# Lesson 9

# Astronomy and the Scientific Method II – Kepler's Laws

## Teaching Scenario

### MAIN IDEA

Astronomy has contributed substantially to the development of the sciences and to the development of some of its basic concepts, such as the concept of the scientific law. One such example is the formulation of the laws on planetary motion, also known as Kepler's laws. In this lesson, the students are introduced through Kepler's laws into the concept of the scientific law. More specifically, they learn the process of the discovery, the different forms of formulating and of applying scientific laws which to explain and predict the natural phenomena. The knowledge of the nature and structure of a scientific law is helpful both in the cognitive and meta-cognitive level.

### GENERAL AIM OF THE SCENARIO

The aim of the scenario of the lesson is for the students to learn through the laws of Kepler, the structure and the form of a scientific law, as well as the contribution of Astronomy to the formation of the laws of Physics.



### SCIENTIFIC CONTENT OF THE SCENARIO

The laws of Kepler refer to the motion of the planets around the Sun in our solar system.

1st Law or the Law of Elliptical Orbits: The planets move in elliptical orbits, with the Sun placed on one of the two foci of the ellipse.

2nd Law or the Law of Equal Areas: The line segment joining the Sun and the planet sweeps out equal areas in equal times.

3rd Law or the Harmonic Law: The square of the orbital period of the planets is proportional to the cube of the large semi-axis of its elliptical orbit around the Sun.

As orbital period we define the time interval needed for a planet in order to complete a whole orbit around the Sun.

### IDEAS OF THE STUDENTS

- There is only one scientific method and it always includes a laboratory experiment.
- All scientists perform experiments in a laboratory.



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## A) INSTRUCTIONAL OBJECTIVES

**Knowledge**:

The students, after completing the lesson, will be able to:

- Acknowledge that the scientists develop a theory, a scientific law, a generalization, in order to contribute to the explanation or the prediction of the natural phenomena.
- Know the structure and the form (verbal or mathematical) of a scientific law.
- Formulate the laws of Kepler.
- Adopt the view that a scientific discovery might not include laboratory experiments.

**Skills**:

The students, after completing the lesson, will be able to:

- Infer the laws of Kepler based on data taken from simulations/ images.
- Apply the laws of Kepler.
- Be able to construct an ellipse with simple materials (paper, styrofoam, drawing pin, pencil or chalk on the school yard).

**Attitudes**:

The students, after completing the lesson, will be able to:

- Cooperate in groups.
- Develop a positive attitude towards science.
- Develop a positive attitude towards the STEM specialties.



## B) TEACHING MEANS AND MATERIALS

- Video projector.
- P/C.
- Internet connection.
- Simulation.
- Experimental setting.
- Construction materials.
- Power point presentation.
- Work sheet of the student.
- Evaluation sheet of the student.

## C) TEACHING METHODOLOGY

We suggest the specific teaching proposal (Inquiry-based learning) based on the following theoretical assumptions:

A. The new knowledge is constructed by the student and is not transmitted by the teacher. The already existing knowledge plays a significant role for the learning of the students. Based on the social dimension of knowledge, learning is conducted through social interaction.



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B. The teaching is structured from the specific to the abstract, or from the partial to the general.

C. The use of analogies in teaching connects the already existing knowledge of the student with the new knowledge.

D. The cooperation between the students in small groups facilitates their social interaction and their learning, especially in what concerns difficult cognitive goals.

E. The teaching of aims relevant to science is preferably to be conducted in a direct manner, where each stage of the scientific methodology is presented and evaluated distinctly.

As it has been pointed out (Egger, 2009a, Egger 2009b), the teaching about the scientific procedures can be based on the following ideas:

a. To make the scientific procedures explicit instead of implicit to the students.
b. To use storytelling.
c. To use real data

In the present teaching scenario, the scientific procedures are explicit. In our teaching approach we use simulations and images and also real data. Also, activities of constructivist teaching are included, such as the promotion of the ideas of the students by asserting their own hypotheses, and the meta-cognitive activity of the comparison between the hypotheses and the conclusions of the students. The teaching scenario also includes an activity which aims to connect the object of astronomy, and more general, science and engineering, with the labour market.



F. The instructional procedure followed is in accordance with the inquiry-based learning method that includes the following steps:

- The phenomena
- Questions by the students
- Questions of the lesson
- Answers/Hypotheses
- Experimentation (data from simulations and images)
- Conclusion
- Comparison between the initial hypotheses and the final conclusions of the students.
- Generalization



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- Extension/Application.

**Open-Structured Inquiry**

The inquiry-based method of learning-teaching may be determined either as a non-structured or open inquiry, or as a structured inquiry. The subject (teacher or student), who determines the procedure and the activities, also determines the type of the inquiry method. According to the open inquiry method the student is the one who determines the phenomena of study, the questions, the procedure, the conclusions. According to the structured inquiry the teacher is the one who determines the majority of the teaching variables, whilst the students participate in the procedure and reach conclusions, which are then used in order to answer the questions (Bunterm et al., 2014).

The proposed method of teaching is a combination of open inquiry and structured inquiry. The activities up to the point of the questions posed by the students are the beginning of an open inquiry procedure, while the rest of the teaching course follows the lines of structured inquiry.

## D) CREATION OF THE EVALUATION TEST

The evaluation test was developed according to the following principles:

- The questions correspond to the teaching aims.
- There were used questions of many forms (of objective and open type), which correspond to the teaching aims (Kassotakis, 2010).
- The students answer to the attitude questions with a "yes" or "no"[1].

## E) SCENARIO DURATION

Two teaching hours - about 90 minutes in total.

## F) STAGES OF THE TEACHING APPROACH

**Introduction-Framework of the lesson (2 minutes)**

The aims and the course of the lesson are announced, and the students are called to formulate their own questions based on the storytelling, the images and the simulation. The students are divided into working groups of 4-5 students. The worksheet is distributed to each group.

[1] The analysis of the attitude questions can be performed either by the classic Item Response Theory (Türk, 2015) or by the modern corresponding theory (Tang, 2016). The teachers can find many more similar questions in the paper by Chapman, Catala, Mauduit, Govender και Louw-Potgieter (2015) "Monitoring and evaluating astronomy outreach programmes".



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**Activity 1: Story Telling (7 minutes)**

The video with the story telling is presented, in order to induce questions by the students. The projection of the storytelling video is optional since it has been projected in lesson 8 as well.

**STORYTELLING**

Humans counted the passing of time with the succession of day and night, with the succession of the seasons, with the motion of the celestial bodies. So, they developed calendars that followed the Sun and the Moon during the whole year, in order to arrange the movements of their flocks, the sowing of their grains. Humans always traveled the seas, always plowed and sowed the ground. But, they knew, that all this had to be done at the right moment, the right time. For this reason, time was deified in their minds, and they explained everything they could not explain otherwise, with Saturn, whom he considered to be the regulator of life and death, of the rebirth of nature and humans. They looked at the sky, and he, always with his eternal wisdom, showed them signs. Therefore, when humans saw the Hyades shining in the celestial canopy, he understood that autumn, with its beneficial rains was coming. But, when the Pleiades were moving slowly across the sky, then he understood that this was the right time for the “ploes”, the travels. Humans looked always at the sky, and liked to watching the stars. They watched them rising and setting always in the same order, the same regularity; the only difference being, that these creatures lived in the sky, just as they were living on Earth. But immortal creatures, since they were always there. They liked to connect the stars with imaginary lines and create forms of heroes and gods. They made stories about them. So, when they saw three stars in a row always running behind a cluster of seven stars, they said, it cannot be, these three stars must be the belt of a glorious hunter, Orion, who runs to catch Pleione, his beloved one. As the years were passing, the mythological representation of the world and of the motion of the planets is abandoned, with the dawning of philosophical inquiry. The laws for the motion of the Sun and the Moon, of the planets, that were postulated with satisfactory accuracy by the philosophers of the ancient world, place the foundations of scientific thought. As in our days, where we make telescopes, space-crafts, so in those days they constructed scientific instruments for the study of the sky. Twenty-two centuries ago, the Antikythera Mechanism is constructed, an instrument that summarized the whole of the scientific astronomical thought of that era. It could determine the places of the Sun, the phases of the Moon, it could predict the time of the eclipses and of the Olympic games. The Universe as it was conceived then was depicted on its front; with the planets, the Sun, the Moon, in their complex dance on the celestial canopy. But, as Aristotle said, the desire to study, to observe, to learn, is in the nature of man





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This is why our exploration of the celestial canopy, our effort to solve all the mysteries and the enigmas it hides, continue perpetually. But, which is this primordial force that drives us to discover all these mysteries, to solve all these enigmas?

It is perhaps, as the astrophysicists say, "because we are truly made out of stardust" ?

**Activity 2: The phenomena (1 minute)**

The teacher projects images related to scientists and scientific laws.

**Activity 3: Questions of the students (2 minutes)**

The students are guided in order to pose their questions about the story telling and the images, and write them down on the work sheet.

**Activity 4: Questions of the lesson-teacher (3 minutes)**

The teacher presents the questions of the lesson.

1. Which is the structure and the form of a scientific law?
2. Does a scientific discovery always include a laboratory experiment?
3. Which are the laws of Kepler?
4. How can I construct an ellipse with simple materials?
5. How could Kepler infer the equal areas law?
6. How can I apply the laws of Kepler?



**Activity 5: Answers-hypotheses of the students (5 minutes)**

The students write their answers to the above questions on the worksheet, without any guidance from the teacher.

**Activity 6.1: Slide projection (2 minutes)**

The students, based on the slides, conclude that the scientists try to formulate laws and theories.

**Activity 6.2: Which is the form of a scientific law?**

The students, based on the slides, conclude that laws and theories can be formulated verbally or mathematically.

**Activity 7: The discovery of the laws of Kepler (the phenomena and the questions for the students) (5 minutes).**

The teacher presents through the use of a simulation[2] the motions of the planets and asks the students to pose their own questions. The teacher indicates the stage of the scientific procedure (discovery, formulation, application).

[2] http://astro.unl.edu/classaction/animations/renaissance/kepler.html



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**Activity 8: The discovery of the laws of Kepler (questions of the lesson) (2 minutes)**

The teacher presents the questions about the laws of Kepler:

- Which is the form of planetary orbits?
- Which is the relation between the time of the orbital motion of a planet and the area swept out by the radius connecting the planet and the Sun?
- Which is the relation between the orbital period of a planet and the major semi-axis of its elliptical orbit around the Sun?

**Activity 9: Discovery of the laws of Kepler (hypotheses-answers of the students) (3 minutes)**

The students write down teacher on the work sheet their hypotheses/ answers to the above questions without any aid from the teacher.

**Activity 10: Discovery/Formulation of the laws of Kepler (20 minutes)**

The students, based on the simulation of the above activity, infer:

1. The three laws of Kepler:
   a. About the planetary trajectories, by showing the trajectories of different planets.
   b. About the areas.
   c. About the orbital periods.

The conclusions are expected to be qualitative. Then, the mathematical formulation of the law is presented.

2. The form and the structure of a scientific law.

3. The scientific procedures.

**Activity 11: Construction of an ellipse with simple materials (10 minutes)**

The students work in groups and construct an ellipse with simple materials [3]. The procedure followed, under the guidance of the teacher, is shown in the presentation, as well as on the worksheet of the lesson.

Construction materials:

- Thick cardboard[4] 35x50 cm.
- Push pins.

[3] The relevant video with the drawing of the ellipse can be shown, or the teacher can draw the ellipse on the blackboard (https://www.youtube.com/watch?v=0maahsJQOJE).

[4] We propose the use of white cardboard.



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- Scissors or cutter.
- String.
- Pencil
- Marker.
- Ruler of at least 50 cm, or tape measure.
- Gnomon

Steps of the construction:

Step 1: The students draw with a pencil, the gnomon and the ruler the perpendicular bisector of the linear segment between the two small sides of the orthogonal cardboard.

Step 2: The students place the first of the push pins in a distance between 5 to 6 cm from one of the ends of the perpendicular bisector, and the second push pin in a distance of about 35 cm from the first, on the perpendicular bisector.



Step 3: The students cut with the scissors a piece of the rope-not an elastic rope- of about 1m, and tie with a knot its two ends. They place the string as shown in Image 1, in order to cover both of the foci of the ellipse ($E_1$ and $E_2$), as given by the two push pins.

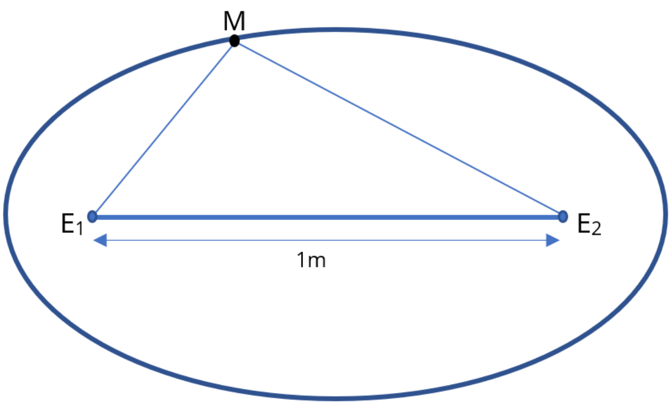


Image 1: Drawing the ellipse.



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Step 4: The students draw with the marker the ellipse by using the rope, making sure that the string is stretched and forming a triangle with its vertices given by the two push pins ($E_1$ and $E_2$) and the end of the marker (M). As we move the marker, the ellipse is drawn. We pay attention, so that the tip of the marker stays always perpendicular to the cardboard.

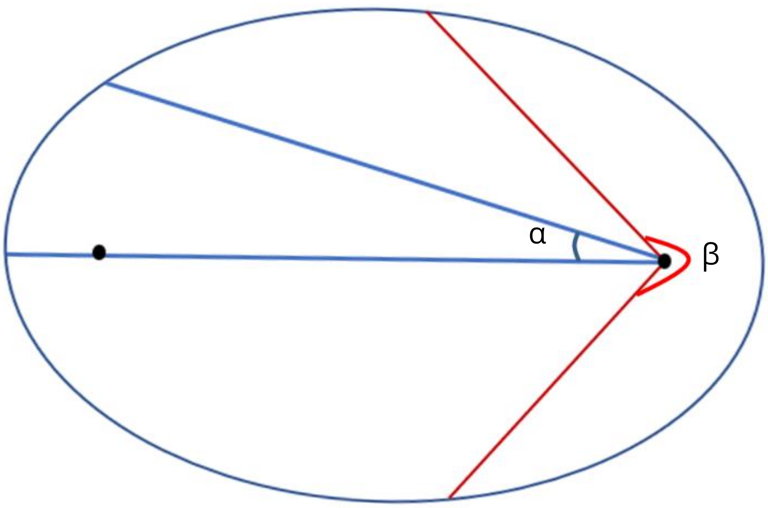
**Activity 12: Investigation of the 6th question. How did Kepler conclude the equality between the different areas? (10 minutes)**

<u>Materials:</u>

- The ellipse drawn in activity 11.
- Two wooden sticks about half a meter long.
- Protractor.
- About 90 marbles of a diameter of 1.5 cm.

The students are asked to draw two areas (A and B) in the ellipse drawn of the preceding activity, as shown in Image 2. The acute angle measures 18° and the obtuse angle measures 265°. Then, they are asked to find which is the largest area, and to justify their answer by using the marbles[5].






[5] Relevant activity in the web address: http://www.esa.int/Education/Teach_with_Rosetta/Marble-ous_ellipses_-_speed_and_time_of_orbiting_bodies_Teach_with_space_P02



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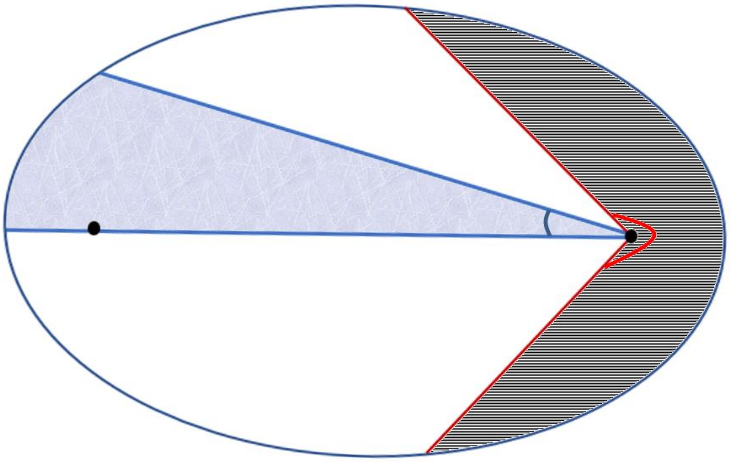

Image 2: Calculating the areas

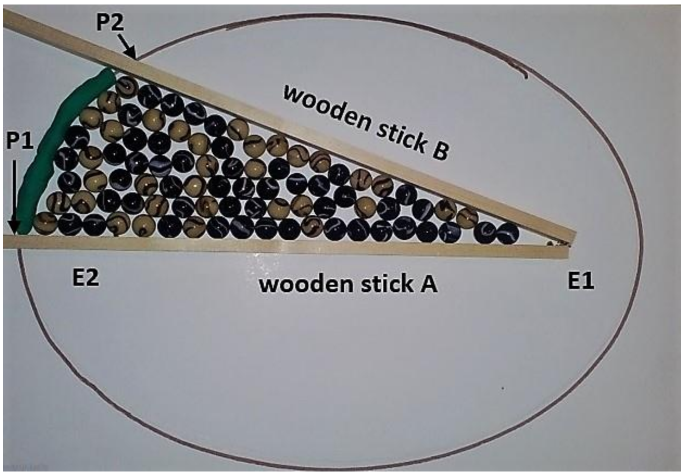


Image 3: Simulation of the movement of the planets in our solar system

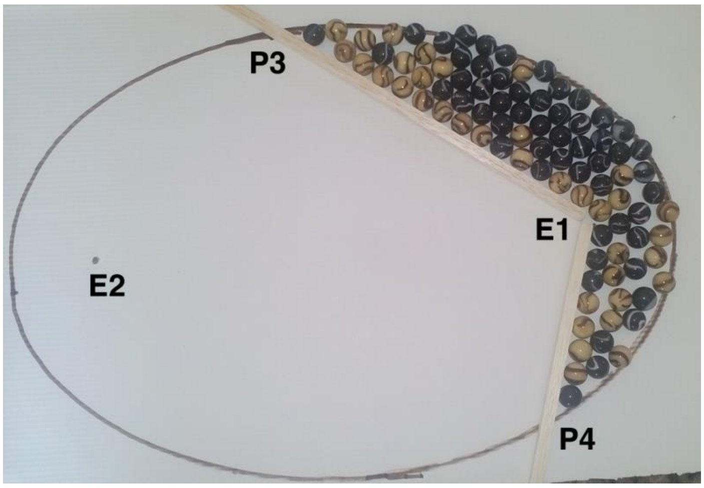


Image 4



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### Activity 13: Conclusions.

The students fill in the gaps in the following sentences:

- The final goal of science is the discovery …………. and ……………….
- 1st law of Kepler: ………………………………………………………………………………
- 2nd law of Kepler: ………………………………………………………………………………
- 3rd law of Kepler: ………………………………………………………………………………

…………………………………………………………………………………………………………

The formulation of a scientific law is done ………………………………………………………

### Activity 14: Comparison between the final conclusions and the initial answers of the students (2 minutes)

The students, divided in groups, compare their initial answers with the final conclusions.

### Activity 15: Application of the conclusions (7 minutes)

The students answer to questions related to the application of their conclusions.

### Activity 16: Connection of the lesson with vocational guidance (10 minutes)

In this specific activity the students are asked to propose a solution to a problem related with STEM professional specialties[6]. Each group presents its proposals to the rest of the classroom.

### Activity 17: Evaluation (7 minutes)

The students answer to the questions of the evaluation sheet.

## REFERENCES


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6 STEM specialties: for example, physicist, chemist, biologist, technologist, mechanician, mathematician.



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5. Kassotakis, M. (2010). *The Evaluation of the performance of the students: Means-Methods-Problems-Perspectives*, Editions Grigoris, Athens (in Greek).

6. Tang, X. (2016). Rasch analysis of responses to the Colorado learning attitudes about science survey. *Master Thesis*. Texas State University. Department of Physics.

7. Türk, C. (2015). Astronomy Attitude Scale: Development, validity and reliability. *Journal of Studies in Education*, Vol. 5(4): 23–50. http://doi.org/10.5296/jse.v5i4.8134



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