These resources have the goal of supporting secondary science teachers interested in Inquiry-Based-Science-Education in creating in their classrooms learning communities where students play an active role. They focus on supporting the development of competency in using evidence and the related skills of argumentation.

MIND THE GAP PROJECT
FUNDED BY THE EUROPEAN UNION, 7TH FRAMEWORK PROGRAMME (FP7)

RESOURCES FOR INTRODUCING ARGUMENTATION AND THE USE OF EVIDENCE IN SCIENCE CLASSROOMS

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Fins Eirexas Santamaría
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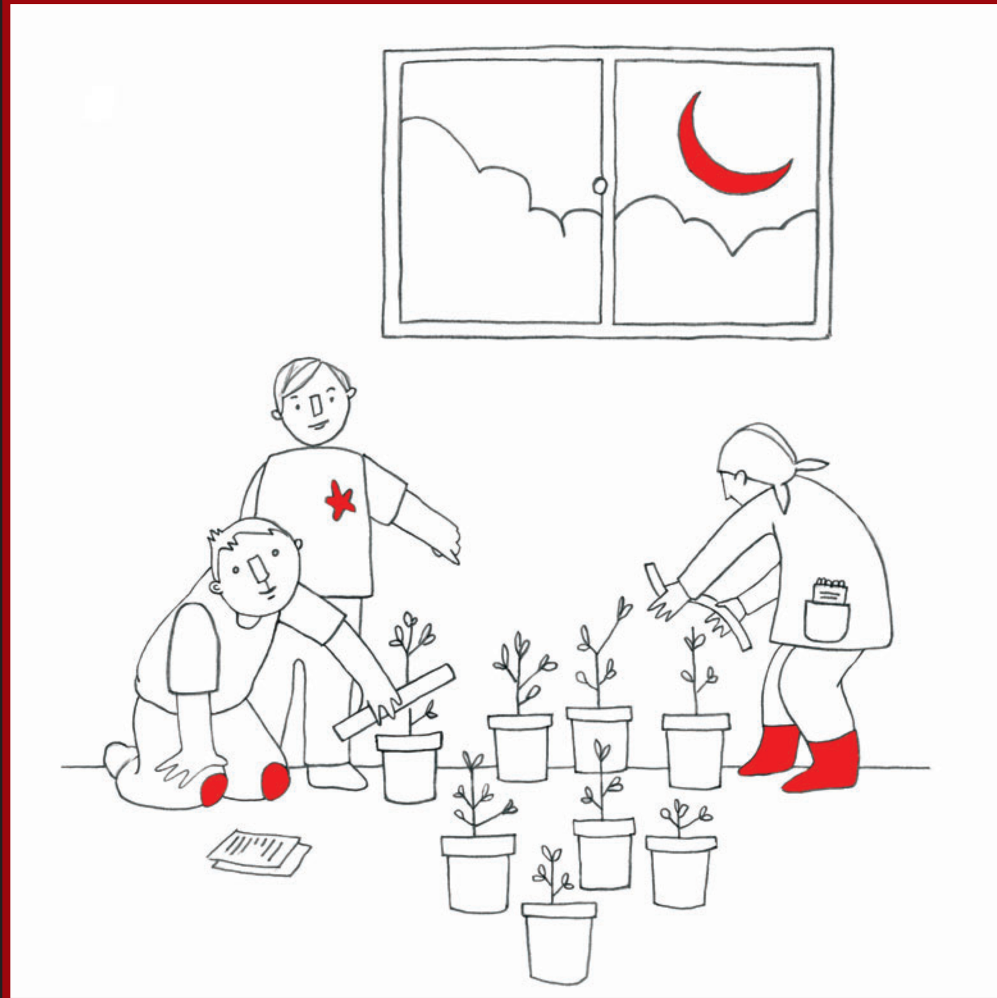

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Artwork: Andrea López

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TEAM AND CONTRIBUTORS TO MIND THE GAP-USC AND RODA

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Mind the Gap team at the University of Santiago de Compostela

María Pilar Jiménez-Aleixandre
Juan Ramón Gallástegui Otero
Fins Eirexas Santamaría
Blanca Puig Mauriz

RODA project (ReasOning, Discourse and Argumentation) at USC

Joaquín Díaz de Bustamante
Ramón López Rodríguez
Víctor Álvarez Pérez
Miguel Bernal Gómez
Beatriz Bravo Torija
Marta Federico Agraso
Cristina Pereiro Muñoz
Carlos Reigosa Castro

Secondary school teacher contributors to Mind the Gap

Ramón Cid Manzano, Sar Secondary School, Santiago de Compostela
Manuel Cid Fernández, David Buján Secondary School, Cambre
Luis Fernández López, Carlos Casares Secondary School, Viana do Bolo
Xulio Gutiérrez Roger, Francisco Barreras Secondary School, A Pobra do Caramiñal
Luis Jar Pereira, Laxeiro Secondary School, Lalín
Xabier Prado Orbán, Pedra da Auga Secondary School, Ponteareas
Antonio Rivas Menéndez, Pontepedriña Secondary School, Santiago de Compostela
Lois Rodríguez Calvo, Fraga do Eume Secondary School, Pontedeume
Adela Vázquez Vázquez, Pontepedriña Secondary School, Santiago de Compostela

9th Grade Students from the Carlos Casares Secondary School (Viana do Bolo), authors of the inquiry-based project about the moon's effect on plants, chapter 6

Adrián Bembibre Maza
Álvaro Bermúdez Yánez
Ruben Pérez Salgado
Iván Vázquez Gómez

These resources have as a goal to support secondary science teachers interested in Inquiry-Based-Science-Education (European Commission, 2007) in creating in their classrooms learning communities where students play an active role.

The particular focus is on supporting the development of competency in using evidence and of the related argumentation skills. Argumentation and the use of evidence are receiving increasing attention both from teachers and from science education research (Erduran & Jiménez-Aleixandre, 2008). Interest in scientific competencies has been increasing since 2006, when the European Union suggested a set of basic competencies that should be used as the central core of learning. Consequently the development of competencies is being translated to policy documents throughout the European Union.

Scientific competencies, which are part of this set, have been emphasized in the PISA framework since 1999. Three scientific competencies are given priority in PISA (OECD, 2006, p 29); these include the abilities to:

– Identify scientific issues and questions that could lend themselves to answers based on scientific evidence.

– Explain or predict phenomena by applying appropriate knowledge of science.

– Use scientific evidence to draw and communicate conclusions, and to identify the assumptions, evidence and reasoning behind conclusions.

However, despite this emphasis both on curriculum documents and in the PISA framework, sometimes it is not easy for teachers to translate these policy orientations to the classroom, to design classroom environments from an IBSE perspective, or to implement learning tasks that promote the development of the capacity to use evidence to evaluate knowledge. In this booklet we propose some “worked-out examples” of tasks involving the use of evidence, which can be adapted by teachers or used as a model for designing their own activities.

The examples form part of teaching sequences on topics from the secondary school science curricula, for we believe that argumentation tasks are more useful when integrated into the science content. Some of these examples were designed as part of the *Mind the Gap* project, and others were tested in classrooms as part of the RODA (Reasoning, Discourse, Argumentation) project, based at the University of Santiago de Compostela, which studies the development of argumentation and scientific competencies in adolescence.

Our work is framed in the constructivist IBSE perspective mentioned above: engaging students in solving problems, in carrying out inquiry projects in the classroom and in knowledge construction. Engaging in inquiry through carrying out small investigations implies not only designing and performing laboratory or field experiences, but also comparing different explanations about a phenomenon, evaluating them in the light of the available evidence, formulating hypotheses, writing reports and communicating with others about scientific issues.

These resources are published thanks to the funding of the European Union, through the 7th Framework Programme (FP7), Science in Society, as part of the project "*Mind the Gap: Learning, Teaching, Research and Policy in Inquiry-Based Science Education*" code SIS-CT-2008-217725, directed by Doris Jorde from the University of Oslo. The goal of the project is to establish connections among research in science education in Europe –that shows the benefits of an inquiry-based focus – and science classrooms, where sometimes the dissemination of these results takes time. Within this project the team from the USC participates in the argumentation and communication work package.

Besides the printed editions (in Galician, Spanish and English), the booklet can be downloaded as a pdf file from the project website:

www.rodausc.eu

All chapters, except 7 (references), follow a common structure: introduction for teachers (identified as I1 in chapter 1, I2 in 2 etc.), classroom activities (A1, A2 etc.) and comments about the activity (C1, C2 etc.). Chapter 4 is drawn from a teaching sequence; chapters 3, 5 and 6 present tasks that could form part of teaching sequences, whereas 1 and 2 provide shorter exercises that can be used to introduce the use of evidence. For the structure of chapter 2 we were inspired by the resources from the IDEAS project (Osborne et al., 2004), carried out by a team of which Sibel Erduran was part. Sibel Erduran is also a member of the argumentation work package in Mind the Gap, together with the University of Santiago and the University of Lyon.

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I1

1.- WHAT ARE THE COMPONENTS OF AN EXPLANATION SUPPORTED BY EVIDENCE?

What is the use of evidence? An important role is to support or to refute a scientific explanation. An instance could be the origin of mountains. For many years there was no satisfactory explanation. The contraction produced by the cooling of the Earth, which were said to produce folds such as the ones that appear in an apple skin when drying, does not explain why in some areas the mountains were higher than in others, nor how it was possible that the more recent ones (Himalaya, Alps, Andes, Pyrenees) were so high when at the time of their formation the earth had already partially cooled. The theory of plate tectonics gave a different explanation: the mountains were caused by the phenomena produced at the plate borders, an explanation nowadays supported by strong evidence.

For the purpose of promoting the use of evidence in the classroom, the most important consideration is to design tasks and activities that require an active role from students. It is not indispensable for them to know the structure of an explanation supported by evidence. However, the models proposed by Stephen Toulmin could be useful for distinguishing, for instance, data from justifications.

In Toulmin's scheme, an argument, or in other words the result of coordinating an explanation with the evidence supporting it, has three essential components:

– **Claim**: the statement that has to be supported or disproved (explanations seeking to interpret natural phenomena constitute a special sort of claim).

– **Evidence** (**data** for Toulmin): observations, facts or experiments that are used to evaluate a claim. In this book we will use both evidence and data.

– **Justification**: a statement that relates the explanation with the evidence.

There are three other components that we could consider auxiliary:

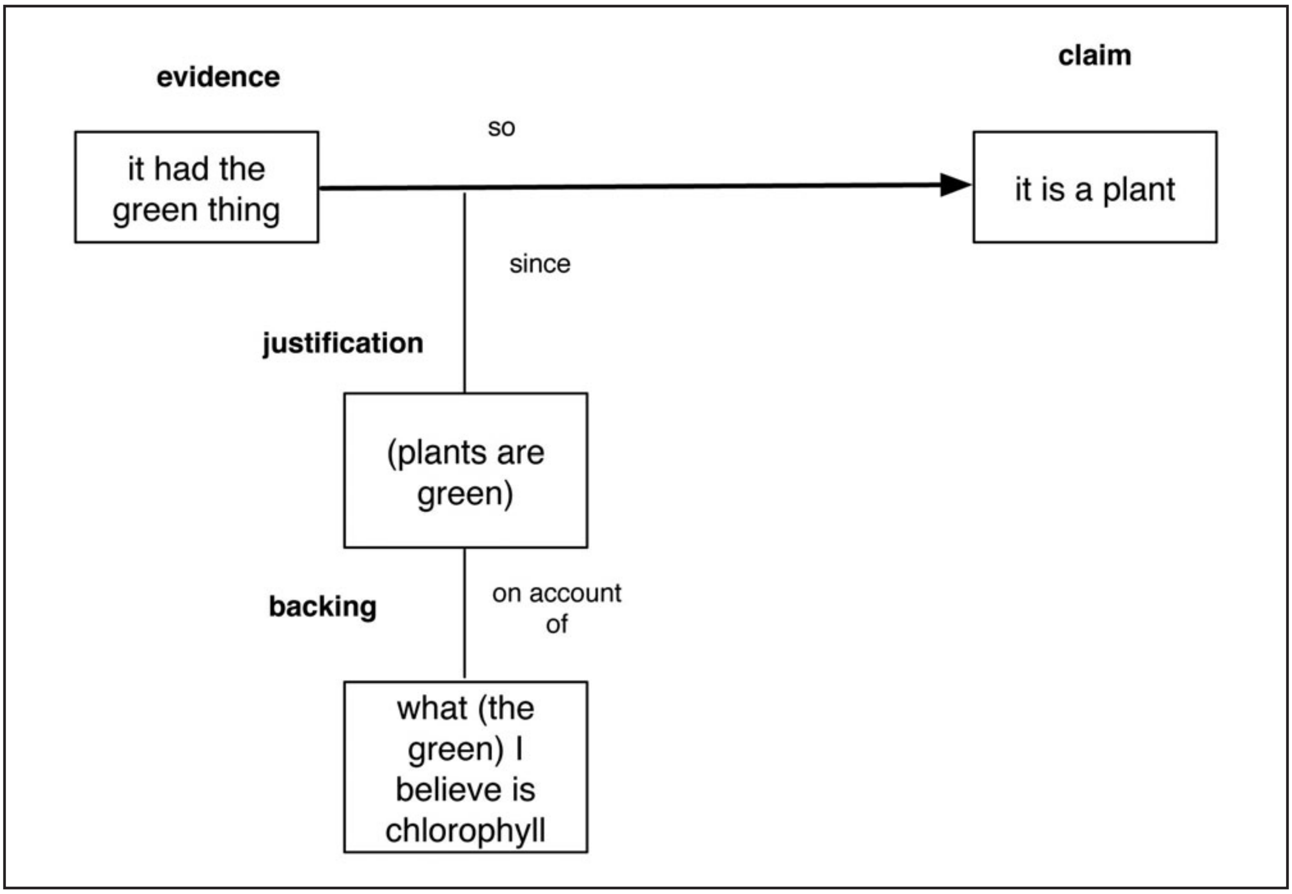
– **Background knowledge**: supports the justification, appealing, for instance, to theories.

– **Modal qualifiers**: express the grade of certainty or uncertainty of an argument, for instance "probably", "for sure", "it depends".

– Rebuttal: for Toulmin, acknowledges the restrictions or exceptions to a claim. However, nowadays in debates that create a confrontation between two opposite explanations, a rebuttal means to criticize the evidence of the opponent.

I1

One instance of an argument represented in Toulmin´s scheme is drawn from the work of Joaquín Díaz de Bustamante: four 9th grade students are presented with the task "the tracks of the thief" (Jiménez-Aleixandre, Díaz & Duschl, 1999), and they have to identify what type of tissue (among four options) corresponds to the sample that they observe through the microscope.



Argument about the type of tissue

In this argument we represent the students' utterances without brackets, and the implicit elements in their reasoning within brackets. Our interpretation is that for Fabri (names are pseudonyms) the observation of green elements in the sample is evidence of it being from a plant, not from an animal. We interpret that the connection between this claim and the evidence is established through an implicit justification: there are many plants that are green in colour. This justification is well-known to the speakers, so perhaps they do not feel compelled to state it, and it allows them to conclude, from the observation of something green, that this is plant tissue. Then Fabri states that he believes that the green thing is chlorophyll. This represents an instance of background knowledge supporting the justification and strengthening it: plants are green due to chlorophyll.

A condition for rebuttal could be potentially opposed to this argument: unless the green colour is due to staining, for instance with methyl green. In fact the green things were parenchyma chloroplasts, and based on this argument, the students were able to identify it.

A1

Choosing a claim in light of the data: nutrients in snacks

Choose the *claim* that you think is best supported by the *data* showed in the table, corresponding to information provided on a snack label. The claim makes reference to the nutritional components (energy, body building or protective) in the food.

carbohydrates	fats	proteins	sodium	others (such as colourings)
60,5	28	5	0,8	3

Nutritional composition per 100 g in corn snacks

A. The snacks contain all the necessary nutrients and are a suitable food.

B. Body building nutrients, such as proteins, and protective ones, such as vitamins and mineral salts, are scant in these snacks.

C. There are little energy nutrients (fats) and more would be needed.

D. In order to be a complete food, more vitamins (protective nutrients) should be added.

Building an explanation from data: free fall of objects

Adriana and Carlos are measuring how long it takes for three objects to reach the floor after we let them fall. The objects are: 1) an eraser, mass 20 g; 2) a sheet of paper (mass 5 g) crumpled until it has a volume similar to that of the eraser, and 3) a sheet of paper without crumpling.

After letting the objects fall, they find that the eraser and the crumpled sheet reach the floor at the same time, whereas the unfolded sheet takes longer.

Build an *explanation* that you find appropriate for this experience using one or more of the following: (or others that you think appropriate):

A. There is some mistake in this experience, because the eraser should land first.

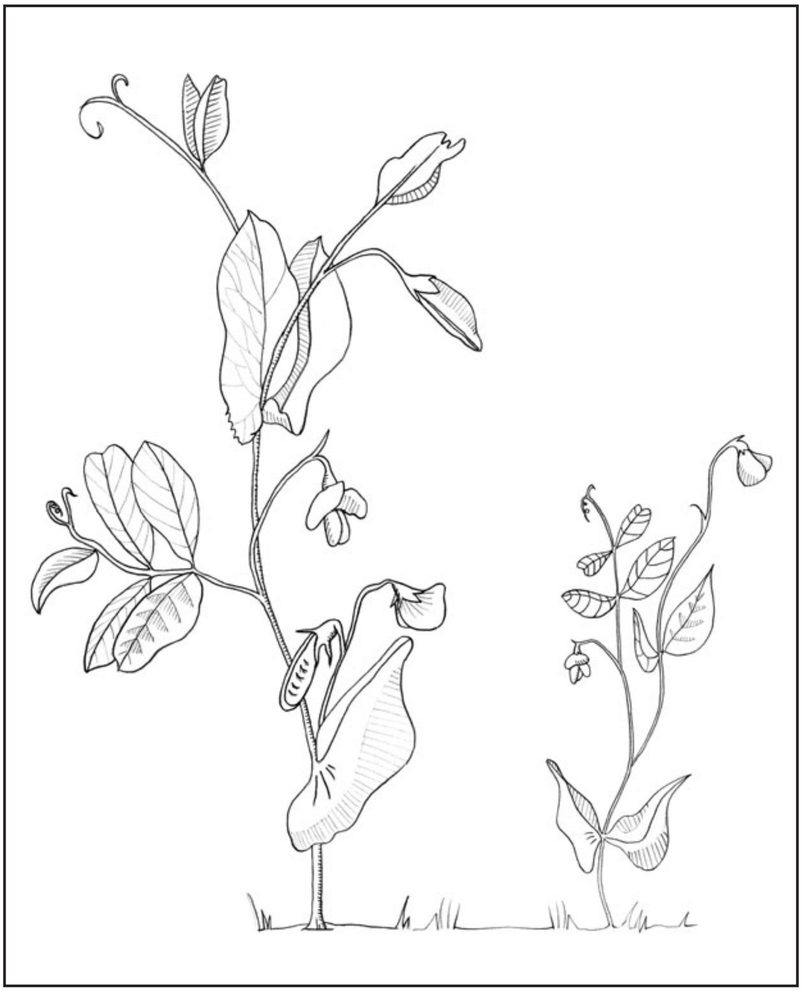
B. The mass does not influence the fall speed, which depends on gravity.

C. The fall speed is greater when the mass is greater.

D. The unfolded sheet takes longer because having more surface area causes it to encounter more air resistance.

A1

Constructing a prediction: the height of peas



Tall and short pea plants

Plant height was one of the seven traits that Mendel studied in peas. In this case tall (we represent the allele as *A*) is dominant over short (we represent the allele as *a*). This means that the phenotype "tall plant" corresponds to both genotypes AA and Aa, whereas the phenotype "short plant" has the aa genotype.

If we cross two tall pea plants that are heterozygous for this gene (Aa), how would the offspring look? Chose the prediction (a, b, c) that you think is more probable from the first column, and link it with its corresponding justification (x, y, z) from the second column.

How would the offspring be if we cross two short pea plants?

OFFSPRING PREDICTION	BECAUSE	**JUSTIFICATION**
a. All the plants will be tall		x. Each gamete carries only one allele (A or a) that can combine in different ways in the zygote
b. Approximately one half will be tall and the other half short		y. Only the dominant allele gets expressed (A)
c. Approximately 3/4 will be tall and 1/4 will be short		z. Because the parents are heterozygous (Aa), half of the descendants carry one form and the other half carry another form

C1

We suggest carrying out these activities as part of teaching sequences because they demand the articulation of concepts and the use of evidence. Regarding competency in the use of evidence, the instances provide different options with the purpose of introducing students to the development of this competency; however, they could be used as well as open questions. We need to keep in mind that the construction of justifications requires a sound conceptual understanding, being sometimes difficult.

Commentary on the activity: Choosing a conclusion in light of the data

In our experience, some of the students tend to ignore or minimize the role of body-building nutrients. They focus on the energy nutrients and to a lesser extent on the protective ones. This explains why, when the question is open-ended, they provide answers similar to A and D. In terms of the use of evidence, this means that they do not pay attention to the meaning of data contradicting their claim, in this case, the low proportion of proteins (in a balanced diet this should represent about 10 to 15%).

Some of the students identify energy nutrients only with fats and not with carbohydrates, which explains the choice of C. In order to support the work with data, such as the table, we suggest asking them to take into account the ingredients from the five columns and to point out the type of nutrients. This requires that the students not ignore any of them. Comparing these data with the proportions in a balanced diet supports the construction of justifications for B, completing the argument.

Comment on the activity: Building an explanation from data

Students are asked to elaborate an explanation (combining B + D) and not just choose one option. The fall of weights is an instance of the discrepancies between alternative views and the school science view. According to science all objects free fall with the same speed, because they experience the same acceleration. In daily life we can observe differences between the fall of leaves and that of fruits from trees, which are attributed to the mass. The intuitive idea that relates more mass to higher speed extrapolates this idea, which is difficult to change. Confronted with data that challenge this idea, some of the students (and the general public) may question the data (A, even though is rarely selected, is interesting to discuss) or consider the discrepant facts to be "anomalous" rather than abandon the alternative explanation, so they choose C.

The ability to choose evidence involves an interaction between pre-existing ideas and reasoning. What is obvious for teachers, that the first two objects reach the ground at the same time, is not interpreted by students in the same way. This provides an opportunity to discuss how data interpretation depends on our theories. According to school science, the eraser and the crumpled paper fall as they should (B), and the unfolded sheet needs additional explanations such as air resistance (D). According to the students' alternative theory, the eraser and the unfolded sheet fall as they should, and only the crumpled paper needs additional explanations.

We suggest carrying out this experiment in the class. There are other options such as using balls in proportions of 1 to 5 or 1 to 10 and observing that the fall time is practically the same. Galilee proposed to compare the fall of a chicken egg with a marble egg. We can compare the fall of a horizontally placed sheet with a vertically placed one to emphasize the effect of air resistance, or place the sheet on top of a folder and observe that they fall together.

Commentary on the activity: constructing a prediction

A trait different from colour and shape, which appear frequently in textbooks, was selected in order to avoid rote-memory answers.

The *data* are provided in the text: tall/short dominance and the fact that both parents are hybrids. Besides the school science answer, only two alternatives are presented, as these cover the majority of answers. The problems with constructing predictions are related to a lack of comprehension of the chromosome (and allele) splitting process in the gametes, and the variety of combinations that can be produced (represented for instance in the Punnett table).

The justifications were constructed in such a way that each one is compatible (to a certain extent) with a prediction: a-y, b-z and c-x. It is possible to evaluate the capacity to articulate a prediction (equivalent here to the claim), because there are students who may choose a or b, options inappropriate from the school science perspective, but relate them to the corresponding justification.

It has to be noted that the plant height can be also influenced by environmental factors: nutrients, the climate in a given moment, the amount of water (from rain or irrigation), etc. This is an example of gene-environment interaction in the phenotype.

I2

2.- HOW DO WE KNOW WHAT WE KNOW? IDENTIFYING EVIDENCE

Science knowledge claims are different from mere opinions, because they are subjected to an evaluation process, being continually measured against the available evidence (Jiménez-Aleixandre, 2008). This does not mean that scientific knowledge is built through a series of fixed steps, although we can say that it is an attempt to answer an unsolved question, and therefore that it originates in a question. For instance, in the case of evolution theory, how did so many different species of living beings emerge? The natural selection model of Darwin and Wallace answers a second question: what is the mechanism through which new species originate from previous ones? In some cases the answer is built as an explanation of observations of natural phenomena; in others a hypothesis is elaborated and experiments are designed to check it. Explanations and evidence interact and are modified as a result of the interaction. In all cases evidence or data are interpreted through the lens of theories, being neither neutral nor totally "objective". Theoretical explanations change, sometimes because new evidence emerges and sometimes because new theories explain the observation better than the previous ones.

In order to promote the development of students' competency in the use of evidence, it is necessary to conduct tasks concerning the evidence supporting selected knowledge claims in the classroom.

In this chapter some examples are proposed in a task inspired by the resources of the project IDEAS (Osborne et al. 2004), which explores the evidential basis for scientific ideas (in Toulmin's terms among the data and the claim) and the justifications that relate evidence and claims. It is not always easy to differentiate between evidence and justification. For instance, sometimes they are embedded in a single statement. For students, connecting evidence and claims may not be too difficult, but many justifications require a deep understanding of the science topic. For that reason, we propose to carry out the tasks about evidence identification with secondary school students, leaving the tasks about justifications for teacher development or for Baccalaureate.

A 2

How do we know that...?

In the left column there are some ideas that we study in science:

– Try to write in the middle column the *evidence* that you know for each one of them.

– Once you have written the evidence, choose three claims and try to write a *justification* of how the evidence supports the idea.

IDEA (KNOWLEDGE CLAIM)	EVIDENCE	JUSTIFICATION
1. Living beings evolve through time: current species come from previous species		
2. Living beings are made of cells		
3. The energy flow in an ecosystem decreases from one trophic level to the next, with a 90% “loss” at each level		
4. Mass is conserved in chemical reactions		
5. Oxygen is necessary for combustion reactions and for the formation of oxides		
6. There is no change of temperature (in pure substances) during a change of state (for instance from liquid to gas)		
7. Sound needs a medium (solid, liquid or gas) for transmission		
8. The Earth rotates around its own axis, causing days and nights		
9. The extinction of dinosaurs was probably caused by the impact of an asteroid		
10. The Earth is about 4550 million years old		

C2

In general, it is harder for the students (and even for teachers) to suggest justifications than evidence. Some evidence and justifications are provided as examples.

KNOWLEDGE CLAIMS	EVIDENCE	JUSTIFICATION
1. Living beings evolve through time: current species come from previous species	Fossil record: existence of organisms with traits of "common ancestors", e.g. dinosaurs with feathers	Confirms the prediction of the existence of transitional forms, which share traits of two or more current groups
2. Living beings are made of cells	Empirical observation through a microscope of cells in the epidermis of ferns; cheek cells.	All animal and plant tissues are composed of cells
3. The energy flow in an ecosystem decreases from one trophic level to the next, with a 90% "loss" at each level	Decrease of biomass across levels (pyramids): proportions of producers, herbivores, carnivores and secondary carnivores	The lower amount of biomass (stored chemical E) in the higher levels shows that most E is used in respiration and maintenance

Claim 1: Evolution

This claim refers to the origin of species, not to the mechanism of natural selection. The evidence most frequently offered by students is paleontological (Puig & Jiménez, 2009). The theory of evolution is an historical explanation, and part of the evidence takes the form of *confirmation of predictions.* An example would be the existence of common ancestors of organisms that, according to the theory, are related, such as birds and reptiles (the ancestors are dinosaurs). Fossils such as Archaeopteryx, which shares characteristics of dinosaurs and birds, show that they had common ancestors. Other evidence might include vestigial organs (such as the appendix), which are only explicable if we consider that in our ancestors they had some role.

Claim 2: Cellular organization

Being made of cells is one of the features that characterize living beings, however there are studies demonstrating that this definition is not applied by some students to certain parts of living beings, such as teeth or shells. It should be noted that the definition raises a problem in the case of viruses, which have no cellular organization but use the cellular machinery of other organisms. Evidence in this case may be empirical, in the form of observation of tissues through the microscope, and the justification is theoretical. We suggest using the fern *Polypodium vulgare*, common on old walls or on the bases of trees throughout Europe.

C2

Claim 3: Energy flow

This idea is necessary, for instance, to understand why the number of links in a food chain is limited, or why it is more efficient eat plants or herbivores than carnivores, issues which can present difficulties (Bravo & Jimenez, 2009). The data consist of the different amounts of biomass in the trophic levels, and the justification connects the data about biomass (chemical energy stored in organic matter) with the statement on energy. Background knowledge, such as the principle of conservation of energy, is also relevant.

KNOWLEDGE CLAIMS	EVIDENCE	JUSTIFICATION
4. Mass is conserved in chemical reactions	Empirical: reaction $Pb(NO_3)_2 + 2\ KI \rightarrow 2KNO_3 + PbI_2\downarrow$ demonstrating that there is no variation of mass	Reagents and products have the same atoms and therefore the same mass
5. Oxygen is necessary for combustion reactions and in the formation of oxides	– Flames are extinguished in closed containers – Oxidation (or not) of iron nails in different media	In both reactions products are combinations of the oxygen atom with other atoms

Claim 4: Conservation of mass in chemical reactions

The evidence is empirical: measuring the mass before and after the reaction. The conservation of mass is easily accepted in liquid phase reactions, but not so easily when phase changes occur, especially if gases appear or disappear. For students from 12 to 14 years old (7th and 8th grade), we propose measuring the mass of a precipitation reaction, for instance

$Pb(NO_3)_2 + 2\ KI \rightarrow 2KNO_3 + PbI_2\downarrow$. When students see that a solid substance is produced, they may think that there is a mass increase, which is refuted by the scales.

The conservation of mass in reactions involving gases, such as the formation of rust on iron or in combustion, is more difficult to test in a school laboratory. For students from 14 to 16 years old (9th and 10th grades), we propose making a prediction based on the conservation of mass and verifying that it is confirmed with the reaction $CaCO_3 + 2\ HCl \rightarrow CaCl_2 + CO_2$, on a scale. We will measure an apparent loss of mass of 0.44 g (CO_2) per 1.00 g of $CaCO_3$, as predicted by calculations based on conservation. However, for students the fact that a blown-up balloon weighs more than an empty balloon does not necessarily justify that the gas inside has some weight. Alternative ideas may create interference with the evidence. In our experience burning magnesium, as proposed in many texts, presents some problems.

C2

Claim 5: The role of oxygen in combustion and in oxide formation

The necessity of oxygen for burning is usually taught in primary school, but there are students who believe that some substances burn "by themselves". We can test the necessity of oxygen for combustion by measuring the time it takes for a candle to be extinguished after covering it with containers of different volumes. As the products both of combustion and of oxidation are combinations of the oxygen atom with other atoms, the conservation of atoms requires the presence of oxygen in reagents.

For iron oxidation a good proposal is discussed in Mortimer & Scott (2003): each student places an iron nail under the conditions that they consider appropriate for rusting. After three weeks the nails are brought to the class and compared. In a second phase students design an experiment for examining the role of air, water and light in the iron oxidation, demonstrating, for instance, that iron does not rust if you remove the oxygen dissolved in water.

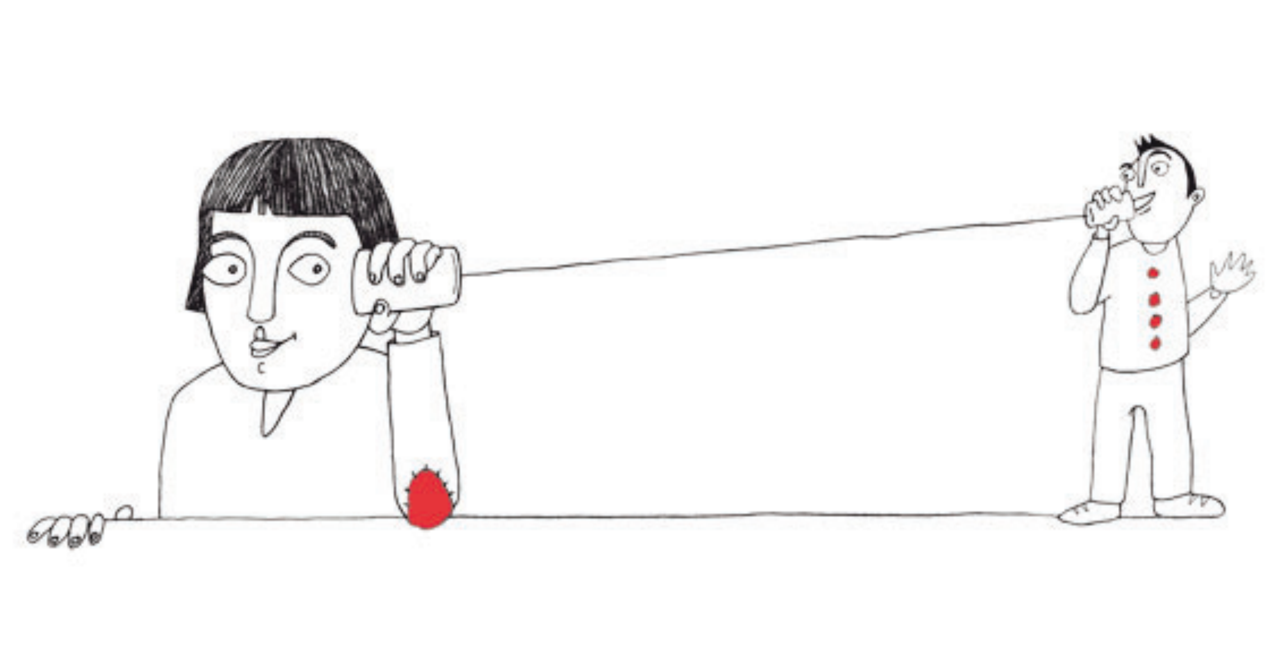
KNOWLEDGE CLAIMS	EVIDENCE	JUSTIFICATION
6. There is no change of temperature (in pure substances) during a change of state (for instance from liquid to gas)	Empiric: Measuring the temperature of water while it boils	Changes of state require energy. Once boiling temperature is reached, all the energy is invested in the change of state
7. Sound needs a medium (solid, liquid or gas) for transmission	– Empiric: a string telephone with two plastic cups and a string – When a vacuum is produced we cannot hear any sound	We hear because sound travels through the string (or through other media, such as the air)

Claim 6: Defined temperatures for a change of state

The property of having a defined temperature during a change of state is used as a criterion to distinguish between pure substances and mixtures. Students can measure the temperature of water while heating it and construct a graph with the temperature data over time. If it is possible to use a heat source that can be regulated, students can check that the boiling point will not rise even when the power is increased: the water boils with more intensity but at the same temperature. The justification is that a change of state requires energy. Once boiling temperature is reached, all the energy is invested in the change of state.

C2

Claim 7: Sound needs a medium for its transmission



In daily life sound is usually transmitted through air. The students may build a telephone with a string (that must be tight) and two plastic cups, thus verifying that sound is also transmitted through solids, a science activity students tend to find enjoyable.

If the school laboratory has a vacuum jar where we can place a ringing bell, they can check the prediction that sound cannot be heard when the air is removed with a vacuum pump. The War of the Galaxies would have been very quiet!

It may be interesting to discuss other claims from physics (or from other sciences) about which there is no empirical evidence appropriate for secondary school, for instance that electric current is a flow of electrons.

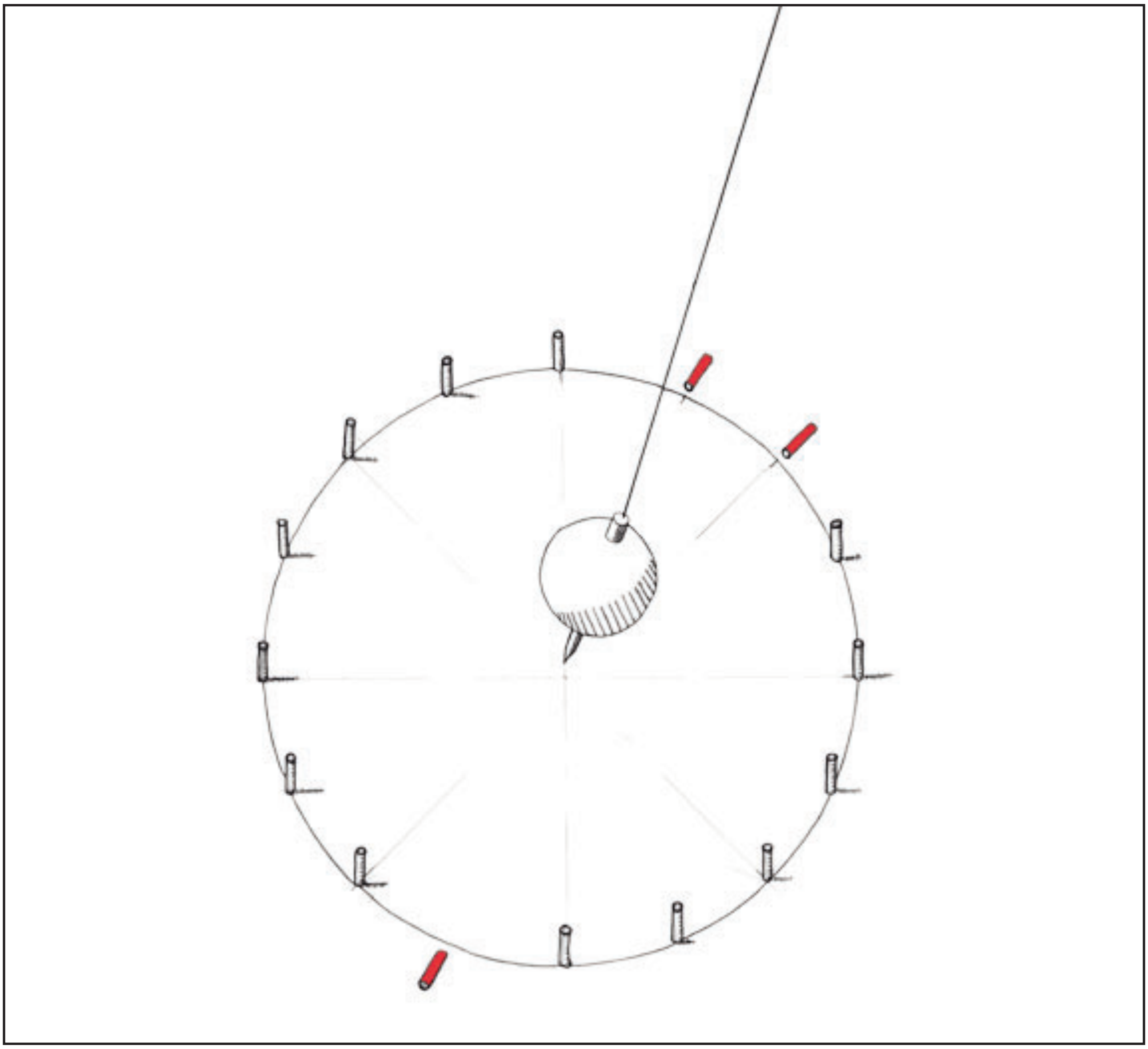
KNOWLEDGE CLAIM	EVIDENCE	JUSTIFICATIONS
8. The Earth rotates around its own axis, causing days and nights	Foucault's pendulum: the pendulum's plane of oscillation appears to rotate	The plane of oscillation does not move, it must be the Earth rotating beneath it
9. The extinction of dinosaurs was probably caused by the impact of an asteroid	Iridium concentration at the Cretaceous-Tertiary (K-T) boundary around the world	Iridium is a rare metal in the earth's crust, while common in some asteroids
10. The Earth is about 4550 million years old	Radiometric dating: amount of some radioactive isotopes	Constant rate of decay of some isotopes and their proportion in the rocks' components

C2

Claim 8: The Earth rotates around its own axis

We may say that no one doubts this claim, but it is difficult for students to suggest evidence. Foucault's pendulum, housed in the Paris Panthéon and now replicated in Science Museums around the world, is the classic piece of evidence. Its plane of oscillation appears to move, but as we know that the oscillation plane is still, this rotation must be explained by the fact that the Earth is turning below the pendulum. Some of the devices have a circle of beams that are placed in its trajectory by the spinning Earth, making them fall.

The interpretation of this experiment is not intuitive for students, since the observation seems to show something completely different: we observe the apparent movement of the pendulum, making the beams fall down. In order to establish a connection between data (observation of the phenomenon) and claim (the Earth rotates), a prior knowledge of pendulum laws is required. Therefore, it would be interesting to carry out prior demonstrations with the pendulum. Another piece of evidence may be the Hafele-Keating experiment: aircraft flying eastwards and westwards with clocks aboard.



C2

Claim 9: The extinction of dinosaurs was due to the impact of an asteroid

This is an example of how the discovery of new evidence can shed light on the debate among competing theories, in this case about the extinction of dinosaurs (and other organisms). In 1980 Alvarez and his team reported high concentration of iridium in sedimentary layers at the Cretaceous-Tertiary (K-T) boundary around the world. As iridium is an extremely rare element in the Earth's crust but is abundant in asteroids, Alvarez et al suggested the impact of a large asteroid as the cause of the mass extinction 65 million years ago. Such an impact might cause phenomena such as fires and dust clouds that would block sunlight, darkening the atmosphere and inhibiting photosynthesis, resulting in a mass extinction that included the dinosaurs. This hypothesis, still subject to controversy, was reinforced by new evidence, such as the identification in 1990 of the Chicxulub crater in Yucatan, Mexico, which coincided with the age of extinction.

Students can evaluate, based on the available evidence, competing theories seeking to explain the extinction: volcanic eruption, climate change, cosmic radiation, genetic problems, predation of eggs by mammals and poisoning by the emergence of flowering plants.

Claim 10: The earth is about 4550 million years old

Radiometric dating based on the steady decay of the isotopes of certain elements is used for finding the age of rocks. The quantities of given pairs of elements, such as K/Ar or U/Pb, in the minerals of a rock are used to determine the time of its formation.

We can ask students to evaluate previous claims based on methods used historically to estimate the age of the Earth. For instance: a) Bishop Ussher (1650) claimed, based on the Bible, that the world was created on October 23 of 4004 B.C.; b) Buffon (1779) calculated 75000 years based on the rate of cooling of a sphere; c) Kelvin (1862) calculated from 20 to 400 million years based on the cooling of the Earth since its formation; d) Joly (1899) determined the earth's age to be between 80 and 100 million years, assuming that the salts in sea water come from the erosion of the continents.

I3

WHY DOES THE WATER RISE? USING EVIDENCE TO CHOOSE THE BEST EXPLANATION

In science it is usual to have more than one explanation to interpret an event or phenomenon. The question then is to decide, on the basis of previous knowledge and available data, which is the best explanation. The construction of scientific knowledge involves, in many cases, a process of choice among theories competing to explain a phenomenon. In science classrooms students are often asked to opt for the school science explanation and to abandon other alternative ones. In the first chapter we mentioned some theories about the origin of mountains, in the second we listed explanations about free fall of weights.

For the purposes of choosing between alternative explanations, we propose a laboratory activity that deals with burning and which appears in many textbooks and other resources. This activity involves analyzing what happens when a candle burning in a saucer of water is covered with a jar.

Two notable events occur: 1) the flame goes out; and 2) the water level rises, to a certain height, in the jar.

Concerning the first process: the flame goes out because, after being covered, it runs out of enough oxygen to continue burning. Both the fact and the explanation are usually familiar to the students.

To account for the rise of the water level in the jar, two alternative explanations are proposed, and students are asked to choose one of them on the basis of evidence:

a) As the candle burns the oxygen inside the jar is consumed and the water rises to take its place.

b) As the candle burns the air inside the jar is heated and expands. When the flame diminishes and goes out, the air cools and contracts, causing the water to rise.

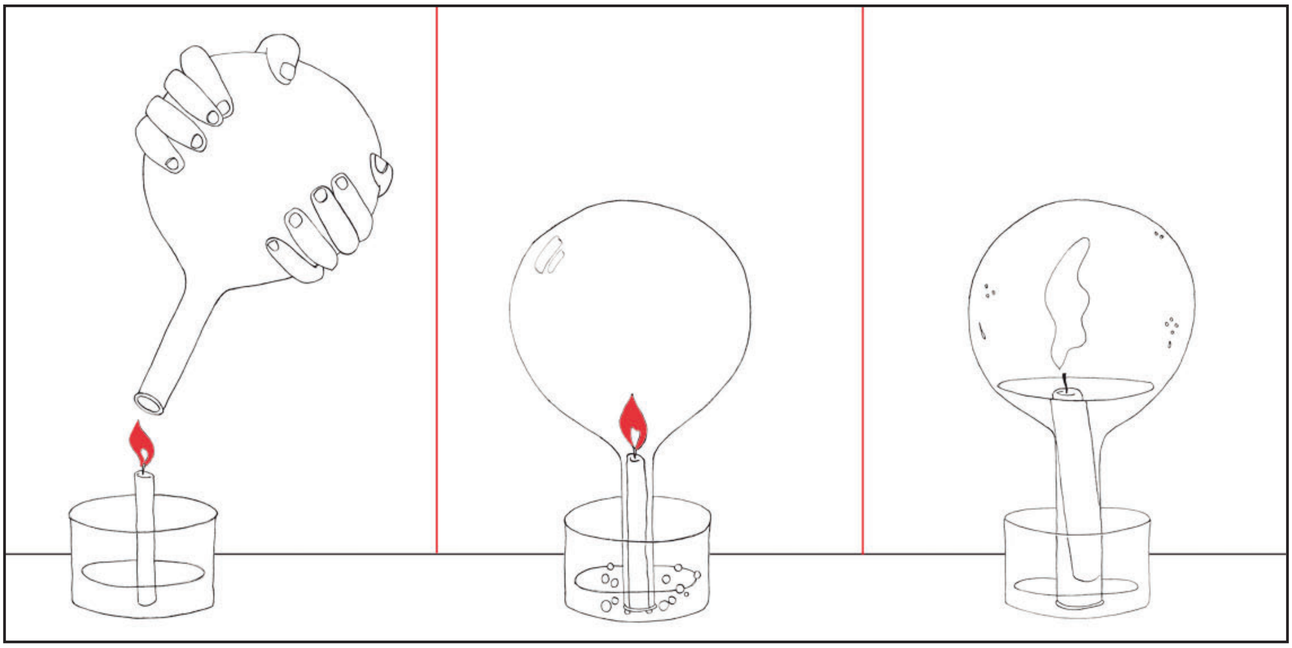
In the first phase, students are asked to indicate whether the explanations a) and b) adequately account for the observations and to choose one of them as the best, in other words, the explanation best supported by evidence.

In a second phase, which could be complementary, or for students at higher levels, additional information is provided: that the flame is extinguished without consuming all the oxygen in the air, as well as data from the stoichiometry of the reaction.

A3

Which explanation about the rise in water level is consistent with the evidence?

Place a burning candle in a saucer or any container with one or two centimetres of water, and cover it with an inverted jar. Place the jar so that it is supported in the saucer. The candle will be now burning inside the flask.



Observe carefully everything that happens.

The flame expires some time after it is covered. Can you explain why it goes out?

....

....

Another thing that happens is that the water rises in the flask until it reaches a certain level, roughly 20% of the flask volume. *Why does the water level rise?*

We can think of two different explanations for the rising of the water level:

EXPLANATION a)

As the candle burns the oxygen inside the jar is consumed, and the water rises to take its place.

EXPLANATION b)

As the candle burns the air inside the jar is heated and expands. When the flame diminishes and goes out, the air cools and contracts, causing the water to rise.

Analysing in detail all that happened, you can decide *which of the two explanations about the rise in water level is better*: note which phenomena you observed and which explanation you think might explain each of them. If necessary, you can repeat the experiment.

A 3

Observation 1:

I observed that at the beginning, while the flame is burning, some air bubbles come up under the flask

☐ yes ☐ no

Do you think that this observation is adequately explained by a?

☐ yes ☐ no

Please justify why:..

....

....

Do you think that this observation is adequately explained by b?

☐ yes ☐ no

Please justify why:..

....

....

Observation 2:

I observed that, after some seconds, the flame gradually diminishes until it extinguishes, and the water level rises up in the flask. The water continues to rise for some time after the flame goes out.

☐ yes ☐ no

Do you think that this observation is adequately explained by a?

Please justify why:..

....

....

Do you think that this observation is adequately explained by b?

☐ yes ☐ no

Please justify whys:...

....

....

A 3

Observation 3:

I observed that the water rises until it fills approximately 20% of the flask

☐ yes ☐ no

Do you think that this observation is adequately explained by a?

☐ yes ☐ no

Please justify why:..

....

....

Do you think that this observation is adequately explained by b?

☐ yes ☐ no

Please justify why:..

....

....

Which of the two explanations, (a) or (b), do you think is better?

Please justify why

....

....

....

A 3

Complementary activity

Two pieces of information that complement the experiment are given below. Please indicate whether each explanation, a or b, adequately account for them and why.

Information item 1:

Oxygen constitutes 21% of air volume. A candle flame goes out when the percentage of oxygen decreases to about 15%, that is, well before all the oxygen from the air is consumed.

Do you think that explanation a is compatible with this piece of data?

☐ yes ☐ no

Please justify why:...

....

Do you think that explanation b is compatible with this piece of data?

☐ yes ☐ no

Please justify why:...

....

Information item 2:

Candles are not made up of pure substances, but simplifying we may assume that they are made of paraffin, with the general formula C_nH_{2n+2} and the burning equation

$$2C_nH_{2n+2} + (3n+1)\ O_2 \rightarrow 2n\ CO_2 + (2n+1)\ H_2O$$

meaning that although the oxygen gas gets "used up" in the amount of "3n+1", there is now a "2n" amount of carbon dioxide gas, which would compensate for about two thirds of the decrease in volume.

Do you think that explanation a is compatible with this piece of data?

☐ yes ☐ no

Please justify why.:..

....

Do you think that explanation b is compatible with this piece of data?

☐ yes ☐ no

Please justify why:...

....

C3

Commentaries on the burning candle task

Some of the observations may change according to the size or shape of the flask used to cover the candle; we suggest using 1 L flasks to make the process a bit longer (about 5 to 10 seconds). When repeating the experiment a second time, care should be taken to renew the air inside the flask and to dry it so it will be the same as it was the first time. In the first phase the students are asked to check whether the observations may be explained by each alternative, which is what makes our approach different.

Concerning the explanation of observation 1, the fact that air bubbles escape from the bottom of the flask when we cover the candle while the flame is burning is only compatible with explanation b, air expansion due to the heat of the flame. According to a, while there is flame, oxygen is being “consumed”, so the bigger the flame, the higher should be the speed of consumption. The gas volume in the flask should decrease, not increase.

Observation 2: the fact that the water level rises when the flame size begins to diminish and that it continues to rise once the flame goes out is only compatible with b: the air cools and contracts. Alternative a cannot explain how water rises into the flask once the flame is extinguished.

Observation 3, that the water occupies about 20% of the flask, may be explained by both. According to a, as the air is 21oxygen, if all of it is “used up” we may expect a decrease of 21% of the total volume. A value of about 20% is acceptable. For b, a contraction of about 20% in volume means the gas cools to about 75ºC, which could be possible.

In the complementary activity, the first data point, that candles go out when the percentage of oxygen decreases to 15% (Kempa 1976, Lavoisier 1776), is only compatible with b. Oxygen constitutes 21% of the volume of air, so if the flame goes out when it decreases to 15%, we should expect a decrease of volume of 6%. The claim that alternative a is not compatible with observations 1 and 2 is strengthened. Observation 3, which was apparently compatible with a under the assumption that all the oxygen was consumed, is no longer compatible.

The second data point, which may be given to students familiar with equation balance and stoichiometry, also strengthens explanation b, as two thirds of the decrease in volume due to oxygen consumption would be compensated by the CO_2.

In spite of this, there are books where the candle experiment is presented as a method to empirically measure air composition.

I4

4.- DECIDING BETWEEN OPTIONS IN LIGHT OF THE EVIDENCE: WHICH IS THE BEST HEATING SYSTEM?

In this chapter we discuss a task that forms part of a teaching sequence about energy, its sources and uses. Sequence and task were designed in order to integrate argumentation and the use of evidence with the learning of science concepts, argumentative competency and scientific literacy.

One of the contexts of the use of evidence is its use in order to decide among different options or courses of action. The competency to evaluate options requires scientific understanding and knowledge about scientific work, as well as using these understandings to justify the choice of one option and the rejection of others. This competency draws from scientific knowledge, but it deals with issues situated in a social context, where science knowledge is generated and applied. The Science-Technology-Society (STS) or socio-scientific perspective requires students to develop critical thinking in order to analyze options.

Science and technology knowledge is not independent from the social context, and may have implications that are not always visible, for instance in terms of values. This is the case with environmental issues related to natural resource management.

The task discussed in this chapter aims to develop not only students' scientific competencies, but also their environmental competency and critical thinking skills. Environmental competency involves the capacity to recognize environmental problems, being aware of one's personal responsibility about these problems and proposing potential solutions. The objective of the task is the development of the capacity to evaluate knowledge claims through the use of evidence. Students construct arguments about a socio-scientific issue as they choose one among several possible heating systems and energy sources. Such tasks have the dual purpose of contributing to the objectives related to learning science while at the same time promoting citizenship education by educating critical citizens who can participate in independent decision-making.

A4

Choosing a heating system (student worksheet)

(simulated) letter from the University of Santiago de Compostela (USC)

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

The office of the Vice-chancellor for Strategic Planning from the USC

INFORMS

Due to the launching at the University of Santiago de Compostela of an Energy Optimization Plan (EOP), the first to be implemented at a Spanish University, which has the goals of:

+ (economic) efficiency and – (environmental) impact

REQUESTS

The elaboration of a report on an improved heating system for the construction of new buildings for the Health Sciences Faculty. The reasons used for the decision should be made explicit.

It should be taken into account that:

The costs of installation will not be considered, only the maintenance costs (what the Faculty will have to pay for heating).

Both the costs (monthly amount of the heating bill) and the environmental impact must be taken into consideration.

Some possible options are listed in the table of the Consumer Association Journal as well as others from renewable sources.

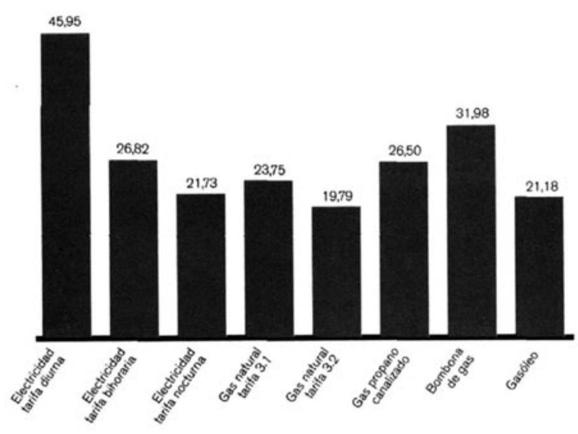
Other suggestions that may be considered relevant for the purposes of reducing costs and minimising environmental impact are welcome.

¿QUÉ ME CUESTA MÁS?

En el gráfico puede ver qué tipo de energía cuesta más. Para hacer la comparación, hemos tomado como ejemplo el coste de calentar un salón comedor con una superficie de unos 20 m² de un piso situado en una zona de clima templado (Madrid, por ejemplo). Como puede ver, la electricidad en tarifa diurna es lo que más cuesta; el gas natural en tarifa 3.2, lo que menos.

Si quiere información más completa al respecto, puede consultar nuestro último estudio sobre los Costes de calefacción individual + agua caliente, en OCU-CM nº 256 (enero 2002). ■

COSTE DE CALENTAR UN SALÓN (EN EUROS)



Sólo tenemos en cuenta el consumo necesario, no el término fijo, cantidad diferente según el tipo de energía, la tarifa y, en el caso de la electricidad, la potencia contratada.

Table from the OCU (Spanish Consumer Association) journal

A 4

For the written report you can use your notebooks, the textbook and the Internet. For instance you can find information on these web sites:

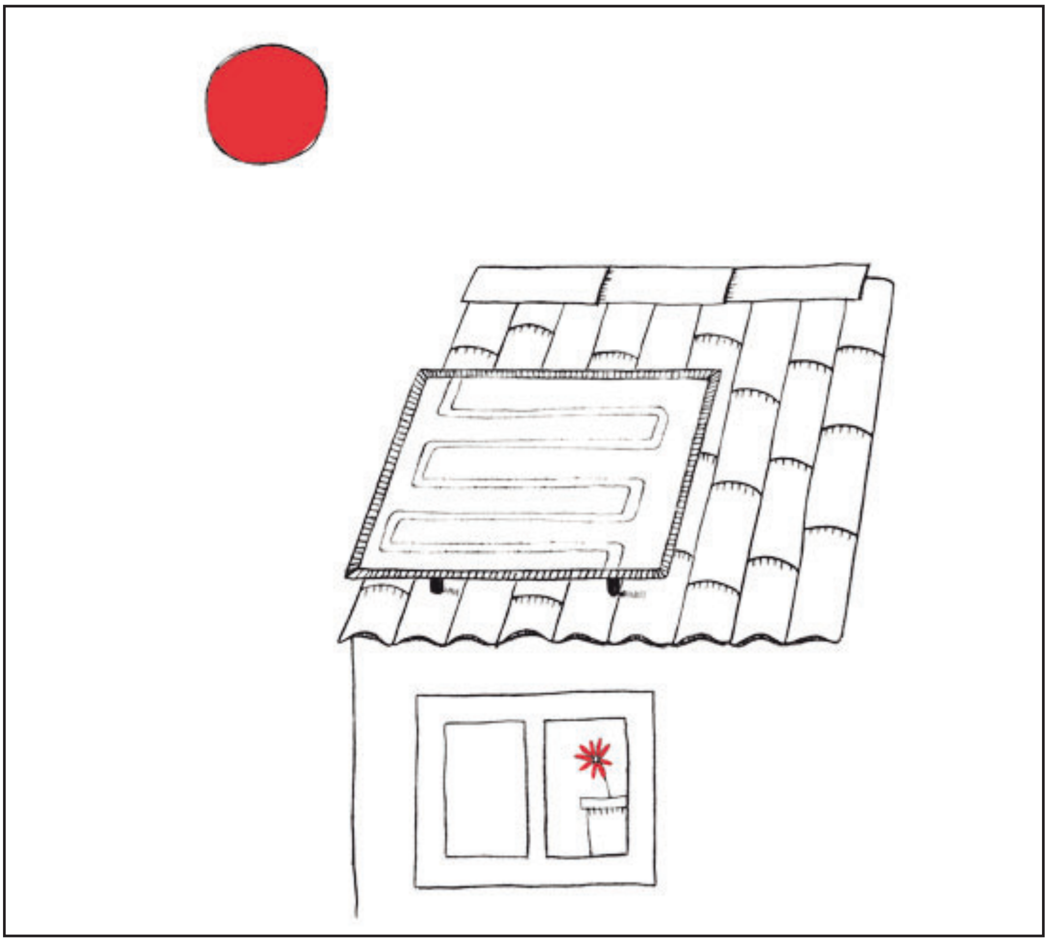
- About energy from environmentalist NGOs: Greenpeace (www.greenpeace.org.uk/efficiencity/about) and Friends of the Earth (www.foeeurope.org/climate/index.htm)

- About renewable energy sources ("green energy") from companies: www.greenmountainenergy.com/;

-Information from companies providing natural gas, electricity, etc. about their products and services: Chevron (www.chevron.com/), Ener.g www.energ.co.uk/renewable_energy; natural gas (http://www.eurogas.org/), Repsol (www.repsol.com/es).

- News about "green energy": Iberdrola and Endesa under scrutiny about "green energy" www.consumer.es/web/es/economia_domestica/2003/11/10/90785.php

- Information about climate change: Intergovernmental panel on climate change: www.ipcc.ch



C4

Commentaries on: Choosing a heating system

This task was carried out by the teacher Xulio Gutiérrez Roger and the researcher Fins Eirexas with two classes of 12th grade students (17-18 year of age). The task was part of a teaching sequence on Energy Resources, in the context of the Earth and Environmental Science course, and took four sessions: during the first three the students worked in small groups collecting information and writing reports, and they held a joint debate in the fourth.

What do the students need in order to carry out the task?

First they need to collect information about the existing heating system options and the features of different energy sources. The evaluation of each option was guided by the criteria established in the task, both explicit (economic and in terms of environmental impact) and implicit (renewable / not renewable).

In order to reach a decision they needed:

– To select and process information about energy sources.

– To evaluate the impact from each source, using notions such as "natural resource", "renewable / not renewable", and "sustainable".

– To contextualize the options, assessing the actual possibility of implementation in Santiago de Compostela.

– To make a decision about a heating system.

In order to process the information about energy sources, evaluating their advantages and disadvantages, students had to draw on the data from the dossier (company booklets, press clippings), textbooks and web sites, interacting with them with the purpose of building their justifications. Besides the task requirements, low cost and low impact, and the local context (availability of the source in Santiago de Compostela), students had to consider whether it was possible to buy electricity from a single renewable source as well as other constraints, such as the use of the building as a faculty and the local climate.

During the last session, when students contrasted different options, presenting arguments in favour of their own proposal and against the others, new justifications emerged that were not made explicit in the reports.

Variety of options chosen in two 12th grade classes

Given the criteria established in the task there was no single heating system that could be considered the best. Currently it is not possible in Spain to buy energy coming only from renewable sources, in spite of the commercial claims about "green energy". The possibility of self-generated energy, either solar or wind-powered, is also limited by technical considerations. Therefore the various small groups were forced to choose the "not so bad" option, which included a non-renewable source, as summarized in the table.

C4

OPTION	ENERGY SOURCE	GROUP
A single source	Natural Gas	A, C, F
	Electricity with night rate	E
Combined sources	solar power + natural gas	B, G
	Solar power + electricity	D

Group decisions

A variety of solutions involving energy sources were generated. Groups opted either for single commercial sources as natural gas (chosen by three groups) or electricity, or for a combination of solar power with one of the commercial sources. This variety is a consequence of the problem design, as it is an open task where several options are possible and there is not one "right answer".

What evidence and justifications did students use?

In order to support their decisions the small groups appealed in their reports to different data, first related to the criteria set in the task: a) economic costs; and b) environmental impact. Students tended to interpret environmental impact mainly in terms of pollution from different sources and, in a few cases, in terms of whether or not the energy source was renewable. Other evidence related to: c) impact on the landscape; d) physical (calories produced) and chemical (composition) characteristics; e) geological data, such as the geothermal gradient; f) technical considerations, such as insulation and g) effects on health.

In their justifications students used evidence not only to defend their options, but also to discard others. For instance, there was an argument concerning "green energy" (from renewable sources) that it was not possible for a consumer to determine the origin of the energy purchased.

C4

EVIDENCE	**JUSTIFICATIONS** (OPTIONS IN BRACKETS)
Pollution	"It produces fewer pollutants than any other fossil fuel" (A, natural gas) "Fuel was discarded because it produces several polluting gases (CO, CO_2, NO, NO_2)" (G, solar + natural gas)
Economic cost	"Night rate, because it uses electricity only at night, when it is cheaper" (E, electricity) "its rates [*of electricity*] are always much more expensive than the natural gas option" (C, natural gas)
Other impacts: landscape	"It is transported through underground pipes, meaning that landscapes and plant and animal life are not damaged" (F, natural gas)
Physical (calories produced) and chemical (composition) characteristics	"Produces a great amount of heat, approximately 11500 Kcal./m^3" (A, B, G) "It [natural gas] is composed of methane and also ethane and propane" (E, electricity)
Geological	"it [*geothermal energy*] is not usable in Santiago" (A, natural gas)
Technical	"in order to use solar energy, the building should be constructed (...) an appropriate orientation" (G, solar + natural gas). "solar energy is intermittent (...) it would be solved with a storage cell" (B, solar + natural gas)
Health	"It leads to [*air pollution*] numerous respiratory diseases and allergy reactions" (A, natural gas)

Summary of evidence and justifications

How the sequence and task design promoted the use of evidence

The design of the task as an authentic problem, where students can see the relationship with daily life, promotes engagement. The openness favours the generation of a variety of options, which in turn promotes data selection and argumentation, as it is necessary for each group to produce evidence to justify their option.

In their justifications, as it was not possible to choose a fully renewable source ("green energy" as advertised by some electricity companies), students had to appeal to the "not so bad" option, in the teacher's words. This shows that they had to contextualize the task in real life and analyze information, competencies relevant in the development of critical thinking, an important skill, for instance in evaluating advertisements.

I5

5.- ARE THESE COPERNICUS' REMAINS? EVALUATING EVIDENCE

In previous chapters we have discussed different proposals to explore the role of evidence in knowledge evaluation and to learn how to use evidence. Data and pieces of evidence have a function in the confirmation or refutation of statements. But it is also important to discuss how evidence itself is evaluated, in other words, which criteria to use in order to determine the reliability of a given piece of evidence, its connection to the claim that is subject to confirmation and the adequacy of a piece of evidence or a set of such pieces.

This process involves answering questions such as: Is this evidence reliable? In a given set of pieces of evidence, are some more robust than others? Does this evidence connect to the claim that we are examining? To what extent does a set of pieces of evidence better support a claim or a theory than a single piece of evidence?

An example of how a set of different pieces of evidence supports a theory is evolution. From the two claims that make up this theory, we will discuss the first, which states that all living beings have a common origin; they descend from one or a few organisms. Some evidence confirming the theory of evolution is paleontological, for instance the existence of transitional forms such as Archaeopteryx, mentioned in chapter 2, that confirm the prediction about the transitional forms between ancestors and organisms descending from them. Other evidence is genetic, such as the degree of similarity among DNA profiles, which is higher in species that have closer common ancestors. For instance, the degree of resemblance between the DNA of humans and that of chimpanzees is 98%. Others are instances of interaction with culture, as the selection of lactose tolerance in adults in connection with cattle domestication and the availability of milk. Likewise there is a diverse range of evidence supporting plate tectonic theory.

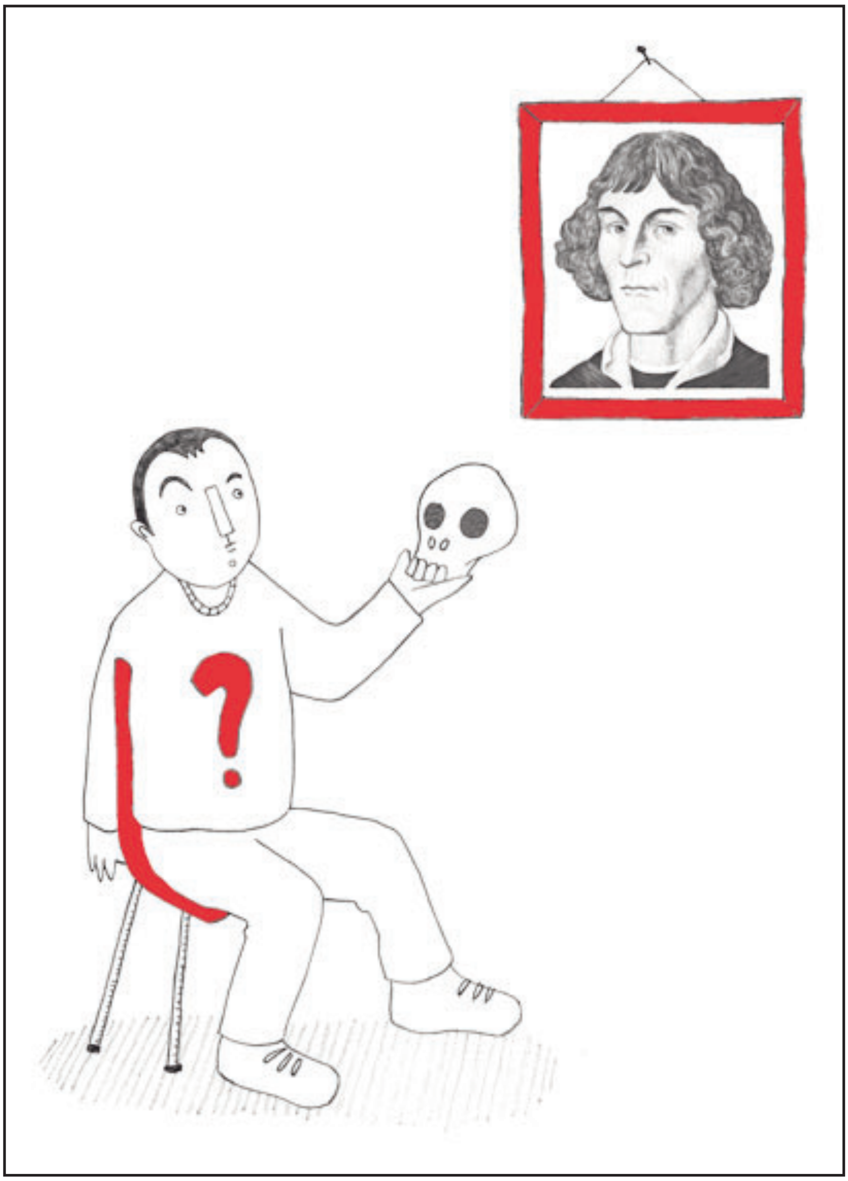
In order to explore these issues in the classroom we propose an activity adapted from Jiménez-Aleixandre (2009), which is based on a case that was recently covered by the media and that combines a subject relevant to the history of science with the use of contemporary forensic methods.

A5

Are these Copernicus' remains?

Nicolaus Copernicus (1473–1543) was an astronomer who articulated the idea that the Earth revolved around the sun and not the other way around, compiling data to support it. Copernicus died when he was 70 years old in Frombork (Poland), where he had lived his last years. In the XVII century, during one invasion of Poland by Sweden, part of his library was taken to Sweden where is kept in Uppsala University. Copernicus was reportedly buried in Frombork Cathedral, but most of the tombs in it were unmarked (which was not infrequent at the time). For many years archaeologists from different countries searched in vain for his remains.

In August 2005 a team lead by archaeologist Jerzy Gassowski, at the bishop's request, dug up the floor in Frombork Cathedral and found, near one of the altars, some bones and a skull with several teeth, remains that they attributed to Copernicus. The identification was initially based on the resemblance between the skull and Copernicus' portraits, for instance a broken nose and a scar above the left eye.



Forensic studies of the skull showed that it belonged to a man about 70 years old. The Forensics Laboratory of the Polish Police used computer graphics to produce a reconstruction of the face of the man to whom the skull belonged. This computer reconstruction bore a great resemblance to a portrait of Copernicus (this facial reconstruction can be seen at http://news.bbc.co.uk/2/hi/europe/7740908.stm).

Marie Allen, Swedish genetics expert, analysed DNA from a tooth, a vertebra and a femur bone. This DNA was compared with four hairs retrieved from the pages of the book *Calendarium Romanum Magnum,* once owned by Copernicus and now in Uppsala. The DNA test showed, in November 2008, that two of the hairs, the tooth and the bones belonged to the same individual.

A5

Which pieces of evidence about Copernicus identification are more reliable?

The data and analysis mentioned above appeared in the media with headlines as: “DNA confirms that the remains found in 2005 belong to Copernicus”; “16th century skeleton identified as the astronomer Copernicus”, or “Two-century hunt for tomb of astrologer Copernicus is over” (this is an error, as an astronomer is not the same as an astrologer).

a) Do you consider that there is *sufficient* evidence to identify the remains as those of Copernicus? Would it be enough to have only one or two of these pieces of evidence? Explain your answer.

b) Make a list with all the pieces of evidence described as contributing to the identification of the remains and order them from more to less *reliable*, that is, from the one you find most convincing to the one you find less convincing.

c) Now order them from the ones you consider more *specific* (in other words, those that prove that the remains belong specifically to Copernicus) to the ones that you consider less specific (for instance, those that may show that it is someone from the same time, or who shares other features with him).

d) Can you think of an *alternative explanation* (different from the proposed explanation that the skull and bones belong to Copernicus) for one or several of these pieces of evidence? If one (or more) of them do not prove that this body belongs to Copernicus: What does it prove?

C5

Commentaries on the activity: Are these Copernicus' remains?

The task is designed to promote the development of criteria for evaluating evidence, such as sufficiency, reliability, specificity and the possibility of alternative interpretations. This development would need teacher support.

a) Do you consider that there is *sufficient* evidence to identify the remains as those of Copernicus? Would it be enough to have only one or two of these pieces of evidence? Explain your answer.

The criterion of sufficiency is rather general. This question seeks to highlight that some pieces of evidence may point in a particular direction without having enough weight, as for instance the broken nose and scar above the eye first mentioned in 2005. It is also interesting to have the students reflect about the accumulation of data, because even if one of these two features would not be considered reliable evidence, the combination of two (or more) increases the reliability, as is it less probable that they coincide in several people simultaneously. In our experience, when using the task in teacher professional development, teachers identify this accumulation.

b) Make a list with all the pieces of evidence described as contributing to the identification of the remains and order them from more to less *reliable*, that is, from the one you find most convincing to the one you find less convincing.

There are seven pieces of evidence mentioned in the text. A possible order (there are others) from more to less reliable could be: 1) the DNA test; 2) the scar over the left eye; 3) the broken nose; 4) the age of 70 years; 5) the computer reconstruction of the face; 6) the fact that the remains correspond to a male (this is implicit); 7) being buried inside the cathedral.

In this case the reliability indicates the probability, according to the evidence, of the remains belonging to Copernicus. For instance, the DNA tests have a reliability of more than 99%. Concerning the scar and broken nose, students may consider one or the other of them more reliable (the frequency of each injury may be discussed); it is interesting to note that these pieces of evidence do not prove the identification, only suggest that it is possible that these remains belong to the astronomer. The same is true of the fact that the remains correspond to a 70 year old person: it does not prove the identification, but indicate that it is compatible with the evidence (if they were from a 40 year old, it wouldn't be). Some students thought the computer reconstruction is not so reliable, given that it was produced with knowledge of Copernicus' portraits.

The fact that the remains belong to a male (also shown by the DNA test) is very unspecific, as discussed below, but it constitutes part of the set of features to be considered. Finally, although it is not very specific, it should be taken into account that not just any citizen could be buried inside the cathedral (and close to an altar), but only illustrious people. It is important to explicitly discuss that even though some of these pieces of evidence, taken one by one, are not very relevant, the accumulation of these individual pieces grants more reliability to the claim.

C5

c) Order them from the ones you consider more *specific* (in other words, those that prove that the remains belong specifically to Copernicus) to the ones that you consider less specific (for instance, those that may show that it is someone from the same time, or who shares other features with him).

Specificity, the degree to which a given piece of evidence relates to the claim being examined, is another important criterion for selecting evidence. A possible order may be: 1) the DNA test; 2) the scar over the left eye; 3) the broken nose; 4) the computer reconstruction of the face; 5) being buried inside the cathedral; 6) the age of 70 years; 7) the fact that the remains correspond to a male. Although in some cases the more specific pieces of evidence are the more reliable (among other reasons, for being so specific), in other cases there is no correspondence, and it can be argued that the sex and the age, in strict terms, only prove that the person was a man and that he died at age 70.

d) Can you think of an *alternative explanation* (different from the proposed explanation that the skull and bones belong to Copernicus) for one or several of these pieces of evidence? If one (or more) of them does not prove that this body belongs to Copernicus: What does it prove?

It is important for the students to be aware that one piece of evidence can have several possible interpretations. For instance, the DNA test proves that the hairs and the teeth belong to the same person, but not that he was Copernicus, and may be explained by the fact that these books were used by others, as indicated by the fact that only two of the four hairs correspond to the same person as the teeth. This person would also be illustrious, so he was buried in the cathedral.

The fact that a piece of evidence could have more than one interpretation allows knowledge to change, not only through new evidence, but also through new theories that lead to different interpretations.

I6

6.- DOES THE MOON INFLUENCE PLANT GROWTH? DESIGNING AN EXPERIMENT TO GENERATE EVIDENCE

The use of evidence is not developed in a space isolated from the rest of teaching, but rather within the framework of teaching sequences and activities carried out in the classroom, the laboratory and the field. In particular, use of evidence and argumentation may be framed within the Inquiry-Based-Science-Education (IBSE) perspective. Inquiry has the goal of engaging students in authentic science, which, according to authors like Chinn and Malhotra (2002), means not so much hands-on learning as participating in the processes of reasoning and knowledge construction that characterize science.

What does it mean to practice scientific work? What activities do students carry out when they are engaged in inquiry? Inquiry does not mean a fixed set of "steps", but Chin and Malhotra propose the following to be among the cognitive processes in which the students should be engaged when conducting authentic inquiry:

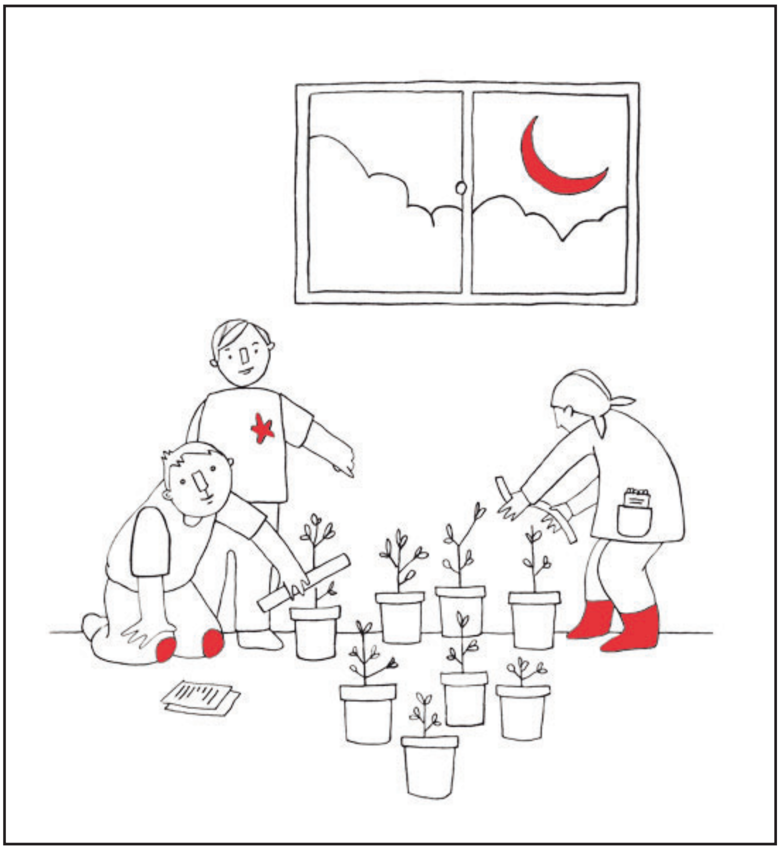
– Generating their own research questions to be investigated.
– Designing studies, planning small investigations and experiments.
– Making observations, collecting and analyzing data.
– Explaining results: transforming observations into other data formats, questioning their results in order to find possible flaws.
– Developing interpretations (theories) for given results.
– Studying research reports from other people.

As these authors point out, in many cases school experiments do not share these features, as the students do not decide upon the questions to be explored or plan the investigations Instead they follow instructions, and the same happens with other processes. However, although they occur less frequently, there are instances of inquiry and IBSE in schools.

The work discussed in this chapter corresponds to a question generated by 9th grade students Adrián Bembibre, Álvaro Bermúdez, Rubén Pérez and Iván Vázquez from a Galician high school, as well as to a study that they themselves designed and planned. Their biology teacher, Luis Fernández (Fernández & Jiménez-Aleixandre, 2009) requires, as part of the coursework, investigations planned and carried out in small groups about topics that they themselves determine. We suggest that students should be given this opportunity, although in this chapter the activity is based on a question decided upon by others.

A 6

Does the moon influence plant growth?



Sometimes we hear that it is better to plant, collect or prune plants during a given phase of the moon cycle (or that it is better to cut your hair with a waxing moon or a full moon). For instance, we may be told to sow fast-germinating seeds (such as beans) between the new moon and the crescent moon and to sow slow-germinating seeds between the full moon and the last quarter or to prune during the waning moon. Other say that plants grow faster during a full moon and that it would be better not to plant anything during a new moon.

Adrián, Álvaro, Rubén and Iván, 9th grade students, have heard their families and neighbours repeat this popular belief. They searched for information in the school library and on the Internet, but they could not locate studies demonstrating whether the lunar cycle had any influence on plant growth. That is how they describe their objective: "To ascertain scientifically whether the moon cycle affects plant growth".

You are asked to collaborate with this group in their research. Plan, as precisely as you can, what you think you should do in order to test whether it is true that the moon phases affect the plants. Some questions that may help you in this planning are:

– What would you consider to be *evidence* showing that the moon phases affect plant growth?
– What *data* should you collect in order to produce this evidence (or the contrary)?
– *How many* experiments do you need to plan?
– How can we *check* that we are testing the moon phase and not something else?
– What *equipment* do we need to conduct these experiments?

A 6

The group decided that they would consider as evidence that plants sown in a given moon phase grew higher; the data that they should collect would be the measurement of the plants sown in the four moon phases. So they planned four experiments, one for each phase. In order to ascertain that they were testing the moon phase, and not something else, Adrián and his colleagues proposed the use of identical equipment in the four experiments, and to measure the water supplied. The materials and equipment for each experiment were: a) 15 seeds of low bush beans, Bina brand; b) universal soil, Turba green brand; c) cotton for the beginning of germination; d) plastic cups of 220 cm^3 (15x4); e) a syringe to supply 20 cl of tap water each time; f) a bore from the technology department, in order to measure the height of the plants. Here is how they describe the experiments:

"We began on the 29 of February, at the beginning of the waning moon. We put 12 bean seeds in cotton dampened with 20 cl of water. A week later we transplanted them to cups full of soil, adding another 20 cl of water. We supplied water weekly until the 28 of March, when we measured the plants from the base of the stem to the top. We repeated the process in the three other moon cycles."

The following table summarizes the results in cm (of the plants that grew, not all of them did)

PLANT NO.	WANING MOON	NEW MOON	WAXING MOON	FULL MOON
1	3.56	3.1	8.22	19.5
2	0.8	9.6	7.8	18.2
3	3.08	8.9	11	21.5
4	13.2	8.5	11.5	22
5	9.9	8	14.5	21
6	13.22	3.9	–	6
7	8.9	11.9	–	–
8	7.4	2.5	–	–
9	5.82	4	–	–
10	8.5	2	–	–
11	5.69	3	–	–
12	5.13	2.1	–	–
AVERAGE	**7.1 cm**	**5.6 cm**	**10.64 cm**	**18 cm**

You are asked to help Adrián and colleagues to *interpret* these results. Do you think that it is possible to draw any *conclusion*? If you had to repeat the experiment: Would you do something differently?

A 6

The conclusions written by Adrián, Álvaro, Rubén and Iván were:

1. The bean plants that grew the highest, based on the data from the mean plant heights, where those planted in the full moon (even when the mean was constructed for all 15 seeds)
2. If we take into account the data dispersion in the results from the four moon phases (with high and low values in all of them, and seeds that did not germinate), we cannot conclude, for this case, that there is any influence of moon phase on bean plant growth.
3. It would be necessary to explore this question in depth, with new experiments, in order to reach stronger conclusions.

Do you agree with these conclusions? If you agree partially: With which part of the conclusions do you agree and with which part do you disagree? Justify your answers.

Conclusion 2 states that they cannot conclude that there is some influence of the moon phase in plants growth. Do you agree? Why?

Can you think of an alternative hypothesis (different from the moon's influence) to explain why the mean is higher in the full moon phase? How would you test it?

With these results, some people would be a bit annoyed since, after so much work, they cannot clearly confirm or deny the moon's influence. Do you think that, in spite of this uncertainty, experiments like this are useful? What could be learned from them?

Conclusion 3 states that new experiments would be needed. Can you think of some things that should be considered in order to plan these new experiments? Remember that the purpose is to produce results that provide new, stronger evidence about the moon's influence.

Plan and carry out an experiment to improve the existing conclusions and to test the alternative hypotheses.

C6

Commentaries on the activity: Does the moon influence plant growth?

Our proposal is to work with each of the three A6 worksheets consecutively, to promote the elaboration of students' own proposals. It would be better if they can actually, with the teacher's help, carry out the experiment. In that case the second and third worksheets could be used to compare their results with the ones described here.

Concerning what students would consider as evidence, the debate about the different proposals (that may coincide or not with those described), could focus on the criteria discussed in chapter 2: if the evidence is sufficient, reliable and specific.

Some of the students would draw a different claim from the data, interpreting that the mean of 18 cm in the plants sown during the full moon, higher than in the other phases, points to the positive influence of the moon in that phase. For students it is not easy to accept that the results from an experiment may not be conclusive, either for confirming the hypothesis or for refuting it.

However, the interpretation proposed by Adrián and his colleagues has the virtue (as was recognized by the teacher Luis Fernández when discussing it in the classroom) of acknowledging uncertainty as an integral element in scientific work: there are many cases when it is necessary to repeat experiments, to redesign them or to ask ourselves whether there were errors and what could be improved.

The suggestions for a better design of the experiment are related to the alternative hypothesis –different from the moon's influence – that may explain why the beans planted during the full moon are higher. An example is the control of variables: the students took care that all the plants received the same amount of water, but they did not control, for instance, whether the temperature was the same in all the cases. Although it is difficult to maintain constant temperature in a school laboratory, it is possible to measure the room temperature to test whether there were substantial differences. Taking into account that the seeds were planted in the waning moon on February 29, and in the full moon on March 21, an alternative hypothesis could be that the temperature was rising during these four weeks. Although it is not possible to retrieve the data on laboratory temperature, it is possible to retrieve the town temperature in that period: in February it may be below 0º C, while in March it could reach 20º C.

After carrying out an activity like this, which involves challenging folk beliefs, the students usually ask the teacher for "the right answer". Besides suggesting carrying out new experiments, there are websites of associations such as ECSO (European Sceptics Organisation, http://www.ecso.org) where the influence of the moon and stars are discussed. In Spanish, science teacher Jorge Cruz's Blog discusses in detail the influence of the moon (jcruzmundet.blogspot.com/2009/04/el-mito-de-la-influencia-lunar_10.html) and the inexistence of evidence about it. Cruz indicates that this influence is attributed either to the differences in illumination among the phases or to gravitational attraction.

C6

In terms of the influence of the light, as Cruz points out, the amount of solar light reflected by the moon is of little significance compared with sunlight.

The hypothesis about gravitational attraction is based on the moon's influence on tides. It is argued that, since living beings contain a high amount of water, and there is also water in the soil, it would influence them too. This is an analogical argument, rather than evidence. To contradict it, Cruz indicates that lakes and dams are huge liquid masses and there are no tides in them, nor is there any perceptible moon influence. He calculates, from the gravitational attraction definition, the attraction of the moon on a seed of 2 g (this is the mass of a clove of garlic, and folk beliefs forbid planting them during a waxing moon, for they would be thrown out of the soil). This attraction is three thousand times smaller than the Earth's attraction, so it would be not possible for the garlic to be "expulsed". According to Cruz an alternative hypothesis is that birds peck in sown fields, taking the seeds out.

Another study of a folk belief, that blessed bread does not get mouldy and is imperishable, was undertaken by a student from the same high school. This student's work won an award from a Science Museum, creating a great deal of social impact in the town (Fernández & López Carracedo, 2005).

These instances illustrate how the use of evidence is related to the development of critical thinking, with the critical analysis of beliefs without evidentiary support.

7 .- RESOURCES FOR SUPPORTING ARGUMENTATION AND THE USE OF EVIDENCE

WEB-BASED RESOURCES

- Project **RODA-MTG** (where this document may be downloaded): www.rodausc.eu
- **Mind the gap**: www.uv.uio.no/english/research/projects/mindingthegap/index.html
- **Pegase** (CNRS-Université de Lyon): http://www.inrp.fr/pegase-en/
- **IDEAS** (King's College London) www.kcl.ac.uk/schools/sspp/education/research/projects/ideas.html
- Project **Viten** (Oslo University): www.viten.no
- **Concept cartoons**: http://www.conceptcartoons.com/science/news.htm

GENERAL REFERENCES ABOUT ARGUMENTATION: INTRODUCTION AND CHAPTERS 1 & 2

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