconds/ minutes/ hours and so on? Possible assignments for securing the comprehension of the inclined plane: Where is the connection between free fall and the motion along the inclined plane? Where lay, according to Galilei, the advantage of this construction?
2.	A contemporary copperplate engraving (material 8-a) presents different perspectives on Galilei's work with the inclined plane: bored prince, scholars consciously turning their backs on the experiments and fully devoting themselves to the old scripts (Peripatetic=devotee of Aristotle's lessons) or possibly scheming courtiers. The artist himself positively stresses Galilei and his participants of discussion. The material is suitable for a contemporary historical classification. An assignment could be to choose a person in the picture and to then describe the situation from his or her point of view. Even without an introduction to the contemporary reception, the picture clarifies that Galilei's methods and ways of thinking were rejected by a lot of his contemporaries.
3.	The pupils develop construction plans for water clocks for the time measurement and then build them (contemporary water clock -> material 8-c). A suitable water clock is characterized by a constant and strong flow of water. This requires an as constant as possible hydrostatic pressure in the water clock. Alternatively, the teacher can prepare water clocks (example: material 8-d).
4.	The pupils develop an experiment plan to reconstruct Galilei's measurements and write the results down (perform measurements several times!). By planning and conducting, they independently close the gap between the theory-driven presentation of the measurements in the dialogue and the real experiment.
5.	After this the measurement results are compared to those of Galilei. Variations are discussed with regard to optimization and idealization (measurement uncertainty, systematic errors caused by friction, systematic errors caused by the rotational energy of the ball.).
6.	Finally a phase of "philosophizing with children" is introduced. In little discussion groups, the pupils develop a preliminary answer to the question about whether nature can count. The teacher regulates and moderates the ideas of the pupils and only comments on them at the

	end (support -> chap. 5.3.3 The role of mathematics in interpreting nature). Possible supporting assignments: Discuss in your group whether mathematization was useful for the evaluation of your experiments with the inclined plane. Discuss in your group whether mathematization is a scientific method. Also take other examples of your physics lessons into consideration. Galilei thought “mathematics to be the language of nature”. What did he mean?
7.	The results of the reflection on the role of mathematics are generalized in the reflecion corner (central key words: mathematization of nature, theory-driven thinking).

Alternatively, an introduction via the experimenting of the pupils can be chosen. The scenic dialogue could then be used as support for the interpretation of the measurement results in one of the following lessons. There is however the danger of asking too much of the pupils by wanting them independently reconstruct Galilei’s experiments. The above presented course of steps and activities has the advantage of making highly structured experimental instructions superfluous. The scenic dialogue motivates pupils to reconstruct a scientific experiment. Unsuitable is the assignment of checking Galilei’s measurement results. This would hardly be a convicing activity for the pupils since Galilei appears to them as a well-know scientist and deviations from his measurments will not be estimated as a honest proof of his results anyhow.

7.8 Astronomical observations and the unity of physics

In chapter 7.3 Galilei’s and Aristotle’s different views of the world order became apparent. For Aristotle there was a fundamental differentiation between laws of motion applying to motion on earth and to the motion of heavenly bodies. A lot of Galilei’s contemporaries held on to this differentiation and thought heavens to be filled with a fifth element (quinta essentia) in which heavens’ bodies could move freely without any friction and continuously along circular paths around the earth. In 1609 Galilei heard of a new instrument, the telescope, for which the Dutch Jan Lipperhey filed a patent. It consisted of a convex lens with a long focal length, a concave ocular with a short focal length and an aperture stop for an increased image sharpness [1]. By using better lenses, Galilei was able to increase the magnification by a factor of nine, later even more. With this instrument he made a lot of astronomical discoveries:

- The surface of the moon has a structure of mountains and craters, which equal those on earth.
- Jupiter is circled by several moons (Galilei discovered the four biggest ones). In that it is similar to the earth.
- Venus has phases like the moon, which could only be explained with its circulation around the sun.
- The sun is not a perfect heavenly body, but has a changing structure of spots.
- The Milky Way consists of separate stars and is no consistent band.

Therein Galilei saw a strong evidence for the Copernican word system. Heavenly objects seemed, according to his observations, a lot less "un-earthly" than Peripatetics (school referring to Aristotle's lessons) argued.

The different world systems are discussed referring to the question about whether a uniform or non-uniform physics (of the earth and the heavens) applies in the context of the new development of the telescope. For that, another scenic dialogue is used (material 9). Apart from that, the pupils can also use replicas of Galilei's telescopes for example to reconstruct Galilei's moon observations[2]. This could for example happen in the context of a "star-observation-night" at school. The quality of the telescopes should not necessarily be very good. Galilei's lenses were, referring to the contemporary standard, quite high-quality, but cannot be compared to the lenses which are industrially produced today. For this reason Aristotle has the possibility to doubt Galilei's observations in the dialogue. The interpretation of the observations as an evidence for the Copernican theory therefore was – like observations in science generally – theory-driven.

Material 11 presents an original text by Galilei to Markus Welser with whom Galilei corresponded about scientific questions. Galilei clarifies that he would not have been able to make his revolutionary astronomical observations without a technical innovation – the telescope.

For the reflection on the nature of science (e.g. for the reflection corner) this paragraph provides the following aspects:

- observations are theory-loaded
- sciences attempting to achieve uniformity
- technical innovations advance science

More suggestions and acitivities:

- Galilei observed the heavenly bodies with the help of a telescope. Get to know what a Galilei telescope is composed of and explain its functional principal with the help of the optical path.
- Identify Galilei's fundamental observations (material 9 and/or material 10).
- Galilei supports the Copernican world view. Explain in how far his observations are suitable to support this world system.
- Galilei writes in his astronomical messanger (material 10) that the discoveries were only possible thanks to the "seeing glass". Discuss in your group in how far the development of new technologies/ research instruments provided/ provide new findings in science in the past and also today. Find other examples referring to science.
- Among other things, Galilei observed the surface of the moon and drew true to detail sketches. Observe the surface of the moon with your replica of Galilei's telescope and draw some sketches yourselves. What difficulties could there have been for Galilei observing the moon, if he had used a comparable telescope? For a comparison also have a look at the surface of the moon through a modern high-quality telescope and point out differences. (As an alternative high-quality pictures of the moon photographed through a telescope could be made available here)
- You can use the following link to get to know more about the construction of Galilei's telescope and Galilei's astronomical research areas:
  http://brunelleschi.imss.fi.it/esplora/cannocchiale/index.html
  Also do the simulation of the moon observation on this website!
- Develop a short argument between a supporter and an opponent of the Copernican worldview. Also take the arguments Galilei drew from his observations into consideration! Present the argument in a role-play!

[1] For the history of the development of the telescope in the context of Galilei's discoveries see Teichmann and Höttecke (2009). Here also the teaching and learning aspects for the reflection on the nature of science are presented.
[2] Simple models of Galilei's telescopes are for example available from http://www.astromedia.de/

8 Obstacles to Teaching and Learning

8.1 Students' preconceptions about inertia

The physical concept of inertia does not correspond to the everyday experiences of pupils. It is not implicitly believable that a body, without excerting any forces on it, behaves inertly and that the direction as well as the absolute value of its velocity do not change. On the contrary, an essential element of the pupils' preconceptions is that a force is considered to be the source of motion. The same holds for motions with constant velocity. Some pupils imagine the force to be like an integrated or imprinted force (momentum, jolt) suggested by the medieval impetus theory. Empirical surveys also confirm that there should be, from a pupil's perspective, a qualitative difference between rest and movement (e.g. Nachtigall, 1986). This conception corresponds with our everyday experiences, contradicts, however, the modern view. Moreover, pupils comprehend inertia as being lame or in the sense of overcoming a barrier. It can also happen that inertia itself is interpreted as a kind of resistance to movement (Jung & Wiesner, 1981). Then the bodily experience of being lame (e.g. in an accelerating car) is interpreted as the action of a force. This however is, from the perspective of non-accelerated systems, physically incorrect.

This case study focuses on the development of the pupils' preconceptions from moved objects to physically correct conceptions. Aristotle explicitly differentiates between the state of rest and the state of motion. By explicitly making the Aristotelian mechanics a topic of discussion in class, points of contacts develop for the pupils' own ways of thinking. With the transition from the Aristotelian to Galilei, a new classification of motion is introduced. Rest and constant movements are now elements of the same group. The two historic characters thus serve to explicate and to develop the pupils' preconceptions further.

8.2 The "reflection corner" – a method for addressing the nature of science explicitly and reflectively

Research has indicated that learning about the nature of science is more efficient if the nature of science is addressed explicitly and reflectively. The "reflection corner" is a method which facilitates and structures the students' reflections about role, function, conditions and properties of science, scientific knowledge, and its production towards general insights about the nature of science.

Learn more about this method...

9 Pedagogical Skills

9.1 Handling of non-predefined results and open-ended activites

The case study comprises several activities whose results are not predefined.

The exercise concerning the classification of motion (chapter 7.1) leads to different results obtained by the pupils. How should a teacher react to this? Surely it would be problematic to declare classifications neither being similar to Galilei's (which would be expected too much of the pupils) nor to Aristotle's (which is possible) classification system as incorrect.

A difference in the quality of the results of the pupils can nevertheless be determined and can then be reported back to them: Are the categories consistent in themselves? Consistency would for example be established if motion were differentiated according to the medium in which they happen and according to their location (in the air, in water, on earth, in space). Inconsistency would for example be established if classifications comprised functional categories mixed with physical ones (e.g. motion for the transportation of something, motion of buoyancy in a medium with low density).

In the egg-race exercise (chapter 7.4), the pupils are assigned with letting a piece of plasticine roll as far as possible after having rolled down an inclined plane. This competition with non-predefined results leads to the idea of optimization. The pupils come to different solutions and results concerning the problem. How does one assess the different results and which kind of feedback should teacher give back? In addition to the success (the piece of plasticine rolls the farthest) also the degree of systematization of the pupil's approach could be used as a feedback category. Have the test parameters been varied randomly or structurally? Have measurement results been recorded thoroughly and have they been compared with the results of others? Have the pupils used their previous knowledge in order to solve a problem?

9.2 Initiating explicit reflections on the nature of science

The moderation of openness also has to be applied in pupil discussions and activities for addressing the nature of science explicitly and reflectively with the reflection corner. Open phases of discussions are, in scientific lessons, less common than for instance in social sciences or humanities. The teacher has the function of moderating contributions of the pupils, to order and to structure them. A graphical representation on the blackboard, in which the teacher clusters several contributions of the pupils according to topics, might help. Only after the graphical representation has been finished, it is judged by the pupils as a whole and thereafter by the teacher. Such methods of moderating open-endedness and student-centeredness shall reduce the role of highly structured teacher-pupil-dialogue, in which pupils often only try to guess what the teacher would like to hear.

Scientific surveys show that knowledge about the nature of science is not simply acquired along the way in otherwise good content-based lessons. This is very unlikely even if the lessons are oriented towards history or philosophy of science. Researchers therefore have recommended to address the nature of science explicitly and reflectivly. Due to this the method of the reflection corner, which is supposed to help the teacher to encourage and moderate the pupils' processes of reflection, has been developed.

9.3 Philosophizing with children

The case study suggests the questions about the relation between mathematics and physical description (chapter 7.7). A lot of physics teachers are lacking philosophical background information here in order to being able to encourage pupils to reflect philosophically and to classify and evaluate their results of discussion. It might help to read texts referring to the topic (e.g. the text by E.P. Wigner und E. Hedrich). An important result of this section of the case study is to successfully encourage pupils to think independently and to be engaged in discussions about the topic. The correctness of their answers regarding the philosophical discussion however is, in comparison to this, less important.

9.4 Handling of scenic dialogues

In literature lessons teachers are used to having pupils recite or also stage scenic dialogues. In physics lessons, however, teachers are not used to such methods. The following procedure is helpful for the evaluation of such scenic dialogues:

- reading with assigned parts
- ensuring initial reading comprehension (What is the dialogue about?)
- individual intensive reading of the text, pupils underline essential passages of the text
- ensuring deeper reading comprehension in a class discussion, teacher poses key questions
- repeated reading of the dialogue with assigned roles (now with a deeper understanding of the text)
- optionally developing a graphical representation on the blackboard with contrasting positions
- subjective judging of the different positions referring to credibility, adequacy and accuracy by the pupils

10 Evaluation and refinement of case study

Parts of this case study have been tested with pupils in junior high school (about 14-15-year old) several times. The results were directly integrated into the design of the materials.

11 Further User Professional Development

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12 Written Ressources

Materials for teaching and learning

material 1	Pictures for the activity "Classification of bodies in motion"
material 2	Scenic dialogue between Aristotle and Galilei: Aristotle’s lessons
material 3	Scenic dialogue between Aristotle and Galilei: Perspectives on the problem of motion
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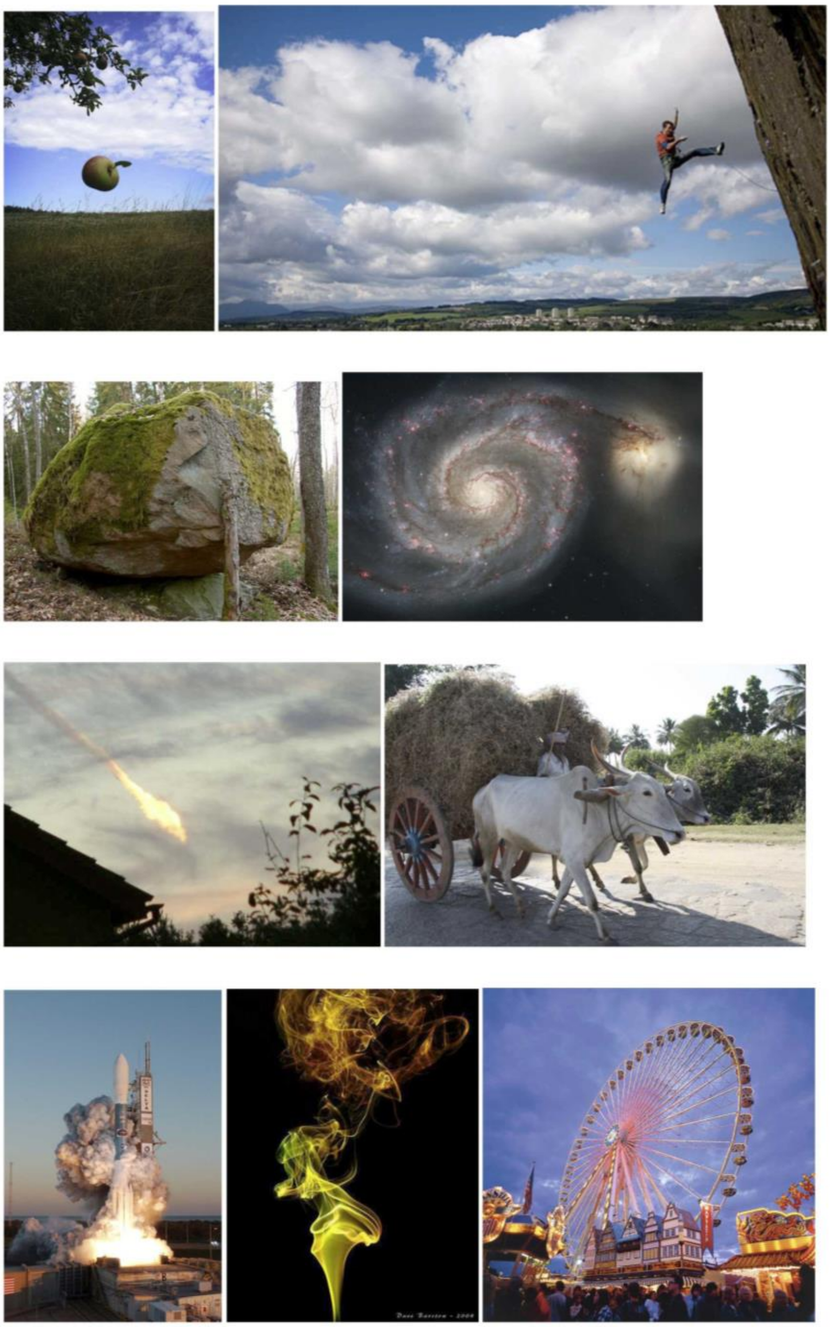
Bewegung - Material 1

Material 1 ist auf dieser Seite im JPG-format und im Download als pdf-Datei erhältlich. Ähnliche Abbildungen wie die hier vorgeschlagenen findet man im Internet oder Zeitschriften.

- **Material 1: Ordnen von Bewegungen / Classification of Bodies in Motion**



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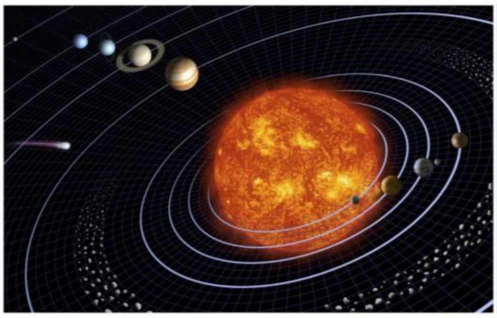
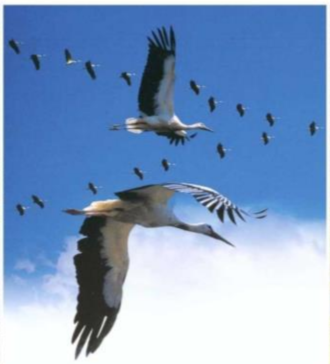




moving bodies - material 2

Scenic dialogue between Aristotle and Galilei: Aristotle's lessons

A: My dear Galileo, you may hardly imagine, how happy I am about being allowed discussing with a scientist such as you are. All hail!

G: The pleasure is mine. All hail! Gladly I will discuss the motion of the bodies of this world. We only know little about it.

A: Now, this is astonishing. After all, I have already written a lot about it a long time ago. Since then a lot of new knowledge has surely been contributed?

G: Surely! However, a lot of which one was sure about then is questioned today.

A: And do I have to fear that among those ideas there are also some of mine?

G: My dear Aristotle, you are a man of science and you know that hardly any idea exists forever.

A: You are right. However, one's own ideas are as important as one's own child. Yet, I do remember: Even in my times there often were discussions among scholars.

G: I think you are alluding to how scientists wanted to order processes in nature?

A: That is it exactly.

How does one order nature? Actually, all humans do it, even though they are no scholars. They order from top to bottom, heavy or light, fast or slow or they order things according to their function. A fork is indeed different from a manure fork. But we scholars order nature according to considerate principles, which have to be reasonable and well thought through. This I have shown then.

G: Up to today a lot of scholars still refer to your famous scientific writings. They want to reproduce your ideas as literally as possible. I, however, in this regard entertain - forgive me – great doubts.

Some have even interpreted your ideas in the wrong way. Even happier I am now to have the opportunity to talk to you in person. Please take a little time and personally present your view on the phenomenon of motion. I want to be sure not to understand your excellent writings in the wrong way.

A: Your thirst for knowledge adulates me. The key to my knowledge, so I want to confide to you, lays primarily in the closeness to nature. On a lot of walks I practiced to experience nature with all my senses.

G: But how were you able to put an order to this manifold world? It seems almost impossible to me to take all details into account at the same time.

A: Not so impatient! I have already said that scholars have to develop certain principals as foundations of every order.

G: Those however want to be well thought through then.

A: Yes, this is what I said.

Only after long considerations I came to the awareness that motions can be ordered according to their purposes. As in nature indeed nothing happens without a purpose. From my observations I drew the conclusion that the natural aim of a lot of motions on earth has to be rest. Reaching this aim actuates every motion of a body and is its cause.

A. *Lets a stone fall down. The stone indicates a state of rest on the floor.*

See for yourself. The stone stays in rest. It has reached its aim of falling to the ground and to rest there.

G: Well yes, I have my doubts here, but more about this later.

Explain to me now, please, how you proceeded with your work!

A: Yes, yes, just a moment. I have not finished yet.

Just think about a stone you push. See for yourself!

A. *pushes the stone. It moves and comes to rest again.*

After a short distance it becomes slower and slower until finally every motion stops and it remains immobile on its position. It is the same with all things. Sooner or later they rest.

G: I understood you so far, but should this have already been all ?

A: No, surely not. Furthermore I asked myself in how far motions differ from each other further.

G: Are you alluding to the differentiation into four kinds of motion?

A: I see, you eagerly studied my lessons. Well done! Indeed motions can be divided into three earthly and one heavenly motion.

G: Can you give me an example of how you used your classification system?

A: Sure, lets begin with the first kind of motion. This happens if a body moves with the aim of resting at its natural place. This I have already shown you with the stone.

G: Do you mean the class of uninfluenced falling and rising bodies?

A: Yes, because heavy bodies strive for the centre of the earth, while light bodies rise towards the heavens to reach their natural place there. As the stone falls to the floor, steam or smoke rises upwards. These motions belong to the first kind of motion.

G: Good, but what about living human beings, plants and animals. What purpose do you assign to their manifold motions?

A: These creatures have their purpose in themselves. They can determine their motions themselves. This makes them special. Therefore this second kind of motion is to be thought of as natural. After all, all living things are creatures of nature.
G (*smirking*): Then I do understand you right that it is a motion of the second kind if a pig approaches the feeding trough? As it indeed has the aim of eating. If the food falls next to the trough, though, you call this motion one of the first kind.

A (*seriously*): You understand me quite well. However, I hope that you do not mock me!
G: I would never do this! But now tell me, what about all those motions, which are not natural?

A: Indeed there are motions which violate a body in its natural rest. For example imagine (*takes a stone and throws it away*) throwing a stone into the air, which before had rested on the farmland. Its natural purpose, its rest on the farmland, is thereby violated.

G: You mean, I force another absolutely unnatural purpose on the stone.

A: Exactly and therefore I call this third kind of motion violent motion. They do not happen of their own volition. A carriage standing on the field has to be pulled by an ox or donkey before it moves. If this external aim ceases, then the carriage stays still.

G: But if I remember correctly you talked about another kind of motion, namely the heavenly one. What differentiates this from the other earthly kinds of motion?

A: Heavenly motion is indeed perfect motion. The planets move eternally without resting. These motions are of a completely different kind than the earthly ones.

G: They do not have a purpose?

A: You are wrong here, because motion in the heavens has a purpose, as well: the eternal motion on a circular paths around the centre, the earth.

G: I see now, how you came to four different kinds of motion referring to their purposes. In this way, every imaginable motion in the universe can be classified indeed! And the heavens seem to be very special to you.

A: It was my aim to classify every motion we can observe. As I have already emphasized at the beginning of my explanations, it is most important to us to find nature's own order, especially because nature seems so confusing.

Also I have already identified that all matter has to be ordered according to the elements earth, fire, water, air and the matter of heavens. I hope that my elements lessons, according to which I have ordered the things in the world, are still valid today.

G: Well yes, lets discuss this another time.

moving bodies - material 3

Scenic dialogue between Aristotle and Galilei: Perspectives on the problem of motion

G: I have thoroughly followed your explanations about the different kinds of motion all the time. However, I do have a question now, which became almost distressing as time passed.

A: Well, shoot then!

G: I do agree with you that motions have a certain cause. There is one thing I do not understand, though: Why do you necessarily see the cause of motion in a bodies' striving for rest?

A (*annoyed*): I have already explained to you that specific criteria are necessary for classifying.

G: You look at a stone, which fell from a mountain, in its end position on the ground?

A: Sure, because his inert purpose is to reach this natural condition of rest.

G: But have you never before looked at the process of motions? Do you not find it interesting to study HOW the stone falls? I ask myself, what happens on the way from the mountain to the ground.

A: I do not understand that thoroughly. Alone it is necessary to know, why the stone moves. As we know that it is a natural motion, the stone will naturally strive for rest, until it achieves it. HOW it does this can never be foretold – THIS is unique for every single body!

G: But one cannot only answer the question about what aim nature tries to reach with motion, though. In my studies I am also concerned with how motions proceed, so with motion itself. You did the same thing with motions in the heavens when you talked about the perfect circular paths of the planets. Here you surely want to know HOW the planets move? But if you observe motion on earth you are not interested in the process of a motion, but only in its purpose? You contradict yourself.

A: Be careful and do not forget that the motion in the heavens, because of its divine perfection, cannot be compared to earthly motion. Human beings can describe only motion in the heavens, as the planets are put on their circular paths by divine influence. I therefore consider your approach as unnecessary work. You might easily loose the essential purpose out of sight. If you stop asking about the purposes then you will not come to true knowledge.

G: Excuse me, dear Aristotle, it seems we are not at odds about the knowledge itself, but rather about the way we practice science.

A: You want to suggest that it would be wrong to practice science the way I have always done it?

G: But no! I can pacify you: The search for a classification system for the phenomena is still very important in science. Only we do not classify motion referring to its purpose anymore.

A: Astonishing!

moving bodies - material 4

Scenic dialogue between Galilei and Aristotle: Idealization and Inertia
(based on original text by Galilei)

Galileo: I would like to do a little thought experiment with you. Thereby you do not have to acknowledge anything you are not really convinced of.

Aristotle: I would never do such a thing!

Galileo: Imagine an even and smooth plane. It could for example be made of glass. It is inclined a little. And now also imagine an absolutely round ball. It for example could be made off metal. Now, if I put the ball on the plane, do you not agree that it should stay still?

G. smirks mischievously.

Aristotle: And the plane is inclined?

Galileo: Certainly, I made the conditions!

Aristotle: Then the ball will certainly not stay still. It rolls down the inclined plane.

Galileo: You are absolutely sure that the ball rolls down?

Aristotle: I am absolutely sure! What a question!

Galileo: I do not want to talk you into something.

Aristotle (*angrily*): I think you want to drive me crazy!

Galileo: Well, this is it. How long and with which speed would the ball continue its motion? Keep in mind that the ball shall be absolutely round and that the plane shall be absolutely smooth. All external and accidental influences we do not consider. We even want to abandon the air working against the ball.

Aristotle: I did understand that. In this case the ball would roll down faster and faster. This is obvious. And the more inclined the glass plane, the faster the ball will become.

Galileo: Lets imagine this the other way around. Imagine, the ball is pushed and then rolls up the glass plane. How long would this motion last for?

Aristotle: The motion would we be forced. If one would not push the ball again and again then the movement would cease. The ball would slow down and finally stay still.

Galileo: Exactly. If one lets the ball roll down, it becomes faster and faster. If one pushes it however, so that it rolls up the glass plane, it becomes slower and slower. What, however, if the plane was neither inclined upwards nor downwards?

Aristotle: Well, the ball does not have a reason for rolling up or a reason for rolling down. Then it should stay in its natural place and rest.

Galileo: This is my opinion, as well, provided that it has not been pushed before. But what would happen if the ball was pushed now?

Aristotle: If the plane is not inclined, then the ball does not have a reason for becoming faster or slower.

Galileo *(loudly)*: Then the ball does not have a reason for staying still, either. How far would the ball roll now?

Aristotle: The ball would roll up to the end of this absolutely smooth plane.

Galileo: If the plane had no end though, then the motion should never end, right?

Aristotle *(contemplating)*: Mmh, that does sound reasonable, but a never-ending motion? No, that is an absurdity! You have got ideas!

moving bodies - material 5

Scenic dialogue between Aristotle and Galilei: Thought experiment about a free fall

A: I admit, dear Galilei, that in some cases the method of idealization can be applied very well, but still I have to ask you, how do you proceed with complex kinds of motion such as the motion of free fall? You want to describe, you have said so before, motion with simple rules. I observed the falling of different bodies countless times. In the process I saw very clearly that heavy objects reach the ground faster than light ones. A heavy rock falls down - you have to admit that – definitely faster than a light silk cloth. I can also explain this with my ideas about causes of motion: the heavier a body the greater its eagerness to reach its natural place – in this case, the ground. As a result it falls faster than lighter bodies. Those do not have such a great eagerness to reach the ground. After all, very light bodies even rise for their natural place is up there. How do you want to find a general rule applying to all of those countless bodies on earth?

G: I am very happy that my words encourage you to further considerations so much. Of course I have read your theories about the motion of falling. However, I have to contradict you in the fact that bodies fall with different rates. For it is very easy in reality: all bodies fall with the same rate.

A: Open your eyes, Galilei! You will immediately see that you are wrong!

G: Again your senses distracted you from the important things. I will give you an understanding of it with the help of a little thought experiment.

A: A thought experiment? Oh, not again!

G: I assure you, you will gain as expressive results as if you had conducted the experiment yourself. Be patient and at the end you will agree. Lets assume there were two bodies of the same material, the bigger one is A, the smaller one B. Lets assume, we let both of them fall from the same height at the same time.

A: I tell you, the heavier body A will reach the ground earlier, just as the stone did. Because of its greater mass it will fall faster than body B, which will behave like a silk cloth.

G: You have always seen it this way, my dear Aristotle, but you are wrong. Lets assume now, we unite body A and B by tieing them together. Then we let them fall down again. Should not, according to our assumption, the unification of both bodies move slower than A, the rock?

A: Mmh! I am not so sure about that, yet.

G: Well, just take it into consideration. According to your opinion a slower body B then would hamper the motion of the faster body A. So, if A and B were tied together, then this unification of both would move slower than A alone.

A: Some strange ideas you have.

G: Now, my dear Aristotle, you will surely agree that, on the other hand, the unification of both bodies A and B is also heavier than A or B alone. So the unification, in which the bodies are tied together, should fall faster than A alone. After all, you said that heavier bodies fall faster than light ones.

A: Oh, I realize the contradiction to the first statement. The unification of both bodies cannot fall faster and slower than A at the same time.

G: You see! That is it. You have to admit that I am right!

A: But you know, dear Galilei, I think that by tieing bodies like A and B together, a completely new body is formed.

G: I tell you, the only solution is that all bodies fall with the same rate! Body A as fast as body B and also as fast as the unification of both bodies A and B.

A: And I stick to it, heavy bodies fall faster than light ones and in your strange thought experiments you assume very bizarre conditions.

moving bodies - material 6

Thought experiment about falling bodies of different weight
(Extraction of Galilei's "*De Motu*")

“Let there be two mobiles of the same species, the larger a, and the smaller b; and, if it can be done, as our adversaries hold, let a be moved more swiftly than b. There are then two mobiles one of which is moved more swiftly than the other; hence, according to what has been presupposed, the combination of the two will be moved more slowly than the part, which alone, was moved more swiftly than the other. If then a and b are combined, the combination will be moved more slowly than a alone: but the combination of a and b is larger than a alone: hence, contrary to our adversaries' view, the larger mobile will be moved more slowly than the smaller; which would certainly be unsuitable. What clearer indication do we require of the falsehood of Aristotle's opinion? But, I ask, who will not recognize the truth of this on the spot, when he examines it in a pure and simple and natural way? For if we presuppose that the mobiles a and b are equal and that they are very near each other, then, by the consensus of all, they will be moved with equal swiftness: and if we understand that while they are being moved, they are joined, why, I ask, will they double the swiftness of their motion, as Aristotle held, or increase it? Accordingly, let it be sufficiently confirmed that there exists no cause, per se, why mobiles of the same species should be moved with unequal speeds, but there certainly is one why they should be moved with equal speed. But if there were some accidental cause, such as, for example, the shape of the mobile, it must not be classified amongst the causes per se: and moreover, the shape helps or hinders the motion but little, as we shall show in the proper place. Also, one must not, as many are in the habit of doing, immediately revert to extremes, by taking, for example, a piece of lead of very large size, and, on the other hand, a tiny blade or a leaf of the same lead, which sometimes will even float on water: for since there is a certain cohesion and (so to speak) a tenacity and a viscosity of the parts of air as well as of water, this cannot be overcome by a very small heaviness. Accordingly, the conclusion must be understood as concerning those mobiles where the heaviness and size of the smaller one is large enough that it is not hindered by that small tenacity of the medium; such as, for example, a leaden ball of one pound. Moreover, as for scoffers of this kind, who perhaps persuade themselves that they can defend Aristotle, what happens to them if they revert to extremes, is this: the greater the difference between the mobiles that they choose, the more they will have to toil. For if they take a mobile that is a thousand times larger than the other, before they show that one surpasses the other a thousand times in speed, it will undoubtedly cost them sweat and toil.

moving bodies - material 7

Scenic dialogue between Aristotle and Galilei about the free fall and the role of mathematics in science

A: We both agree that the free fall is very important to science. However, it is hard to describe. A body has just started falling and yet, this motion ends only seconds later again.

G: You are right and for a long time I had to think about a suitable construction with which I would be able to slow down the free fall without changing the basic principle itself.

A: To slow down the free fall, you say? How, again, does this work?

G: I got the idea of letting a brass ball roll down an inclined plane. The ball rolls down the plane. Actually, it does fall indeed; only more slowly as if I held it up and simply let it fall down.

A: A clever idea. If the plane is only inclined a little bit, then the ball indeed falls very, very slowly. One can observe it falling. However, I see a problem! Is not the resistance the plane sets against the motion of the ball greater than the resistance of air?

G: You are right. This was a big problem for me. Therefore I smoothed all surfaces, as well this of the inclined plane as the one of the brass ball. In this way the ball was hardly slowed down on its way down. I think, I can praise myself of having developed a nearly perfect construction.

A: And how were you able to measure the time? With an hourglass, perhaps?

G: Admittedly, the measurement of time was another difficult problem. With an hourglass I hardly would have been able to make reliable measurements. Therefore I used a water clock.

A: Yes, I heard about this. A really useful invention. One has to have a jar out of which water flows steadily through a little hole. The flowed out water equals the elapsed time during the measurement. If one weighs the water after a measurement, one actually weighs the time. A nice idea!

G: This I think! Finally I came to the conclusion that the ball became faster and faster during its downward motion. I wanted to understand the law of this motion more precisely. First I divided the whole length of the inclined plane into equally sections. With my water clock I then had to measure the time the ball needed to roll down different sections.

A: And, what have you found out?

G: I came to an exact law of the down rolling ball. First the ball rolled down the first section in a certain time unit. For passing through the second section the ball needed less time, after all, it had become faster. In the same time unit the ball had needed for the first section, it now passed through three more sections. I let it roll down further. In a third time unit the ball now passed through another five more and in another time unit seven more sections. The ball got faster and faster and thereby was following an interesting principle: 1-3-5-7 and so on! Magnificent, is it not?

A: But ...

G (*interrupts* A): I tell you, nature is beating the time for the falling ball. 1-3-5-7-9-11! Hah! You do have an idea about how this series continues, don't you?

A: Well...

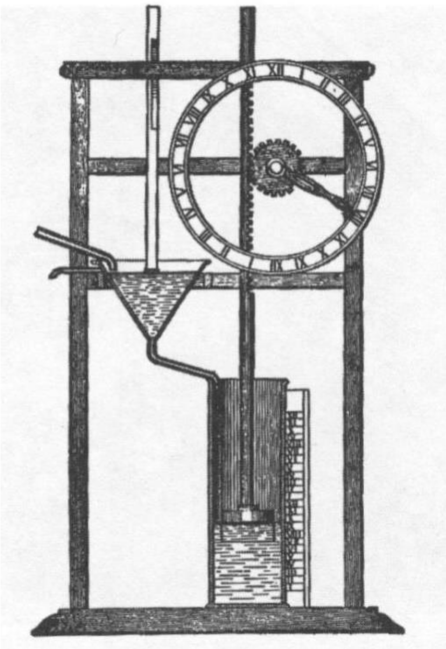
G (*interrupts A. enthusiastically*): Exactly! The odd numbers! I tell you, if a body falls, then it does not fall somehow or other! It follows a clear law!

A: With all due respect, Galileo, your argument is a bit too mathematical for me. So many numbers! I already had to learn from my teacher Platon that mathematics – if one gives it too much attention – only confuses one's mind. And if he had known you, then this only would have confirmed his views. At best mathematics should be an ancillary science. You however want to base a law of nature only on a game of numbers.

G: Your suspicion towards this mathematical description I really cannot share. Rather I am of the opinion that the book of nature is written in the language of mathematics. The letters occurring in it are numbers and geometrical figures. Only this is why nature is understandable for human beings, because they understand the language of mathematics!

A: Oh, I really do hope that this is your personal opinion only. Science surely cannot have developed in this direction.

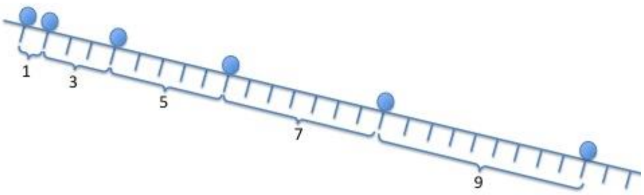
G (*is happy*): I fear, also this time I have to disappoint you.


water clock (Cassidy, D., Holton, G. & Rutherford, James (2002). Understanding Physics. New York: Springer.)

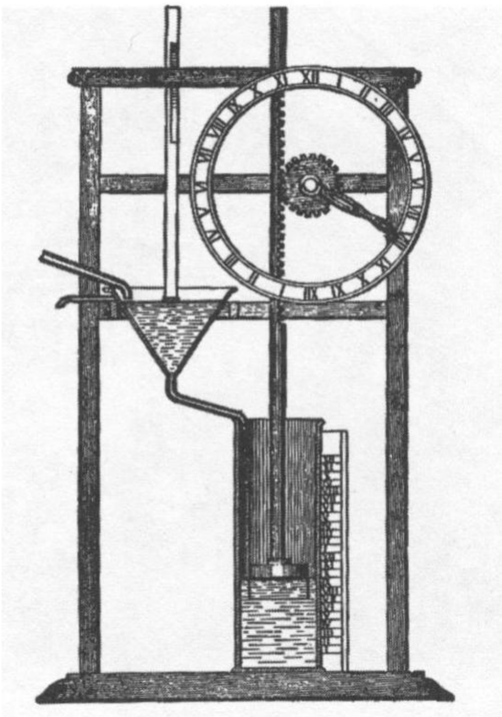
moving bodies - material 8

material 8-a

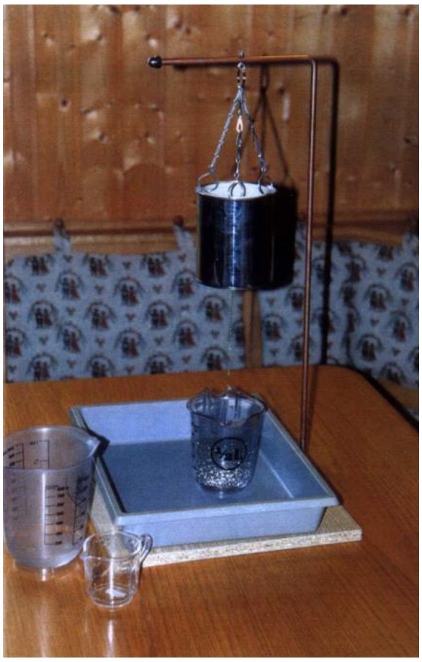
source: http://leifi.physik.uni-muenchen.de/web_ph07_g8/umwelt_technik/07freier_fall/frei_fall.htm



material 8-b: In equally long time units the coped with section tracks add up according to a sequence of numbers consisting of odd numbers.



material 8-c: water clock (Cassidy, D., Holton, G. & Rutherford, James (2002). Understanding Physics. New York: Springer.)



material 8-d: self-built water clock

moving bodies - material 9

Scenic dialogue between Aristotle and Galilei: questions about astronomy and the real system of the world

A: My dear Galileo, several times in the course of our conversation you said that you also had to tell me a lot of news concerning heavenly motions. However, I can hardly imagine that the contemporary scientific community arrogates to doubt the perfection of the heavens.

G: Well…

A: You have to admit that all conceptions we generated about the motions of the stars and planets in the heavens are in perfect union with everything mindeful eyes saw during nightly observations of the firmament.

G: Out of question! I completely agree with you!

A: And? What are those new things of which you want to convince me now? Tell me!

G: Indeed the heavenly bodies move on geometrical circular paths. I myself was able to follow the single motions with my telescope.

A: A telescope? A far-seer? Is this a specific scientific instrument? It delights you to construct devices, which have to help you with your research?

G: You assume rightly. A really great invention. With it you see everything magnified. I may praise myself of improving the magnification one achieves with a telescope in such a way that the view on the heavenly bodies led us to completely new insights. With it a lot of heavenly bodies seem to be so close as if they were not in infinite distance, but right in front of your nose.[1]

A: You make me curious.

G: With this excellently improved instrument I did not only observe the motion, but also the form and surface of particular heavenly bodies.

A: Astonishing. Tell me more, but do not believe I was convinced of the truthfulness of your observations!

G: My dear Aristotle, with the help of this great magnification it became very clear to me that there must be numerous mountains and craters on the surface of the moon which are similar to those on earth.[2] Thus, heavens cannot be so different from earth.

A: So you are sure that you can trust your bizarre instrument more than the tradition of great scientists, the sanity and the power of your senses? What do you presume, Galilei?

G: This is out of the question. I trust this instrument, because it has proven itself. When I had again spent countless hours with mesmerized looking through the telescope, I also realized spots on the surface of the sun.[3]

A (*slightly taunting*): You should have cleaned your telescope, before you looked through it. Surely a delusion or an error of this telescope.

G: Dear Aristotle, I can understand your doubts, because without this instrument these spots are not visible.

A: I thought so!

G: Also my friends, all of them wise in science, did not know at first, what these sunspots could be.

A: I do you a favor and thus will assume that your instrument really works properly and that your sunspots are not the spots of this telescope in reality. Then the spots maybe could be little planets whose existence is hidden from my naked eye because of the endless distance and the brightness of the sun. They pass in front of the sun. So, why should one impute the perfect sun with spots?

G: Indeed this was one of the first possible explanations. But in the course of my studies it became obvious that they were not heavenly bodies, but a part of the surface of the sun itself.

A: Galilei, this is impossible! In heavens there cannot be anything imperfect! (*sharply*) The sun CANNOT have spots.

G: I think you are wrong and with you a lot of my own contemporaries. All observations fit to the Copernican theory according to which the sun is in the centre of the universe and our earth, just like all the other planets, circles around it. Also the sun circles around its own axis. Its spots seem, observed from our point of view, to wander around on the surface of the sun. Lets not be deceived, the sun itself rotates! You have to admit that neither the sun is perfect [4].

A: Even with your great wit, you are still not entitled to doubting divinity and perfection.

G: Many scientists shared your doubts, but it has been shown that the development of the telescope conveys unforeseen possibilities now also helping to smooth over conflicts about the world systems. In former times Copernicus assumed that the earth moved around the sun, while the great majority was of the opinion that earth was the centre.

A: And only the latter I can confirm with conviction.

G: My believe in the old theories is by far not so persistent as yours is. I researched into the theory of Copernicus and used the telescope to study the heavenly motions properly. Countless hours I spent looking through the telescope, until my effort was finally crowned by success. I discovered four more little heavenly bodies, presumably moons, which circle around the bigger heavenly body called Jupiter.

A: No, this cannot be true, because all heavenly bodies circle around the earth. The earth is the centre.

G: Again, I have to disagree decidedly. As I obtained another evidence when I again and again adjusted the telescope numerous weeks to observe the Venus. Without a doubt I realized that the Venus, similar to the moon, first presented its whole round face and then after some time presented itself crescent-shaped.

Looking for a way of describing this I again found a faithful help in mathematics. With its help I determined the time singular heavenly bodies need for completing a circle.

A: As I have clearly told you before, you give mathematics too much attention and you do nut trust your own senses enough. You should be careful of doubting the perfection of the heavens in such a way.

G: I do not understand, why I should be careful of questioning an old theory, as new insight is generated which is not in accordance with the old knowledge.

If the individual moons circle around Jupiter and if Venus, too, is in continuous motion, so I assure you that also the heavens change continuously and that they by no means equal an unchangeable cosmos. After careful consideration I am absolutely convinced: the natural laws of heavens and earth are the same!

A: I have accepted a lot and presented myself open to your bizarre ideas. However, this really is too much! Never your ideas about heavenly motion can be true, for you have built your house on a wrong fundament by mixing up heavenly and earthly things. This must not be! You will never convince me!

Some didactical ideas:

[1] Showing of illustrations of an original telescope of Galilei respectively a replication (Astromedia)

[2] Presentation of a drawing of the moon by Galilei on a transparency with a beamer.

[3] Illustration of sunspots/ moons of Jupiter.

[4] Illustration of sunspots (compare webpage)

moving bodies - material 10

Galileo on his observations of the moon (extraction of his Sidereus Nuncius, about 1600)

"In this short treatise I propose things for inspection and contemplation by every explorer of Nature. Great, I say, because of the excellence of the things themselves, because of their newness, unheard of through the ages, and also because of the instrument with the benefit oh which they make themselves manifest to our sight.

[...]

It is most beautiful and pleasing to the eye to look upon the lunar body, distant from us about sixty terrestrial diameters, from so near as if it were distant by only two of these measures, so that the diameter of the same Moon appears as if it were thirty times, the surface nine-hundred times, and the solid body about twenty-seven thousand times larger than when observed only with the naked eye. Anyone will then understand with the certainty of the senses that the Moon is by no means endowed with a smooth and polished surface, but is rough and uneven and, just as the face of the Earth itself, crowded everywhere with vast prominences, deep chasms, and convolutions.

[...]

But what greatly exceeds all admiration, and what especially impelled us to give notice to all astronomers and philosophers, is this, that we have discovered four wandering stars, known or observed by no one before us. These, like Venus and Mercury around the Sun, have their periods around a certain star notable among the number of known ones, and now precede, now follow, him, never digressing from him beyond certain limits. All these things were discovered and observed a few days ago by means of a glass contrived by me after I had been inspired by divine grace.

Perhaps more excellent things will be discovered in time, either by me or by others, with the help of a similar instrument, the form and construction of which, and the occasion of whose invention, I shall first mention briefly, or then I shall review the history of the observations made by me.

About 10 months ago a rumor came to our ears that a spyglass has been made by a certain Dutchman by means of which visible objects, although far removed from the eye of the observer, were distinctly perceived as though nearby.

[...]
This finally caused me to apply myself totally to investigating the principles and figuring out of the means by which I might arrive at the invention of a similar instrument, which I achieved shortly afterward on the basis of the science of refraction. And first I prepared a lead tube in whose ends I fitted two glasses, both plane on one side while the other side of one was spherically convex and of the other concave. Then, applying my eye to the concave glass, I saw objects satisfactorily large and close. Indeed, they appeared three times closer and nine times larger than when observed with natural vision only.

[...]
Finally, sparing no labor or expense, I progressed so far that I constructed for myself an instrument so excellent that things seen through it appear about a thousand times larger and more than thirty times closer than we observed with the natural faculty only.

[...]
For it is necessary first that they prepare a most accurate glass that shows objects brightly, distinctly, and not veiled by any obscurity, and second that it multiply them at least four hundred times and show them twenty times closer.

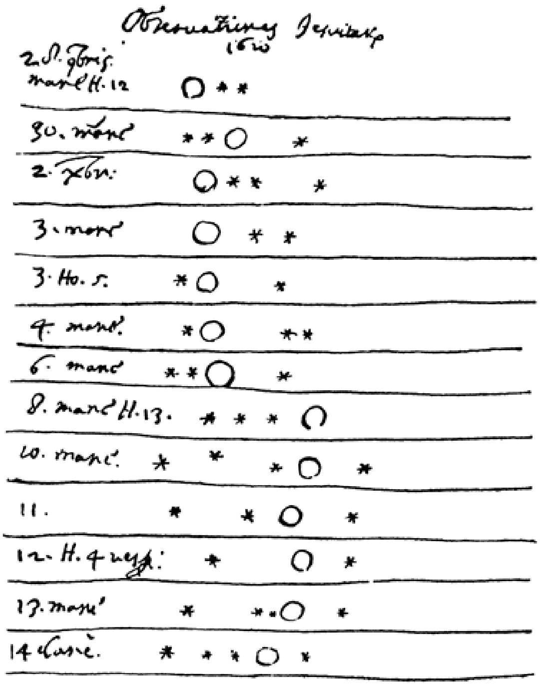
[...]
Let us speak first about the face of the Moon that is turned towards our sight, which, for the sake of easy understanding, I divide into two parts, namely a brighter one and a darker one. The brighter part appears to surround and pervade the entire hemisphere, but the darker part, like some cloud, stains its very face and renders it spotted. Indeed, these darkish and rather large spots are obvious to everyone, and every age has seen them. For this reason we shall call them the large or ancient spots, in contrast with other spots, smaller in size and occurring with such frequency that they besprinkle the entire lunar surface, but especially the brighter part. These were, in fact, observed by no one before us. By oft-repeated observations of

them we have been led to the conclusion that we certainly see the surface of the Moon to be not smooth, even, and perfectly spherical, as the great crowd of philosophers have believed about this and other heavenly bodies, but, on the contrary, to be uneven, rough, and crowded with depressions and bulges. And it is like the face of the Earth itself, which is marked here and there with chains of mountains and depths of valleys.

[...]
For several, as it were, bright excrescences extend beyond the border between light and darkness into the dark part, and on the other hand little dark parts enter into the light. Indeed, a great number of small darkish spots, entirely separated from the dark part, are distributed everywhere over almost the entire region already bathed by the light of the Sun, except, at any rate, for that part affected by the large and ancient spots. We noticed, moreover, that all these small spots just mentioned always agree in this, that they have a dark part on the side toward the Sun while on the side opposite the Sun they are crowned with brighter borders like shining ridges. And we have an almost entirely similar sight on Earth, around sunrise, when the valleys are not yet bathed in light but the surrounding mountains facing the Sun are already seen shining with light. And just as the shadows of the earthly valleys are diminished as the Sun climbs higher, so those lunar spots lose their darkness as the luminous part grows.

[...]
But I sense that many people are affected by great doubt in this matter and are so occupied by the grave difficulty that they are driven to call into doubt the conclusion already explained and confirmed by so many appearances.

Galileo on his observations of the moons of Jupiter



“These are the observations of the four Medicean planets recently, and for this time, discovered by me. From them, although it is not yet possible to calculate their periods, something worthy of notice may at least be said. And first, since they sometimes follow and at other times precede Jupiter by similar intervals, and are very narrow limits, and accompany him equally in retrograde and direct motion, no one can doubt that they complete their revolutions about him while, in the meantime, all together they complete a12-year period about the center of the world. Moreover, they whirl around in unequal circled, which is clearly deduced from the fact that at the greatest separations from Jupiter two planets could never be seen united while, on the other hand, near Jupiter two, three, and occasionally all four planets are found crowded together at the same time. It is further seen that the revolutions of the planets describing smaller circles around Jupiter are faster."

[...]
We have moreover an excellent and splendid argument for taking away the scruples of those who, while tolerating with equanimity the revolution of the planets around the Sun in the Copernican system, are so disturbed by the attendance of one Moon around the Earth while the two together complete the annual orb around the Sun that they conclude that this constitution of the universe must be overthrown as imposible. For here we have only one planet revolving around another while both run through a great circle around the Sun: but our vision offers us four stars wandering around Jupiter like the Moon around the Earth while all together with Jupiter traverse a great circle around the Sun in the space of 12 years.

[...]
The fair reader may expect more about these matters soon."

moving bodies - material 11

Galilei’s letter to Marcus Welser about the role of the telescope for his astronomical discoveries

Galilei’s seeing glass (original from 1609/1610)

Extract from Galileo Galilei’s first letter answering to the preceding letter (4 Mai 1612) about astronomical questions by Mr. Marcus Welser [1]

[…] *And if you are asking yourself now, why Copernicus did not observe especially this* [the phases of Venus, D.H.], *while I did, I just again refer to the fact that I would not have been able to do it without the suitable instrument, either. Nature has not given human beings the perfection of being able to perceive such phenomena. After God was pleased in our days, however, with blessing the human spirit with such a wonderful discovery being able to increase the acuity of our vision, infinite things we had not been able to see due to their distance or because of them being so extraordinarily small, now have become considerably more visible with the help of the telescope.* […]

[1] **Marcus Welser**, also *Marx Welser* (* 10 June 1558 in Augsburg; † 23 June 1614 in Augsburg) was a German historian, publisher and since 1611 mayor of Augsburg.