ARGUMENTATION IN THE CLASSROOM: TWO TEACHING SEQUENCES

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ARGUMENTATION IN THE CLASSROOM: TWO TEACHING SEQUENCES

Project S-TEAM

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INTRODUCTION: ARGUMENTATION IN SCIENCE CONTEXTS

From the two teaching sequences in this document, the one about gene expression makes part of the products of S-TEAM Work Package 7 (WP7), which have the purpose of providing resources and strategies to help teachers to create learning environments for argumentation and discursive practices in science. The objective of WP7 is to disseminate resources to support the teaching and learning of argumentation in science classrooms, as a component of Inquiry Based Science Teaching / Learning (IBST/L). The objectives of the second teaching sequence, about energy flow, produced in the frame of project RODA (ReasOning, Debate, Argumentation), carried out in the University of Santiago, with funding from the Spanish Ministry of Education, are aligned with this general goal.

The teaching sequences are framed in the approaches about argumentation, both theoretical and related to policy, discussed in another of WP7 documents (Jiménez-Aleixandre et al., 2011), available in the S-TEAM website. Here we will only discuss a few key issues that have relevance for the sequences' tasks. The teaching resources produced by WP7 consist of two sets: first, resources and tasks for use in the classroom in primary and secondary schools, and second sequences and tasks for use in teacher education, in order to support the development of argumentation competences. All of them are available in the S-TEAM website. This document belongs to the first set, and consists of two teaching sequences for the science classroom, both developed and tested in secondary school during the terms 2008-2009 to 2010-2011:

Using evidence and modelling about gene expression, corresponding to product WP7.3 *Teaching sequence for argumentation: Applying the model of gene expression*.

Using evidence and modelling about energy flow in ecosystems, part of it discussed, in relation with teacher education, in the book product WP6.15.

Articulation between learning argumentation and learning science

The teaching sequences for argumentation presented here focus on *supporting claims with evidence* in the contexts of genetics and ecology. They are aligned with the research program of the USC team, interested in the articulation between epistemic practices, such as argumentation and modelling, and scientific literacy. The teaching sequences are grounded both on the argumentation literature and on studies about genetics or ecology learning. Our work addresses the development of argumentative competence by students, but not in any context: we seek to promote students' argumentation about *scientific* issues, and in *science* classrooms.

The purpose of the teaching sequences is to provide resources for science teachers interested in introducing argumentation in the classroom. On the one hand, biology teachers may use them with their students. On the other, it is expected that science teachers of chemistry, geology or physics, may adapt them, or use them as templates to construct others about different disciplinary topics. Teachers may choose, for instance, the task focusing on drawing claim from data in chapter 2, or the choices among different explanations or decisions on the basis of a set of pieces of evidence in chapters 4 or 12, setting them on chemistry, geology or physics contexts.

Many science teachers do promote some form of argumentation and use of evidence in their classrooms, for instance when they ask students to justify their claims, to collect evidence in the laboratory and to draw conclusions about it, or when they encourage them to support their claims with evidence. The purpose of these resources is to help them to support argumentation in a systematic way and with a more structured approach. From our experience in teacher education, it seems that argumentation tasks are more relevant for teachers when they are clearly framed in a disciplinary context, for instance in a teaching sequence or task.

It needs to be noted that for us proposing that the students should learn argumentation does not mean that teachers should explicitly teach it. Our approach about how to promote argumentation is through *practice*: engaging students in practising it. We consider more important to design tasks that require an active role from them, and less important or even not necessary to teach it explicitly (Jiménez-Aleixandre, 2008; 2010). We agree with Deanna Kuhn's (2011) in the need for providing students with dense experience in argumentation with peers. Other approaches propose to explicitly teach students the concept of argumentation or the components of an argument, and then to carry out argumentation tasks. There is coincidence in emphasizing the need for classroom environments that support discursive practices, engagement in dialogue and contrast of ideas and interpretations.

The meaning of argumentation and its connections to inquiry

What do we mean by argumentation? It may be characterized in different ways, but for the purposes of these teaching resources, we consider it to be the *evaluation of knowledge claims* in the light of available evidence (Jiménez-Aleixandre, 2008; 2010). This process also involves persuasion of an audience, be it listeners or readers. The interest of science educators in argumentation involves an acknowledgement of the relevance of discursive practices in the construction of scientific knowledge. Doing science, learning science involve experimental work, and also working with ideas, proposing them, discussing them, evaluating them against evidence. Scientists and students need also to communicate scientific ideas, read, make meaning of and write science-related texts. A more detailed discussion of the components of arguments is to be found in the S-TEAM document about argumentation and teacher education (Jiménez-Aleixandre et al., 2011).

How is argumentation related to Inquiry based Science Teaching and Learning (IBSTL)? Different authors agree on the idea that argumentation is supported by an inquiry approach (e.g., Duschl & Grandy, 2008). In IBSTL students play an active role in their own learning; they solve problems, design experiments or undertake research projects participating in scientific practices. To engage in argumentation, to evaluate knowledge, is seen as participation in these practices.

From a policy perspective, we frame argumentation and the use of evidence in scientific competence, one of the eight key competences recommended by the European Union (2006). Scientific competence is the core of the Program for Indicators of Student Assessment (PISA) framework (OECD, 2006; 2009). Three scientific competences are emphasized in PISA, the capacities to:

· Identify scientific issues and questions that could lend themselves to answers based on scientific evidence; recognise key features of a scientific investigation.

· 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.

Is this last one, using scientific evidence to draw conclusions and to identify the evidence behind conclusions, which we consider equivalent to argumentative competence. The characterization of competence focuses on the capacity to *apply and use* knowledge in a variety of contexts and situations. So rather than learning the elements of an argument, the question is learning how to appraise a claim.

The teaching sequences presented in this document extend the efforts of other innovative science education projects. These tasks may be used alongside other resources for supporting argumentation produced, for instance, in the context of the *Mind the Gap* project (Jiménez-Aleixandre et al., 2009), also funded by the 7th Framework Program. All of them are complementary, and need to be seen as part of the efforts toward supporting the introduction of argumentation in classrooms.

The document is structured in two sections, each devoted to one teaching sequence, beginning with a chapter summarizing its goals and structure. Then, the tasks are presented in chapters that follow a common structure: 1) An introduction for teachers, 2) the task in one or more separated pages, that may be printed (from the website) or photocopied for use in schools, and 3) comments about its implementation in the secondary classrooms. The last chapter summarizes some of the challenges encountered and what we can learn from them, in order to promote argumentation.

PART I USING EVIDENCE AND MODELLING ABOUT GENE EXPRESSION

1. Goals and structure of the teaching sequence: Supporting argumentation and modelling

This teaching sequence was designed with the purpose of developing students' competence of using evidence and engaging in argumentation. The context is genetics in the 10th grade (15-16 years), in particular the causal model of gene expression, or relationships between genotype and phenotype, with a focus on gene-environment interactions. The main goal is engaging students in *using evidence* to build or to evaluate explanations about human traits and performances. The sequence was developed and tested through a pilot study and two teaching cycles, in five high school classrooms, involving 127 students (Puig & Jiménez-Aleixandre, 2011). All the schools were public (state schools). In the Spanish curriculum genetics is placed in the 10th grade, the last year of compulsory secondary education. However, in that grade, enrolling in biology is optional for students. For that reason, one of the teachers chose to implement it in a new science course, science for the contemporary world, compulsory for all students in the 11th grade (16-17). The socio-scientific nature of the topic made it appropriate for this course, which addresses scientific issues of social relevance. The implication is that, in different countries, depending on the strand and place of genetics in the curriculum, the tasks may be used in those two grades.

In this chapter we first summarize the goals, then discuss briefly the relevance of the model of gene expression and biological determinism, before presenting the structure of the teaching sequence.

1.1 Goals of the teaching sequence: using evidence, developing critical thinking

The main goal is engaging students in using evidence to build or evaluate explanations about traits and performances. In classroom practice as in science laboratories, the scientific practices of argumentation and explanation are interconnected. As Berland and Reiser (2009) point out, scientific models, causal explanations are constructed through social processes of questioning, evaluation and revision. The tasks in the sequence combine the identification, selection and use of evidence to evaluate claims (argumentation) with modelling gene expression (explanation). These correspond to two of the three scientific competences discussed in the introduction.

These two practices or competences are disciplinary, related to science. Argumentation belongs to scientific practices, and modelling gene expression belongs to scientific practices and to genetics, a particular strand of scientific knowledge. We agree with Tiberghien (2008) about the need to go beyond disciplinary goals when designing science teaching, in view of scientific culture and of citizenship education. We may then say that the sequence has two goals related to science education for students, and a third related to citizenship and to the development of critical thinking:

1) To develop the competence of using evidence to build and evaluate claims and explanations about gene expression, in other words to engage in argumentation.

2) To be able to apply the model of gene expression to issues set in real life contexts, in other words to explain phenomena related to gene expression by using appropriate knowledge.

3) To be able to develop a critical stance towards biological determinism, in other words, to critically evaluate claims about gene-environment interactions.

1.2 Why is it important an appropriation of the model of gene expression?

To use evidence in the context of the model of gene expression requires an appropriate understanding of the phenotype notion and of the influence of environmental factors in the expression of genes. A summary of the model's main ideas may be that while genotype is the set of genes of an organism, phenotype is the expression of these genes, resulting from complex mechanisms involving gene regulation and gene-environment interactions. Phenotype refers to visible characteristics as skin or hair colour, and also to traits that, being detectable, are not visible, such as lactase persistence (adults' ability to digest lactose). Environment influence on gene expression may range from little or no influence, as in blood types, to strong influence, in traits as height, which depends on adequate nutrition.

The relationships among genotype and phenotype in terms of gene-environment interactions account, for instance, for human traits as height or weight, and for human performances such as athletic achievements or intelligence. Students need to understand them in order to engage in arguments about how the environment influences some phenotypic traits, for instance, why nowadays people are taller than several generations ago, which is the topic of the first task.

It is interesting to note how some of the participating teachers (identified with pseudonyms) introduced this issue. Mr. Val explained the influence of environment in the expression of genes, providing six examples, as for instance different causes for rickets, heredity or the lack of vitamin D in the diet, and the effects of temperature of incubation on the sex of crocodile hatchlings. Mr. Quiroga engaged his students in a dialogue about how is genotype manifested or expressed in phenotype. He drew two analogies, the correspondence or lack of it between the building drafts and the actual school, and a music score played by different people. These teaching approaches and their outcomes are discussed elsewhere (Puig & Jiménez-Aleixandre, 2011).

However, there are problems for understanding and applying this model of gene expression, some of them related to determinist views.

1.3 Biological determinism and its connections to racism

Understanding the model of gene expression is necessary for a critical evaluation of determinist views against evidence. By biological determinism we understand positions asserting that all individual traits and performances, including intelligence or criminality are innate, solely determined by genes. In particular this is thought about behaviour or intellectual accomplishments. These positions are related to racist and sexist stances attributing all achievements, and even social differences to heredity. An implication is to justify social inequalities, claiming that investing in education or establishing policies in order to redress inequalities is useless. This is the case of Watson's claim, in task two.

We need to acknowledge that for centuries these beliefs were part of mainstream science, and that science textbooks included hierarchies considering some human races 'superior' to others. Although the current model of gene expression explains the genotype-phenotype relationships as a consequence of gene-environment interactions, there is a persistence of determinist views in society, in literature, the media or jokes. As other socially constructed representations they are resistant to change. This connection to social representations makes this question a socio-scientific issue (SSI). It has been recommended to set teaching tasks in real life and socio-scientific contexts, as they are considered appropriate settings for the use of evidence.

1.4 Structure of the teaching sequence

The teaching sequence has been designed for six sessions, and teachers may choose to introduce relevant concepts integrating them with the tasks, or in a previous session. Here we discuss the six tasks designed in order to promote the use of evidence and modelling. All of them have been implemented in classrooms, in a pilot study and two research cycles extended over a three-year period. The organization of the class is small groups. The structure of the sequence, as well as the performances of use of evidence and the genetics concepts embedded in each task, is summarized in table 1.1.

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Table 1.1. Summary of tasks in the teaching sequence.

Session	Task	Use of evidence: students' performances	Genetics concepts involved
1	*Why are we taller than our grandparents?*	Making sense of data; drawing causal claims from data; elaborating predictions	Model of gene-environment interaction; relationships between genotype and phenotype
2	*People's genotype and phenotype* (adapted from Dixon, 1982, Take two people)	Relating modelling to argumentation; performing a modelling task	Genes and alleles; dominant, recessive; genotype-phenotype relationships; homozygote, heterozygote
3–4	*Black sprinters*	Identifying evidence supporting a given claim; choosing causal explanations on the basis of evidence	Gene-environment interactions; environment factors; genotype-phenotype relationships
5	*Watson on intelligence*	Evaluating a claim in the light of evidence; developing critical thinking	genotype - phenotype relationships; determinism
6	*Cooking doughnuts* (adapted from Johnson, 1991, The doughnuts analogy)	Modelling the influence of environment in gene expression	Model of gene-environment interaction; genotype - phenotype relationships
Assessment	*What would happen with twins?*	Predicting outcomes in a new context; relating causes to effects	Gene-environment interactions

Why are we taller than our grandparents? designed in order to initiate students in working with data, and to mobilize their ideas on gene expression, is set in a familiar context, where students were expected to acknowledge the influence of environment factors in the phenotype (height). About the operations or performances making part of the use of evidence, the focus is on drawing causal claims from data.

People's genotype and phenotype, adapted from Dixon (1982) has as objectives modelling the relationships between genotype and phenotype, involving students in modelling a crossing with a few human traits.

Black sprinters is more complex, and its subtasks require, first to identify evidence supporting a given claim, and second to choose a causal explanation on the basis of the pieces of information provided, integrating them in justifications and so transforming them into evidence. The context is athletics performances.

The focus of *Watson on intelligence* is to evaluate a scientific claim in the light of evidence. The claim is a statement by James Watson, claiming that blacks are less intelligent than white, due to their genes. It addresses determinist representations.

Cooking doughnuts, adapted from Johnson (1991) is a second modelling task about the influence of environment in gene expression, based on an analogy.

What would happen with twins?, was used as part of the assessment, its focus is on the ability to predict outcomes in a new context.

The use of evidence may be addressed in different contexts, disciplinary or others, and in each of them there would be a range of operations making part of it. Each task and related operations are discussed in the next chapters.

2. Drawing claims for data: Why are we taller than our grandparents?

2.1 Introduction: Drawing claims from data

The focus of this task, in terms of the operations or performances making part of the use of evidence is on drawing causal claims from data. For this purpose the students first need to make sense of the information provided, presented as a table with numerical data, as well as to retrieve other information, as improved nutrition.

Being the first task in the teaching sequence and an initial contact with the use of evidence "*Why are we taller than our grandparents?*" was designed in a context familiar for students. The increase of height in younger generations is a well-known fact, and memories of previous hunger in Galicia are commonplace, so it was expected that students would acknowledge the influence of environment factors, such as better nutrition or improved health conditions, in the phenotype, that is in height.

In articulation with the use of evidence, students need to mobilize their ideas on gene expression, on the causes of human (or other organisms) traits. There were at least two possibilities for their responses:

a) Attributing a persons' height to the interaction of environment factors with the genotype; in other words, recognizing genotype as a potential to reach a given height that would be expressed only in certain conditions, as adequate nutrition and health conditions, physical exercise etc. As a consequence, height increase over time would be attributed to a change in these factors. This is aligned with the scientific explanation.

b) Attributing height only to genes. As a consequence, height increase over time would be attributed to a change in genes, mutation or otherwise. It may be noted that, although a mutation causing increased height may happen, it is statistically impossible that it would occur simultaneously in all the population or a big part of it.

The last question in the task asks students to elaborate a prediction about women's height. It may be noted that they were given men's data, the only one available, because they were measured when beginning the compulsory military service.

2.2 Why are we taller than our grandparents? [1]

There are data series about men's height in Spain from the beginning of the 20th century, because their height was measured at 19 years for the purposes of the compulsory military service.

The table below has been prepared using data collected by Professor Rafael Tojo, of the University of Santiago de Compostela. It shows the changes in the average height of Galician males from 1935 to 2005.

Year	**1935**	**1980**	**2005**
Average height	163 cm	170 cm	175 cm

Data collected by Dr. Rafael Tojo Sierra, Research unit on human nutrition, USC.

It can be observed in the table that men's average height increased by 12 centimetres from 1935 to 2005. As Professor Tojo says, it experienced an increase of five centimetres in 25 years, since 1980.

1) *Please, explain in detail which, in your opinion, is the cause for this increase, and what evidence would you give to another person to persuade her or him about it.*

2) *On what does the height of a person depend?*

3) *Do you think that women's height experienced similar changes? Please explain your answer.*

[1] The task may be adapted using data from other countries. See for instance: Weiss, K. M. (2009). Pieces of eight! Evolutionary Anthropology, 18, 125–130. Available at http://onlinelibrary.wiley.com/doi/10.1002/evan.20218/pdf

2.3 Learning from its implementation

We examine what do students need to perform in order to carry out the task, and summarize some results from its implementation in the classroom. It may be noted that the teacher should contextualize the task in the sequence and the genetics models.

First, the students need to make sense of the information provided, presented as a table with numerical data. Usually is taken for granted that 15 year-old students can *interpret simple tables*, but this is not always the case, so the teacher may wish to ascertain that they understand it. They also need to retrieve information not provided, as improved nutrition or health condition over the years, identifying them as environment factors. Although this improvement is commonplace in many contexts, the teacher's scaffolding may be needed. For instance, the teacher may ask the students about the height of their grandparents, about how did they live, what did they eat. Many Galician grandparents were forced to emigrate in the 50s or 60s. Their daily food was cabbage soup. Alternatively teachers may include these data as part of the information provided.

Second, the students need to *draw a claim* from these data, integrating them in a causal explanation, and using the concept of phenotype. Potential answers were discussed in the first section, and next we reproduce some of their responses.

Five classes of 10 and 11th grade students (N= 144) carried out this task in a slightly different format (Puig & Jiménez-Aleixandre, 2009). Most of them gave explanations based on gene-environment interactions, for instance:

" (...) *the fact that we are now taller than our great-grandparents has more to do with food and way of life than with evolution*"

" (...) *in the different generations there is also influence of current habits (way of life, sports, evolution), besides genetics*"

Students mention factors as food, way of life and sports, although it is unclear the reference of the second student to 'evolution' (we interpret it as related to changing ways of life, rather than to biological evolution). However, there were 24 (17%) of them, who interpreted increased height as evidence for evolutionary change, for instance:

"*(...) you see that something changed, that there was some sort of genetic mutation, on account of life conditions and needs being different.* "

"*I believe that it is obvious evidence [*for evolution*] because human beings were evolving little by little with time. In antiquity human beings were quite short, and little by little they were evolving perfecting their body.* "

The second response is an instance of teleological positions about evolution, in terms of a trend towards 'perfection'.

We may understand these difficulties, taking into account that interpretations of changes as mutations, or evidence for evolutionary change, appears in the media, or in popular science books. For instance Diehl and Donnelly (2008) claim that the increase in human height since the times of our great grandparents is an example of (Darwinian) evolution. The implications are that, even in a familiar context, students experience difficulties both to draw claims from data, and to articulate them with scientific models.

3. Relating modelling to argumentation: People's genotype and phenotype

3.1 Introduction: Relating modelling to argumentation

The focus is on modelling genotype-phenotype relationships and the production of gametes. It was adapted from Dixon (1982), introducing: a) the production of the models by students (not by the teacher); and b) exchange of the material models among small groups, asking them to formulate hypothesis about the potential genotypes corresponding to the (represented) phenotype (Jiménez-Aleixandre, 1990).

The scientific practices of use of evidence and modelling are connected, as model revision and evaluation are carried out in the light of available evidence (Berland & Reiser, 2009), as models' explanatory power is appraised against data.

The task addresses students' difficulties with genetics concepts and models, related to their abstract nature. We found the model useful for students, for instance to visualize the existence of two alleles for each trait. The existence of two sets of genetic material, genes and chromosomes, is a central tenet of the model, but studies report that a proportion of students do not apply consistently this idea, even at the end of compulsory secondary education (Duncan et al., 2009).

Students are asked to build an expressed (material) model, using colour pencils and felt-pens to produce schematic drawings of phenotypic traits, as eye and hair colour, (in a simplified version), blood type, earlobe or sex. They are provided with additional information about inheritance models, as for instance blood types, an example of multiple-alleles inheritance. For the 'alleles' they use coloured paper. The objectives are:

a) To model and visualize genotype-phenotype relationships

b) To model and visualize the existence of two sets of genes

c) To model and visualize the role of chance in the production of gametes

d) To formulate hypothesis about potential genotypes corresponding to (represented) phenotypes, and to predict the potential genotypes of offspring.

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3.2 People's genotype and phenotype (adapted from Dixon, 1982)

Working in small groups you are going to build a model about the relationships between genotype and phenotype, selecting a few traits.

Equipment (for each group)

– Two white envelopes
– Colour pencils and felt pens
– Coloured paper or cardboard
– Scissors and a coin

Process

A) Producing genotypes and phenotypes

1) Select *three* phenotype traits to represent, for instance: eye colour (brown/ blue); blood type (A/ B/ 0/ AB); hair colour (dark/ blonde); earlobe (free/ attached), etc. You will also represent the sex, using male (♂) and female (♀) symbols. Now decide which colour (paper) will represent the alleles for each trait (e.g., blue for eye colour, pink for blood type etc.)

2) Using one envelope for the woman and another for the man, represent outside by a schematic drawing the selected *phenotype* traits (three), and the symbol for each sex. Cut a pair of small rectangles of card of the same colour for each trait, and label them. What do they represent? How will that pair be if you have represented a recessive trait? Now put all the cards inside the envelope. Do not forget the cards for sex.

B) Exchange of 'pairs'

3) Exchange the pair of envelopes, so each group would now have a 'pair' different from the one that they produced.

4) *Before opening* the envelope, study the phenotype and propose hypotheses about the possible *genotype* for each trait, and write them. Could there be more than one? Then open the envelope and check each hypothesis with the 'genes'. For how many traits is each parent homozygote or heterozygote? How many different gametes could each one produce (for these traits)?

5) Prepare one male (♂) and one female (♀) gamete, using a coin –to simulate chance– for each heterozygous trait. Then discuss and write the genotypes and phenotypes resulting in a son or daughter. Repeat this step: Are the siblings identical?

3.3 Learning from its implementation

The teacher's support is crucial, as in all modelling tasks. Simplifications should be made explicit: for instance eye colour inheritance depends on multiple genes. Making it explicit would support students' understanding about the nature and role of models.

One of the difficulties observed in the implementation is the construction of the material model of genotype using two cards. Some students intended to use only one card, implying that there is only one allele for each gene. The teacher needs to attend to the process in each group.

After the exchange of the packs, when students are asked to propose hypotheses for the represented phenotypes, some interpreted that there could be only one possible genotype corresponding to each phenotype: for instance only an AA genotype for blood type A, ignoring the possibility of an heterozygote Aa. They do not contemplate that a dominant trait expressed in the phenotype may correspond either to a homozygous or to a heterozygous organism. This is an example about how students' interpretation of data is closely intertwined with their appropriation of the relevant model.

In the whole class discussion it is important to clarify the notion of allele, for instance asking one student to write on the board the potential allele combinations for each trait. The variability among siblings needs also to be discussed and clarified.

Due to time constraints this task was carried out in one session, but we suggest using two sessions, the first to construct the models and to give them appropriate meanings, the second to elaborate hypotheses for the phenotypes and to model the formation of gametes and its combination in the offspring, including emphasis on the role of chance in the process.

4. Choosing explanations on the basis of evidence: Black sprinters

4.1 Introduction: Choosing explanations on the basis of evidence

Argumentation can take place in different contexts (Jiménez-Aleixandre, 2010), for instance the focus of this task is on choosing one explanation on the basis of evidence, while the one in next chapter focuses on evaluating claims. This task addresses how students interpret a real life event: the outstanding performances of black sprinters.

As in the task about height, students need to articulate the use of evidence with the model of gene expression. This one is more complex, first because its focus is on performance, rather than on a physical trait; second because they need to work with a complex dataset. There is a socio-scientific dimension, social representations, for instance in the media, implying determinist views about human races. The task has also as an objective students' development of critical thinking on these representations.

The task addresses several dimensions making part of the use of evidence:

Question (1) asks students to *establish correspondences* among each of the eight pieces of information and the three alternative explanations, in other words to *identify which piece of data support each explanation*. In particular they should identify which ones support the influence of genes and which ones the influence of environment.

Question (2) requires *choosing* one of the three explanations, on the basis of data, so students should *select appropriate evidence* and *integrate it* in the explanation.

Question (3) asks students to decide *which pieces of data constitute evidence* and to justify it. This dimension is related to metaknowledge, knowledge about the *role and nature of evidence*, about the epistemic criteria for evaluating knowledge, for distinguishing evidenced claims from opinion.

The task is designed for two sessions, one devoted to work in small groups, and the second to debating answers in the whole class. Most pieces of information were presented as press cuttings that cannot be reproduced a) by copyright reasons, and b) because they are in Spanish or Galician. Links are provided to sources in English.

4.2 Black sprinters

Handout

How do you explain black sprinters' achievements in athletics?

Since the athletics world championship in Rome in 1987, when there were three white finalists in the 100 m, black sprinters took all the final positions in the Olympic and World Championships. There are different explanations to these achievements:

A) This is due to their genes

B) This is due to the influence of factors such as nourishment, training, etc.

C) This is due to a combination of A and B

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Your tasks:

1) From the available pieces of information, choose which ones support A, which ones B, and which ones C.

2) Choose the best explanation and justify your choice based on the different pieces of information available.

3) From the pieces of information provided: Which ones do you think that constitute evidence and why?

The eight pieces of information (all except the table drawn from press news)

(1) Legs' length

A scientific study in the United States indicated that the legs of black sportsmen are longest in relation to their height than those of white. This could explain their superiority when running: the longest the lower limbs, which act as impulsion levers, the highest would be the runners' speed.

http://www.dailymail.co.uk/sciencetech/article-1294141/Whats-secret-running-swimming-faster-The-position-belly-button-say-scientists.html

(2) *The properties of Yam* (illustrated with a t-shirt "Got yam? Food of champions").

Usain Bolt's father explains the triumphs of his son on the basis of the extraordinary properties of Yam, a tropical plant with a tuber used for food in the Jamaican island.

http://www.reuters.com/article/2008/08/16/us-olympics-athletics-bolt-father-idUSPEK32492120080816

(3) *Sports gene, alpha-actinin: ACTN3*

The gene ACTN3 has two allelic variants: R and X, which can be combined in different ways leading to the genotypes: RR, RX, XX. The presence of the allele R of ACTN3 (RR or RX) leads to production of the protein alpha-actinin located in fast-twitch fibres in the muscles. The allele X does not code for this protein. A scientific study with elite athletes shows genetic differences among "sprinters" and "long distance" athletes. (from *The New York Times*, November 2008).

http://www.nytimes.com/2008/11/30/sports/30genetics.html?pagewanted=all

(4) *ACE protein increases endurance in sports*

ACE protein has two forms, coded by different alleles. Version II improves the cardiovascular activity of athletes, by allowing more blood (and therefore more oxygen) to reach the muscles. This version is more frequent in athletes competing in sports requiring endurance, such as long-distance runners.

Note: ACE (Angiotensin Converting Enzyme) is a protein catalyzing the conversion of one form of the hormone angiotensin, version I, to version II.

http://www.headkicklegend.com/2011/9/21/2439679/ufc-lhw-champ-jon-jones-an-athletic-force-of-nature-or-force-of

(5) High tech shoes and clothing

A new cooling vest, used to avoid heating in sports events lasting two hours or more, delays in 20% the time for the body to reach 39,5º Celsius, the temperature signalling the beginning of decrease in performances (J. Gonzalez Alonso, Spanish expert in the study of thermal stress and performance).

Meschler, the producer of the ultra-light Nike shoes says that they are seeking the return of humans to nature: primitive men would run with naked feet.

http://news.scotsman.com/uk/The-secret-to-Olympic-gold.4153475.jp

(6) *Slave ship routes*

One of the hypotheses attempting to explain the sprinting prowess of Jamaican athletes is, according to Dr. William Aiken: "Since Jamaica was one of the last stops to be made by the slave ships it ensured that only the most resilient and fittest of slaves were alive to disembark in Jamaica."

Dr. Aiken assumes that the inhumane conditions of the voyage would have produced a severe selection pressure that enabled only the fittest slaves to survive the journey.

http://jamaica-gleaner.com/gleaner/20061122/health/health4.html

(7) *Jamaica: Sprinters' island*

Black athletes born in Jamaica or with Jamaican ancestors achieve high in sprint. That is for instance the case for the British Linford Christie or the Canadians Ben Johnson and Donovan Bailey. This supports the belief about the existence of some genetic difference in the Jamaican sprinters.

http://www.genetic-future.com/2008/08/gene-for-jamaican-sprinting-success-no.html

(8) *Olympics Gold medal winners in men's 100 m sprint*

Olympics	Gold medallist / country	Colour of skin	Educated / trained in
Los Angeles 1984	Carl Lewis, USA	Black	USA
Seoul 1988	Carl Lewis, USA	Black	USA
Barcelona 1992	Linford Christie, UK	Black	England since seven years old
Atlanta 1996	Donovan Bailey, Canada	Black	Canada since 13 years old
Sydney 2000	Maurice Greene, USA	Black	USA
Athens 2004	Justin Gatlin, USA	Black	USA
Beijing 2008	Usain Bolt, Jamaica	Black	Jamaica

4.3 Learning from its implementation

The task was implemented in two 10th grade classrooms (N=53) with students working in small groups. We summarize some findings about students' use of evidence, analyzed in detail in other papers (Jiménez-Aleixandre & Puig, 2011; Puig & Jiménez, 2011).

The pieces of information were drawn from press news, with the purpose of reproducing a daily life context and the need to make sense of information with scientific content. Some texts were adapted, others reproduced verbatim. They represent a range of information, by its epistemological status or support in evidence, by the type of factors contributing to performances, and by the support provided to one or more of the three options. The use of complex datasets is recommended both in the argumentation literature and in the policy documents about competence.

About their *epistemological status*, that is if they are opinions or evidenced claims: five correspond to claims supported by data, from scientific studies (according to each piece) as (1) legs' length; (3) sports' gene; (4) ACE protein; (5) High-tech clothing, or from public databases as (8) Olympic medallists. One, (6) Slave ships routes, is a hypothesis based on reasoning. Two, (2) Yam and (7) sprinters' island, correspond rather to opinions, at least as they are worded. For instance, (7) could be transformed in an evidenced claim if it included data about ACTN3 gene or legs' length. Question 3 explored whether students were able to establish these distinctions.

About the *type of factors* contributing to performances: four, (1), (3), (4) and (7) refer to genetics, supporting option A; two, (2) and (5), to environment, supporting B; and two, (6) and (8) to a combination of both, supporting C. It has to be noted that pieces of evidence supporting A and B could be (and actually were) used by students in support of option C. They also made use of data different from the eight pieces, either mentioned in the wording of option B ('nourishment or training'), or implicit in (8), Olympic medallists. We gave examples in B, rather than referring to 'environment factors' as these could be narrowly interpreted by students, for instance as climate.

Results about questions 1, which information supported each explanation, and 2, the choice of one explanation, are discussed together.

The data more easily interpreted as influencing sprinters' performances were (3) sports gene (2), yam and (5), high-tech clothing. The ones used with higher frequency in students' written reports and oral discussions were genes, food and training. For instance they argued about the need to eat well in order to run well. There is correspondence between option A ('due to their genes'), and the wording of items (1), (3) and (4). Students appealed to item (3), entitled 'sports gene', even if the complexities of the full explanation may seem high. It may be noted that some groups used yam, as an example of the influence of food, even acknowledging that it was an opinion (some called it a lie) not supported by a study. It is interesting to note that one group interpreted (1) legs' length as supporting the influence of both genes and environment, claiming that without adequate food the legs would not reach their full length. It is an adequate interpretation, maybe influenced by the height task in session 1.

Other pieces as the Olympic medallists table resulted more difficult. Although some groups claimed, as intended, that it supported the interaction among genes (there are no white winners), and environment (there are no African athletes either), two groups interpreted that it supported only the influence of genes, and one that it supported only environment's. One group reasoned that it showed that the environment had no influence, because the medallists came from different countries.

Given the difficulties encountered to identify gene-environment interaction in this table, in particular the influence (quality of food, health services and coaching) of the country where athletes are trained, and following a suggestion by Per-Olof Wickman, we introduced an additional table in item (8), with data about ice hockey in winter Olympics. As seen in the table all medals in gold, silver and bronze categories, were won by Northern countries' teams. It is expected that students would identify the abundance of ice, together with the hockey tradition in some places as for instance Canada, where it was born, as environment factors that influence performances.

Medallist teams for men's Ice hockey in Winter Olympics

Winter Olympics	Gold medal	Silver medal	Bronze medal
Sarajevo 1984	Soviet Union	Czechoslovakia	Sweden
Calgary 1988	Soviet Union	Finland	Sweden
Albertville 1992 (Francia)	Unified Team (Russia & former soviet republics)	Canada	Czechoslovakia
Lillehammer 1994	Sweden	Canada	Finland
Nagano 1998	Czech Republic	Russia	Finland
Salt Lake City 2002	Canada	USA	Russia
Torino 2006	Sweden	Finland	Czech Republic
Vancouver 2010	Canada	USA	Finland

5. Evaluating a claim in the light of evidence: Watson on intelligence

5.1 Introduction: Evaluating a claim in the light of evidence

The focus of this task is on evaluating a claim. It may be said that, compared with other tasks, as the ones from sessions 1 and 3, which take data as a starting point, here the process is backwards: going from the claim to identify the assumptions behind it, and contrasting it with evidence. This ability to evaluate claims is explicitly addressed in the characterization of scientific competences, as we mention in the introduction.

The claim that the students are asked to evaluate is drawn from James Watson's interview in the *Sunday Times*, October 2007. He claimed that blacks are less intelligent than whites due to genetic factors. In order to support students' evaluation, they are also presented with two items related to environment influence on people performances. In the pilot study (Puig & Jiménez-Aleixandre, 2010) there were four items, one of them the Olympic medallists table discussed in the previous chapter; given the complexity of that item, the task was subsequently modified. The students are asked:

a) To summarize Watson's claim in their own words.

b) To examine each piece of information and to evaluate them in terms of evidence for or against Watson's claim (or lacking relation with it).

c) To identify which type of data would be needed to support or rebut the claim.

Watson's claim is an instance of determinism, the view attributing all human achievements solely to genes, discussed in chapter 1.

Watson's interview: **http://www.timesonline.co.uk/tol/news/uk/article2677098.ece**

To carry out the task the students need to: 1) identify it as *an instance* of the model of gene expression, for the use of evidence is articulated with the use of scientific models; 2) to connect each information with the claim, in other words, to *identify the patterns* in them; 3) to identify *relevant criteria* for the evaluation of evidence, necessary for carrying out parts (b) and (c). This third dimension is related to metaknowledge, or knowledge about the role and nature of evidence.

5.2 Watson on intelligence

Is there evidence to say that there are genetic differences in intelligence between black and white people?

On October 2007, the geneticist James Watson (Nobel prize in 1962 for the discovery of the structure of DNA) declared to the *Sunday Times* that black people are less intelligent than white: "*people who have to deal with black employees find this* [that everyone is equal] *not true*". He claimed that in about 10 years the genes responsible for differences in intelligence would be identified.

1) *Please, summarize Watson's statement in your own words.*

2) *Examine the following pieces of information and point whether they support, rebut or are not related to James Watson's (JW) claims.*

A. The percentage of babies who die before they are one year old (infant mortality) is 4 per 10000 in Spain, France, Holland, etc. In USA (where there is not universal public health system) it is 7 per 10000, with these differences: 5.7 whites and 14 blacks.

A1. I think that
It supports JW's claim
It rebuts JW's claim
It is not related to it

A2. *Please, explain your option, and say how would you convince someone defending the opposite view.*

B. Several studies in Argentina and other Latin American countries show the relationships between child nutrition and intellectual development. Children who suffer chronic malnutrition (hunger) before 2 years of age experience decrease in intellectual performances in school: they have attention difficulties, repeat courses and have language problems. Part of the explanation may be related to the changes in the brain, from about 350 g at birth, increasing to 900 g at 14 months with adequate nutrition.

B1. I think that
It supports JW's claim
It rebuts JW's claim
It is not related to it

B2. *Please, explain your option, and say how would you convince someone defending the opposite view.*

3) *Which type of data do you think that would be necessary in order to prove that: (a) that JW is right; or (b) that he is wrong?*

ARGUMENTATION IN THE CLASSROOM: TWO TEACHING SEQUENCES

5.3 Learning from its implementation

We examine the difficulties encountered for carrying out the task. Watson's statement made to the front pages across the world. We wondered how the public make sense of it, whether they were able to critically evaluate it, to retrieve information challenging it. For this reason it was tested with 9th and 10th grade students, respectively the last year when science is compulsory, and the last in secondary education in Spain.

The first question asks students to rephrase Watson's claim in their own words. For it they need to *identify the meaning* of the statement. Some students interpreted that the items constituted evidence supporting Watson's claim, because they focused only in the first part of the statement ('blacks are less intelligent than white'), arguing that worst health and nutrition conditions would result in poorer performances (Puig & Jiménez-Aleixandre, 2010). In other words, they do not pay attention to the attribution of the differences to genes. An instance:

> "*It supports his claim because not having food and so the brain is not developing, it is clear that they are going to be less intelligent than the others*"

Question 2 requires students to coordinate pieces of evidence with the claim. For it, besides identifying the meaning of the claim, students needed: a) to recognize *the meaning of the items* as instances of the influence of the environment on gene expression (or in the case of item A of different environment conditions for blacks and white); b) to *relate* the data from the items with the claim. Most students related the data to the claim, but some experienced difficulties, as shows this instance about item A:

> "*The fact that there are more black babies dying than white ones has not to do with intelligence, but with the economic possibilities of their parents*."

About question 3, the students propose a range of tests, for instance comparative studies of black and white populations in similar environments, or intelligence tests (which would not provide appropriate evidence). Some appealed to outstanding black leaders, as Mandela, Luther King and Obama, as evidence against Watson. It may be noted that the social nature of the claim caused some students to focus on criticizing its racist implications, rather than on answering the questions.

This points to the need of teacher's support required to develop all the operations making part of the competence in using evidence.

6. Modelling the influence of environment: Cooking doughnuts

6.1 Introduction: Modelling the influence of environment

The focus is on modelling gene-environment interactions, in particular the influence of environment on gene expression, on phenotype. This highly original task was created by the teacher-researcher Sue Johnson (1991) in the Center for Biology Education from the University of Wisconsin[2], to whom we are indebted for her permission to use it as part of the sequence. In the USC we have been using it since the 90s, both in secondary school and in teacher education. While Dixon's activity discussed in chapter 3 was subjected to a deep modification, in this case the adaptation is slight: we use a traditional Spanish sweet '*rosquillas*' (fried or oven-baked doughnuts) recipe, instead of cookies, and make small changes to some questions. We use one doughnuts recipe that can be either fried or oven-baked, which is adequate for the analogy.

Johnson's task uses an analogy to support understanding: as she points out the familiar –relationships between cookies recipes and actual cookies – is used to explain the unfamiliar – relationships between genotype and phenotype. It is a modelling activity supporting the visualization of the influence of environment in gene expression.

It can be adapted to a variety of traditional sweets in each country, taking into account one feature suggested by Johnson: two having similar appearance (phenotype) but a different recipe (genotype); in our case fried anisette and fried lemon doughnuts. We have added two with the same recipe (ingredients), but a different appearance, fried and baked anisette doughnuts.

The students are given the first assignment (recipes) to bake at home several days before the classroom session. The teacher should make sure that the four recipes are going to be baked. The classroom task is carried out in small groups, organized so they have samples of the four types of doughnuts. In the second part students need to exchange doughnuts with other groups in order to have a variety of sweets cooked with the same recipe by different people.

[2] http://cbe.wisc.edu/cbe_pubs/cookie_analogy.html

6.2 Cooking doughnuts (adapted from Johnson, 1991)

A. Prepare cookies at home, following one of these four recipes:

1. Anisette doughnuts (fried) and *2. Anisette doughnuts (oven-baked)*[3]

– 250 g flour	– 1 teaspoon baking soda	– 2 eggs
– 1/2 a cup anisette	– 1 cup milk	– 1 cup sugar
– 1/2 a cup olive oil (plus olive oil to fry them, if they are fried)		

Beat together eggs and sugar. Then add oil, milk and anisette. Combine flour and baking soda, and add them gradually to the mixture, without stopping beating. If needed add more flour until the dough is not sticky. Cut small portions and knead them to cylinders (about half cm diameter), uniting both ends.

1. Fried: Deep-fry them in olive oil, dry on kitchen paper. You can sprinkle with sugar.

2. Oven-baked: Place onto an oven tray and bake in pre-heated oven (170º-180ºC) for about 15 minutes, until golden.

3. Lemon doughnuts (fried)

– 250 g flour	– 1 teaspoon baking soda	– 2 eggs
– 1 lemon rind grated	– 1 tablespoon lemon juice	– 1 cup sugar
– 1 tablespoon water	– 1/2 a cup olive oil (plus olive oil to fry them)	

Beat together eggs, sugar, water, and lemon-rind gratings. Then add oil and lemon juice. Combine flour and baking soda, and add them gradually to the mixture, without stopping beating. If needed add more flour until the dough is not sticky. Cut small portions and knead them to cylinders (about half cm diameter), uniting both ends.
Deep-fry them in olive oil, dry on kitchen paper. You can sprinkle with sugar.

4. Almond doughnuts (oven-baked)

– 200 g flour	– 1 teaspoon baking soda	– 2 eggs
– 1 tablespoon anisette	– 180 g sweetened condensed milk	– 50 g butter
– 50 g sliced almonds		

Combine flour and baking soda and place them in a big bowl or over the kitchen table in a 'volcano' shape. Add in the middle eggs, condensed milk, butter in small pieces and anisette, and knead it. Leave for 30 minutes. Cut small portions and knead them to cylinders (about half cm diameter), uniting both ends. Place onto a buttered oven tray and sprinkle with almonds.
Bake in pre-heated oven (170º-180ºC) for about 15 minutes, until golden.

[3] Anisette (Spanish 'anís'), may be substituted by ouzo or raki. If you do not want to use liquor, you may use aniseed (or a little aniseed essence) instead.

ARGUMENTATION IN THE CLASSROOM: TWO TEACHING SEQUENCES

B. Classroom analysis

B.1 *Observation of the doughnuts*

Arrange your doughnuts on a dish and place them close to dishes containing doughnuts cooked with the same recipe as yours. Please do not taste them now.

1) Were all the doughnuts in a dish cooked with the same recipe? Do all the doughnuts *in a given dish* look identical?

2) Point out all the *similarities* that you observe among doughnuts in a given dish. Point out all the *differences* that you observe among them.

3) Of *all the dishes containing doughnuts cooked with the same recipe*, are the doughnuts identical from dish to dish?

4) Point out all the *similarities* that you observe among them. Point out all the *differences* that you observe among them.

B.2 *Explaining similarities and differences*

Ask the teacher for an empty dish. Each small group needs to put on it one doughnut *from every one of the dishes* (noting the recipe for each one). At this stage you can begin to make taste observations (without finishing them, of course).

5) What are the *possible reasons* why all the doughnuts *baked by the same individual* might not be identical?

6) What are the *possible reasons* why two batches of doughnuts *baked by different people using the same recipe* might not be identical?

7) Explain why doughnuts cooked with recipes 1 and 2 that used *the same ingredients* are so different. Are there doughnuts cooked with different recipes that look similar?

8) Using the doughnuts as examples for living organisms, discuss the *influence* of the ingredients in a recipe and the influence of the way of cooking it. To which elements or features of living beings do the ingredients and way of cooking correspond?

9) Using the doughnuts as examples for organisms, can you always tell by looking at a group of different organisms *which had the most similar recipes*? Explain it.

C. *Conclusion*: Once all groups have finished answering the questions, get back together to the class to discuss them. You may now perform an 'enzymatic analysis' of the doughnuts.

6.3 Learning from its implementation

When used in initial teacher education, student teachers agree with us in finding this activity enjoyable and extremely useful in order to model the influence of environment in gene expression.

Secondary school students in the participant schools also found it exciting. However, the teachers did not always adequately contextualize the task. As a consequence, in some cases, its purpose was not fully understood by all students. For the teachers it may seem easy to establish relationships among the source of the analogy (cooking doughnuts) and the target (genotype-phenotype relationships), however it is not always so for students. Students may not be used to working with analogies and teacher's support is needed in order to explore all the potential of this task. Sometimes teachers are reluctant to use time to explicitly discuss analogies and to establish relationships that look obvious to them, but in our experience this time is necessary for students to grasp the meaning of the activity going beyond to simply enjoying a task so different from standard genetics lessons.

ARGUMENTATION IN THE CLASSROOM: TWO TEACHING SEQUENCES

7. Predicting outcomes in a new context: What would happen with twins?

7.1 Introduction: Predicting outcomes in a new context

This task was a part of the assessment of the teaching sequence, a written test carried out five months after its completion in two classes. Its focus is on the use of evidence and theoretical models to predict outcomes in a context different from the ones used in instruction. It requires students to apply their knowledge to a new situation.

Students were asked to read a brief text about identical twins raised in different environments and, on the basis of these data, to predict what would happen with them at 16 years of age, with respect to particular features of their physical and intellectual development.

In this task the students need to articulate scientific literacy with the competence in using evidence. The purpose was to examine their capacity to build a coherent argument, supporting their claims with appropriate evidence and justifications.

7.2 What would happen with twins?

Two identical twins are born in an African country that is experiencing war. Their mother dies at childbirth and they are separated: one of them, A, stays in the African country living with relatives, while another, B, is adopted by a French family and goes to live in France.

The first one, A, as all his family, has scarce food to eat. He attends the school discontinuously (some days he goes to school, others he does not), because since he is eight years old, on many occasions he needs to work all day.

The second one, B, eats adequate food. He attends school regularly since the age of three.

When they would reach 16 years of age: Do you think that they would be identical in all their features? For instance:

a) Do you think that A and B would have the same height and the same muscle mass or different? Please justify your answer.

b) About reading competence (being able to read and understand a text), and the skills of solving scientific or mathematics problems: Would be the same in A and B or would they be different? Please justify your answer.

ARGUMENTATION IN THE CLASSROOM: TWO TEACHING SEQUENCES

7.3 Learning from its implementation

The question examined whether the students were able to predict that, at 16, the twins would have some similarities, due to their identical genotype, but also some differences, justifying them in the different environmental conditions, that is in the data provided in the task. For instance, about the physical and intellectual traits mentioned in the question, they could:

a) Predict that A would be shorter than B, for although they shared genotype, lack of appropriate nutrition could hinder his development. All students except one predicted that, justifying it in malnutrition, although only 4 out of 46 mentioned the shared genotype (Puig & Jiménez-Aleixandre, 2011).

b) Either predict that B would be more muscular than A, justifying it in the same evidence of malnutrition, or predict that A would be more muscular than B, justifying it in his involvement in physical work. Alternatively they could discuss these two possibilities. The focus of our assessment was on the justifications, and any of these claims was considered appropriate. Only one student predicted than A would be more muscular, supporting it in the need for walking long distances, for instance to fetch water, while (he assumed) B would use car or public transport as most kids in Western countries. The rest of the students, but one, predicted that B would be more muscular, although only four mentioned genes. One student claimed that they would be identical in height and muscle mass, justifying it because they had the same genes.

c) Predict that B would develop better reading and mathematical skills than A, justifying it in the different school attendance. All the students predicted that, justifying it in his problems with school attendance, although only a few, as in the other responses, mentioned that they had the same genotype.

So, in summary, almost all students made appropriate predictions and justified them in the data provided, articulating them with the genetics model. They acknowledged the influence of environment in the twins' development. Nevertheless, only four of them mentioned genes or genotype in their responses (Puig & Jiménez-Aleixandre, 2011). Our interpretation is, not that they do not acknowledge its role, but that they did not perceive the need to mention it, assuming it was common knowledge.

PART II USING EVIDENCE AND MODELLING ABOUT ENERGY FLOW IN ECOSYSTEMS

8. Goals of the teaching sequence: Supporting argumentation and modelling

The teaching sequence was designed with the purpose of developing students' competences of using evidence and explaining phenomena by using scientific models. The context is ecology in the 10th grade (15-16 years), in particular the application of the model of energy flow (energy transfer) to solve problems related to resources management. The main goals are engaging students in *using evidence* to make decisions or to *choose among alternative options* and in coordinating the available evidence with theoretical models. The sequence was developed and tested through two teaching cycles, in four high schools classrooms, involving 66 students. The process of its design, and results from its implementation are addressed in Bravo-Torija and Jiménez-Aleixandre (2010; 2012). In the Spanish curriculum for 10th grade there is an evaluation criterion about relating the diminishing energy in each trophic level to a sustainable management of food resources. However this issue receives a cursory treatment in most Spanish textbooks.

In this chapter we first summarize the goals of the teaching sequence, and then discuss briefly the importance of the appropriation of the model of energy flow and its contextualization in decisions about how to manage marine and terrestrial resources. Finally, the structure of the teaching sequence is presented.

8.1 Goals of the teaching sequence: using evidence, producing representations

A relevant goal of ecology education (as of all science education) should be to prepare students for dealing with real-life problems. For this purpose they need to engage in solving problems, rather than being asked to construct simple food chains. One of these real-life issues is marine resource management. Governments and international bodies are currently facing challenges related to fisheries depletion and discussing how to plan sustainable aquaculture. Students in the 10th grade are in the last year of compulsory education, so most of them are not going to enrol in other biology courses. This grade would be their last opportunity to engage with these issues.

The main goal of the teaching sequence is engaging student in the development of the competences of using evidence and modelling. Working with socio-scientific issues, such as marine or terrestrial resources management, requires students: 1) to apply complex models such as energy flow or trophic pyramid; 2) to transform these models into actions and decisions in real-life contexts (Bravo-Torija & Jiménez-Aleixandre, 2012); and 3) to construct meanings through discourse, for instance about sustainable resources management. Consequently the teaching sequence includes tasks such as modelling energy flow, constructing representations of trophic pyramids (modelling), or solving problems related to resources management by using available evidence. Using evidence and modelling correspond to two of the three scientific competences discussed in the introduction. Therefore the teaching sequence has three goals for students:

1) To develop the competence of using evidence in order to compare alternative options and to choose the option better supported by the available evidence.

2) To develop the competence of modelling energy flow in ecosystems, including producing and explaining the meaning of representations (expressed models) of energy flow, as trophic pyramids.

3) To be able to relate the loss of energy along the trophic chain to resource management. This involves relating energy transfer with their consequences.

The third goal corresponds to one of the evaluation criteria in the Spanish curriculum: "*to explain how energy and matter are transferred along trophic chains or webs, and to draw consequences for sustainable resources management.*"

8.2 Why is it important an appropriation of the model energy flow?

Using evidence and modelling in the context of the model of energy flow in ecosystems require an appropriate understanding of its consequences for resources management. The application of this complex model involves thinking about trophic chains and trophic pyramids as structures representing how energy is transferred among living beings, rather than just reflecting prey-predator relationships. The students need to acknowledge that: a) the origin of energy in ecosystems is sunlight, transformed in chemical energy by producers through photosynthesis; b) chemical energy is stored (as biomass) in organic molecules, along the trophic chain; c) only a small fraction (about 10%) of the energy in each level would be available in the next, while the remaining 90% is consumed in maintenance through respiration, or is lost due to incomplete consumption, and difficulties for assimilation. The students need to appeal to these notions in particular to energy transfer, to explain why each trophic level has much less available energy that the one below.

The relevance of this model for sustainable resources management is that it is much more efficient to eat (or fish) in the lower levels: for instance it is more efficient to eat vegetables than cow meat, or more efficient to eat small forage fish (secondary carnivores), such as sardine, anchovy or herring, than large predators as salmon or tuna. Another consequence is that it would be more sustainable to raise herbivorous than carnivorous fish. However most aquaculture plants raise these large predators, which leads to having more fish (biomass) consumed than produced.

8.3 Structure of the teaching sequence

The teaching sequence was designed by the researchers and negotiated with the teachers. The sequence was spread in five class sessions. Here we discuss the tasks designed to promote the competencies of using evidence and modelling. The classes were organized in small groups. The structure of the sequence, the performances of using evidence and modelling, and the ecology concepts embedded in each task, are summarized in table 8.1.

Task 1 *What is circulating in the trophic chain?,* was designed in order to help students to model energy flow. They produce an analogical model using water and plastic bottles with holes. Students were expected to connect the analogy with the theoretical model, and to draw conclusions for ecosystems.

Why do trophic pyramids have this shape?, seeks to give students opportunities to produce external representations (expressed models) of trophic pyramids, and to reflect on their meaning, in particular to interpret their shape.

How to manage the farm? requires students to apply the energy flow model in the context of terrestrial ecosystems, with explicit options provided. They need to transform theoretical models such as energy flow into decisions about how to manage land resources.

How should scarce fish resources be managed in order to feed more people? also asks students to apply the energy flow model, but to a marine ecosystem, which is more complex. Students play the role of a NGO with the responsibility of managing a bay to feed a population for as long as possible. They need to relate energy transfer with resources management, to select pieces of evidence and connect them with the model of energy flow to justify their choice.

Could aquaculture be a solution?, was used as part of the assessment; it focus is on the application of knowledge to real-life situations, in particular about the potential of the aquaculture as an alternative to overfishing.

Table 8.1. Summary of tasks of the teaching sequence

Session	Task	Use of evidence and modelling: students' performances	Ecology concepts involved
1	What is circulating in the trophic chain?	Modelling energy flow; working with an analogical model	Energy flow, trophic chain, trophic levels
2	Why do trophic pyramids have this shape?	Producing external representations of trophic pyramids and reflecting on their meanings	Trophic pyramids, trophic levels, biomass, energy, productivity
3	How to manage the farm?	Selecting a strategy to manage a terrestrial ecosystem; justifying decisions based on available evidence and theoretical models	Trophic chain, trophic pyramids, energy flow, productivity, biomass
4	How should scarce fish resources be managed?	Making decisions about how to manage a marine ecosystem; using evidence to support their choices and coordinating them with theoretical models	Energy flow, productivity, biomass, trophic chain, trophic pyramids
Assessment	Could aquaculture be a solution?	Identifying a claim and evaluating it in the light of evidence; applying the model of energy flow to the sustainability of aquaculture	Energy flow, trophic relationships, ecological efficiency

Each task and the operations of using evidence and modelling making part of them are discussed in the next chapters.

9. Modelling energy transfer with water: What circulates in the trophic chain?

9.1 Introduction: Supporting models with simulations

The objective, in terms of modelling, is to support students, through a simulation with water and bottles, in the construction of meanings about the process of energy transfer along trophic levels in ecosystems. The goal is to support its transfer to other contexts. Constructing this model has difficulties for students; one of the reasons is that energy is an abstract notion. It is easier to focus on concrete and active phenomena, as who eats whom, than on abstract and "passive" ones (Grotzer & Basca, 2003) such as how energy is transferred. They have problems to understand that available energy decreases along the trophic chain; only 10% of energy is transferred to the next trophic level, while 90% is transformed in other energy forms, not usable by living beings.

Through the simulation, students are expected to be able to connect these abstract notions and theoretical models with concrete objects and events simulated by the flow of water among bottles and the "losses" produced. The ability to make these connections may improve the appropriation of the model of energy flow.

About developing scientific language, students should transform observational language (observe and describe an experience) into theoretical (interpret a phenomenon through scientific models, as energy flow). They are required to describe the activity in both languages and to relate them through the simulation.

It is important that students carry out the simulation themselves, being convenient that all groups start at the same time as it helps teachers to guide it.

When they start transferring the water from one bottle to another, the teacher may insist about the need to carefully observe what is happening, in particular: a) what happens at the end to the water contained in the first (sun) bottle; and 2) what kind of "losses" are produced. At the end of the process students should realize that the water contained in the bottle is only a small amount of the water poured at the beginning.

Once the simulation is finished, students have to answer four questions (we distributed them after the task was completed), reflecting about what happened and relating the observations to ecology knowledge, in particular about the energy flow.

9.2 What is circulating in the trophic chain?

Working in small groups you are going to build a model about energy in trophic chains.

Equipment (for each group)

a) Five bottles of water of one and a half litre. Four of them have holes in its bottom.

b) Water and food dye, preferably yellow or orange, for the first one (sun bottle).

c) A washbowl or tray for collecting the water, to avoid spilling it on the table.

Process of the simulation

Place the five bottles in order according to the trophic chain, from producers to tertiary consumers. When everything is ready, you can start transferring the water from the 'sun' bottle to the next, and from this second bottle to the next until you reach the fifth one. Observe carefully what happens.

Questions

Four of the five bottles represent trophic levels, from producers to tertiary consumers, and the first bottle, represents the sun, the main source of energy for living beings. During the simulation process, you have observed some phenomena. Answer these four questions about them:

1) Please, describe in detail what you have observed.

2) At the end of the simulation, what happened with the water contained in the bottle representing the sun?

3) What do you think the simulation represents? Please explain your answer

4) What would the process mean if, instead of bottles, there were animals and plants?

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9.3 Learning from its implementation

We examine students' operations in order to carry out the task. The questions are increasing in abstraction, from observations to establishing relationships between observed and represented, to the application of knowledge to actual ecosystems.

The first two questions ask students to describe their observations, what has happened along the process. They should explain the flow of water among bottles and the small amount remaining, compared with the initial one in the sun bottle. Students need to take into account two kinds of "losses": 1) water spilled outside bottles; and 2) water that flows through each bottle and is "lost" through the holes in the bottom. Both the flow of water and the "losses" are crucial observations in order to understand the model of energy flow. At this stage teacher's scaffolding may be needed in order to clarify what an observation is: some students relate the simulation directly with the theoretical model instead of explaining what happened during it.

In the third question, students are asked to interpret the simulation. They should relate the flow of water and its "losses" to the theoretical model. To do so, students need to retrieve on the one hand the notion of energy transfer connecting it with the flow of water, and on the other the notions about transformation of solar energy into heat energy, connecting them with the "losses".

The fourth question requires application of knowledge. Students should connect the theoretical model and the simulation with processes in actual ecosystems. To do so, they should apply the model of energy flow, relating each organism to its trophic level, for instance plants to producers, and relating energy transfer, and its decrease along the trophic chain, to the limited number of trophic levels (energy is not transferred indefinitely). Teacher's support is essential to engage students in reflecting about how energy is transferred and what happens during the process. To relate the decrease of energy along the trophic chain to its consequences in the ecosystem is necessary in order to carry out tasks about sustainable resources management.

10. Producing representations: Why do trophic pyramids have this shape?

10.1 Introduction: Producing external representations

The objective of this task is for students to develop the ability to produce external representations, or expressed models, of phenomena or systems. A second objective is to give meaning to the representations of trophic pyramids, to interpret its shape. The role of external representations in learning is being reappraised, by an approach conceiving them as forms of knowing (Pérez Echeverría & Scheuer, 2009). These authors point out that external representations contribute to make knowledge content visible to learners, and support them in relating (represented) content to its changing meanings as they learn.

Students are asked to produce external representations of the trophic pyramids of number of individuals, biomass and productivity, which represent ecosystem's relationships, in particular the decrease of energy along trophic levels. Producing representations of trophic pyramids and reflecting about their meaning make part of modelling. Both operations support students in externalizing their reasoning and in visualizing and testing their theories about ecosystems. This is an original feature of the teaching sequence, as most teaching approaches and textbooks use these representations merely as an illustration of concepts, and students are not asked to produce them.

Students will be able to use representational language (a type of scientific language) to interpret phenomena and to communicate about them. Using this language to provide information about the structure and dynamic of ecosystems makes part of the linguistic competence.

The task was carried out in small groups, which supports knowledge exchange among students, although teachers may choose to carry it out individually. The three parts of the task, building trophic chains, building trophic pyramids, and explaining their meaning, have increasing cognitive demand.

10.2 Why do trophic pyramids have this shape?

Study carefully these tables of data; then carry out the three exercises below:

Table 1. Instance of terrestrial ecosystem (prairie)

	Nº of individuals	Productivity (kcal / km² / year)	Biomass (kg / km²)
Humans	10	8×10^4	480
Cows	45	1.19×10^7	10 350
Grass (Lucerne)	2×10^8	1.4×10^8	82 110

Table 2. Instance of marine ecosystem

	Nº of individuals	Productivity (kcal / km² / year)	Biomass (kg / km²)
Salmons	120	70	540
Sardines and Herrings	8280	900	1800
Carnivorous plankton	108×10^5	11 000	5400
Herbivorous plankton	36×10^7	110 000	18 000
Vegetal plankton (Microscopic seaweed)	2×10^9	1 825 000	10 000

1) Build the two trophic chains for the organisms making part of the ecosystems of table 1 and table 2.

2) Using the data from the tables and the trophic chains that you constructed, draw the trophic pyramids for number of individuals, biomass and productivity for each of the ecosystems. Please explain the steps that you followed.

3) Why do the resulting figures have the shape of a pyramid and not a different geometrical shape? Discuss it in the group and explain it. Exercises 1 and 2 may help you to answer this question

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10.3 Learning from its implementation

We examine how students carried out this task, in terms of operations performed to produce the external representations, concepts used to ground them, and their interpretation. There are two operations in the task: a) producing the representations of the trophic pyramids; and b) interpreting their shape and meaning.

In the first exercise, students are asked to produce trophic chains. Although this may seem an easy process, they encountered difficulties in the marine ecosystem, more complex and less known. Teacher's support was needed, for instance to relate each organism to its trophic level, and to clarify the paradox of herbivorous plankton having more biomass than vegetal plankton.

In the second exercise students produce the representations of the trophic pyramids. To do so they need to consider that the differences among trophic levels should be reflected in the representation of the trophic pyramid, with each level decreasing in width in respect to the previous one. In this process some students encountered difficulties in: 1) attributing a trophic level to each organism and relating it to its position on the trophic pyramid; and 2) deciding a given width for each step.

In order to help students to overcome these difficulties, teachers had to support them in deciding the scale for the representations. For instance, to help them to understand the so called "rule of 10%" –only 10% of the energy from one trophic level is transferred in available form to the next–. This should be reflected in the representation of the trophic pyramid, as any level is a tenth part of the level immediately below it.

In the third exercise, students are asked about the shape. This requires relating the representation to the theoretical model supporting it, energy flow. In other words, they need to acknowledge that the decrease in number of individuals, biomass or productivity is due to the decrease of the available energy across the ecosystem. To do so, an appropriate understanding of the data is essential. Four out of 18 small groups did not discuss this question or answer it. Perhaps this is related to the use of inappropriate models such as "who eats whom" instead of the model of energy flow.

In this task, the transformation of languages is promoted. To carry it out, students should move from observational language (data) to representational (drawing of the pyramid) and to theoretical (energy flow) and vice versa.

11. Applying the model: How to manage the farm?

11.1 Introduction: Using models in different contexts

The focus of this task is on transforming theoretical models such as energy flow or trophic pyramids into decisions about how to manage resources in a terrestrial ecosystem in order to obtain the highest efficiency in terms of use of energy. To carry it out means to apply the energy flow model in the context of farm management. Working in small groups students need to: a) select pieces of information and connect them with the relevant models; and b) evaluate different options with basis on the available evidence.

This task has a similar focus that the one about marine ecosystems in the next session (chapter 12). The reason is that, in order to be able to use evidence and models, students need to practice with them, not once but repeatedly, in different contexts. It has to be noted that, frequently, two tasks or problems that, for the teacher, have the same focus are considered by students to address different issues. The differences between this task and the one about marine ecosystems are: 1) *Complexity*: the one about farm management is less complex, requiring mainly an application of the energy flow model, and a comparison among the amount of food and corn needed by each animal, while the task about a marine ecosystem requires to take into account two models, energy flow and ecosystems maintenance; 2) *Explicit versus not explicit options*, options are provided in the task about farm management, while in the task about marine ecosystems students need to elaborate them; 3) *Familiarity*: terrestrial ecosystems are more familiar to students; 4) *Difficulties*: terrestrial ecosystems offer less difficulties, while marine ecosystems pose some problems to students, for instance the data about biomass (higher in herbivorous plankton than in vegetal plankton).

These features made this task more appropriate for a first practice with modelling and the use of evidence. As the students' difficulties are similar, we will discuss its implementation in chapter 12.

11.2 How to manage the farm?

Each small group represents a family. You have inherited a piece of land from a great uncle, consisting in a hectare (about two and a half acres) of cultivable land in his hometown. Your task is *to decide how are you going to manage this piece of land*, in particular, what to do with it in order to get as higher a yield as possible.

You have several options:

a) Using it to grow corn (or other vegetables).

b) Using it to grow corn in order to raise cows.

c) Using it to grow corn in order to raise chicken.

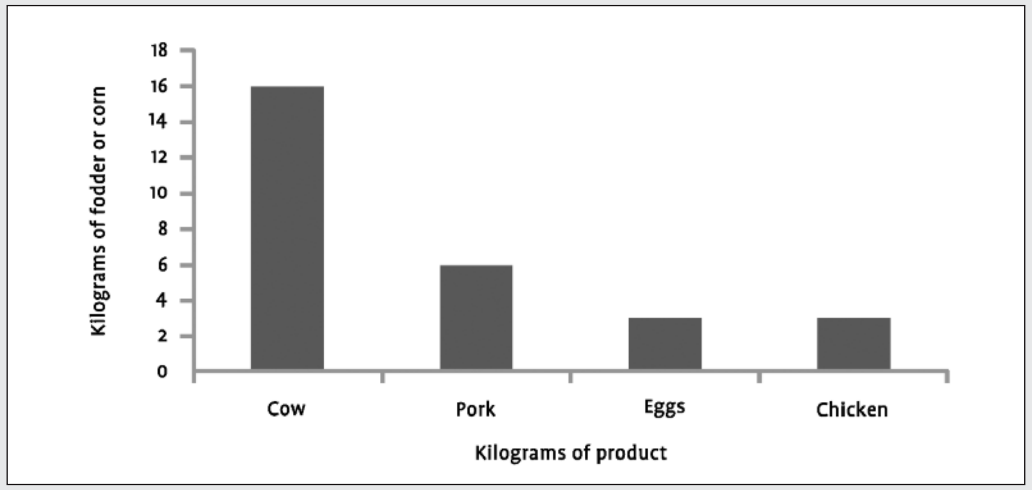
d) Using it to grow corn in order to raise pigs.

e) A combination of two or more of the previous options.

You would need to use the pieces of information below in order to plan what to do. Once you reach a decision, you need *to explain and justify it carefully* to the other small groups.

Information

1) Graph representing the number of kg of fodder and / or corn needed to get one kg of each different animal product.



2) The table of the meadow ecosystem that you used in the previous session.

	Nº of individuals	**Productivity (kcal / km² x year)**	**Biomass (kg / km²)**
Humans	10	8×10^4	480
Cows	45	1.19×10^7	10 350
Grass (Lucerne)	2×10^8	1.4×10^8	82 110

3) The trophic pyramids of numbers, energy and biomass resulting from the data in the table, which were constructed in the previous session (*the drawings were provided in the handout*).

12. Using evidence to make decisions about resources management

12.1 Introduction: Using knowledge in an authentic context

The focus of this task is on transforming theoretical models such as energy flow or trophic pyramids into decisions about marine resources management. Students are asked to decide about what to fish in a bay in order to feed people for as long time as possible. In the bay there are different species, forage fish, herring and sardine, which are secondary carnivores, and salmon, tertiary carnivore.

The objectives are: a) to relate energy transfer with resource management; and b) to select evidence and to connect it with the model of energy flow to justify their choice.

From the perspective of operations making part of the competence in using evidence, students need to: a) select relevant data from the information provided; b) relate different sets of data and identify patterns in them; c) draw conclusions from data; d) coordinate data with theoretical models; and e) evaluate different alternatives. To do so, students need to take into account both pieces of evidence and theoretical models:

1) *Pieces of evidence provided*: a) diets of herrings and sardines, and diet of salmon; b) trophic chain; c) data tables of biomass and productivity; and d) representations of trophic pyramids, produced in the second session.

2) *The theoretical models of energy flow and trophic pyramids* addressed in the previous sessions, and the model of ecosystem dynamics from previous years.

Students are also engaged in communicative practices, the elaboration of a written report about the decision in the small group, and its oral debate in front of the class.

The task is carried out in small groups since the exchange of opinion favours the co-construction of arguments. Teacher's support is needed in order to guide students in the designing of the management plan, in particular to help them to integrate different theoretical models or to take into account available evidence.

12.2 Resources management in a bay

A small town on the seaside was hit by a hurricane. Afterwards, many people were homeless, their harvests destroyed, and most of their cattle was lost. Currently the main resource they have for surviving is a small bay, where several fish populations exist, including sardines, herring and salmon.

You are a NGO team, sent in order to help the people in the town to manage the bay, so that it provides them with food for several months while their crops are able to grow again and cattle can be raised. *Your objective in this task is to decide how to manage the bay in order to feed the population for as long as possible.* You will need to arrange the most efficient way of using the fishing resources available, and to elaborate a plan, explaining how you would carry it out.

The following resources may be helpful

A) *Useful scientific information*

1) *Salmon diet* (Powell, 2003): mainly sardines and herring, in a proportion of 1:5 that is, for producing one kilogram of salmon, 5 kg of sardines/herring are needed.

2) *Sardine and herring diet* (Powell, 2003): they eat plankton, mainly herbivorous and carnivorous plankton.

3) *Table with the productivity and biomass in this trophic chain*

	Productivity (kcal / km^2 / year)	**Biomass (kg / km^2)**
Salmon	70	540
Sardines and herrings	900	1 800
Carnivorous plankton	11 000	5 400
Herbivorous plankton	110 000	18 000
Vegetal plankton (microscopic seaweed)	1 825 000	10 000

4) *Trophic chain*

Solar energy ⟶ **Vegetal plankton** ⟶ **Herbivorous plankton** ⟶ **Carnivorous plankton** ⟶ **Sardines and herring** ⟶ **Salmon**

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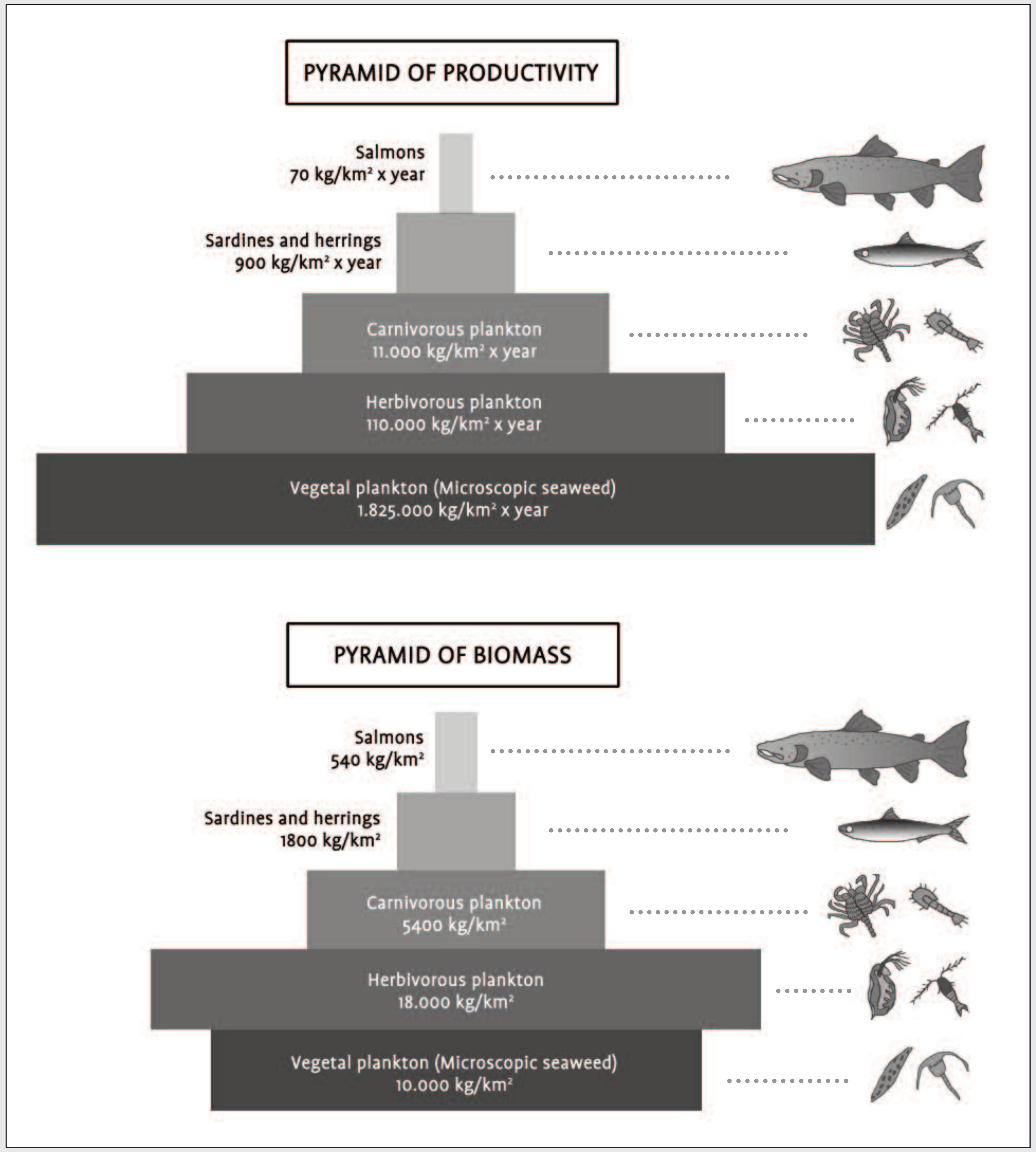
5) *Trophic pyramids*



B) *Simulation*: a blue card representing the bay, and pasta from different sizes, representing the trophic levels. Each "trophic level organism" is of a bigger size than the previous one, and there are greater amounts of the "organisms" from lower levels.

Remember: It is important to take into account what you learnt in this lesson.

Your task: Describe in detail your plan, so it can be discussed with the other groups.

12.3 Learning from its implementation

It may be noted that sustainable management would need to integrate two models: a) *energy transfer*, leading to an option for higher ecological efficiency; this involves fishing more at lower trophic levels (sardine and herring) and less at higher (salmon), e.g. in proportions as 5:1 (supported in data about diet) or 10:1 (supported in data about productivity and biomass); and b) *ecosystem's maintenance*, reproduction and renewal; in other words, considering that fishing too many individuals from a given population, for instance sardine, would result in an impossibility to reproduce, compromising the existence of these resources for other trophic levels and for future generations.

An appropriate interpretation of data is needed in order to integrate these models with the information provided and to reach a decision. Key points are for instance the diet of salmons (5:1 proportion) or the biomass and productivity of salmons compared to herrings and sardines. In this task, as in the previous one, students need to move between representational and theoretical languages, to reach decisions such as to fish more herrings and sardines than salmons, for instance in a 5:1 proportion.

The different data sets represent more data and of higher complexity than they are used to handle. Standard tasks either do not require students to use data or provide only a limited set of them. In the implementation, students' difficulties in the use of evidence in a decision-making context were identified (Bravo & Jiménez, 2011), in particular: a) in identifying and interpreting data and evidence, and in establishing connections among different data sets; b) in integrating evidence in justifications; c) in framing evidence in theoretical models; and d) in considering alternative options, not just one.

About the use of models, we found that the model of ecosystem's maintenance and "who eats whom" were used more frequently that the model of energy transfer (Bravo & Jiménez, 2012). Only three groups out of 16 were able to integrate both theoretical models in the justification of their decisions. This shows that students have problems for coordinating two theoretical models.

Due to the complexity of the task, teacher's continuous support is essential. For instance when the teacher identifies difficulties he or she can help students reflect about the goal of the problem, providing a new approach that they have not yet considered. To be able to coordinate theoretical models is a complex process, but with the teacher's support the students from our study were able to carry it out.

13. Evaluation of knowledge transfer: Herbivores or carnivores?

13.1 Introduction: Transferring knowledge to new contexts

The objective of this task, used as part of the assessment, is to apply new knowledge in order to reflect about the potential of the aquaculture as an alternative to overfishing. Students have the opportunity to apply models such as energy flow to a problem of social relevance.

Teachers may wish, before implementing the task, to review issues addressed in previous sessions, or how students applied their knowledge to make decisions. In particular they may introduce aquaculture as an alternative to marine resources management. Although aquaculture is prominent in the media, some students may not be familiar with it. It could be interesting to give students familiar examples of raised fish such as salmon, trout, gilthead bream or sea bass.

Another issue that could be addressed is the diet of farmed fishes, for instance by eliciting students' ideas about what kind of food do they usually eat. If no one mentioned the idea of animal feed, it could be necessary to draw an analogy about how chickens and cows are fed on industrial farms. It would be better if students establish the relationships themselves, because it will help them to identify the main claim of the text and the evidence supporting it.

The assessment task can be carried out in groups or individually, depending on its goals. In this case, it was used for assessing the competences of using evidence and modelling and the application of scientific knowledge to real contexts.

The teacher distributes the text to students, leaving them some time to read it and addresses questions about vocabulary or information that they have difficulties in understanding. It may be a good idea to show images of the species involved in the text for, depending on the country, students may not be familiar with them.

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13.2 Could aquaculture be a solution?

Read these extracts from S. Simpson's "The Blue Food Revolution", *Scientific American* 314, February 2011, and answer the questions.

"The aspect of marine (saltwater) aquaculture that has been hardest to fix is the need to use small, wild fish as food for the large, farmed varieties. (The small fish are not farmed, because a mature industry already exists that catches and grinds them into fish meal and oil.) [...]

30 percent of Kona Blue's feed is ground up Peruvian anchovy. Yellowtail could survive on a vegetarian diet, but they wouldn't taste as good [...]. Nor would their flesh include all the fatty acids and amino acids that make them healthy to eat. Those ingredients come from fish meal and fish oil, and that is the issue. "We are often pilloried because we're killing fish to grow fish," Sims [*manager of a fish farm*] says. Salmon farming, done in coastal pens, draws the same ire.

Detractors worry that rising demand from fish farms will wipe out wild anchovies, sardines and other forage fish. Before modern fish farming began, most fish meal was fed to pigs and chickens, but today aquaculture consumes 68 percent of the fish meal. Consumption has lessened under advanced feed formulas, however. When Kona Blue [*the fish farm*] started raising yellowtail in 2005, its feed pellets were 80 percent anchovy. By early 2008 the company had reduced the share to 30 percent –without sacrificing taste or health benefit, Sims says– by increasing the concentration of soybean meal and adding chicken oil, a byproduct of poultry processing. The compound feed pellets are a big improvement over the egregious practice of dumping whole sardines into the fish cages. Unfortunately, this wasteful habit remains the norm among less responsible farmers."

Questions:

1. What is the main conclusion that you draw after reading the text?

2. From the pieces of information provided in the text: Which ones would you use to support your conclusion? Please, explain your answer.

3. Based on the text and on what you have learned: Which actions would you propose to improve aquaculture current practices, from an environmental perspective? Please, explain your answer.

13.3 Learning from its implementation

The first question asks students to draw the main conclusion. To do so, they need to make sense of the information, selecting key ideas in the text. The main idea, repeated in different forms, is that the central problem in aquaculture is the need to catch small wild fish to feed farmed species. Other relevant ideas relate to alternatives to this use, for instance soybean. Although this is not the central claim, it can be considered adequate, because it means an acknowledgement of the problem of aquaculture's sustainability. Eventually, some conclusions might appear referring to fish in general, without identifying the issue addressed. Understanding texts with scientific information is taken for granted in science classrooms, but studies show that not all students are able to extract the meanings from them.

The second question asks students to identify evidence supporting their claim. To do so, they need to decide which pieces of information constitute evidence and to justify it. An important aspect is the coherence in selecting evidence: for instance, if students conclude that the main problem of aquaculture is the need to use small wild fish as food for the farmed one, they can support it with evidence from these excerpts: "*small fish are not farmed, because a mature industry already exists that catches and grinds them into fish meal*"; the one beginning "*30 percent of Kona Blue's feed is ground up Peruvian anchovy. Yellowtail could survive on a vegetarian diet, but they wouldn't taste as good*"; and the one beginning "*Detractors worry that rising demand from fish farms will wipe out wild anchovies, sardines and other forage fish.*"

The third is an open-ended question: students are challenged to propose alternatives for environment-friendly aquaculture. Potential answers can make reference to raising herbivorous species such as carp and tilapia, or to the reduction of fish meat in the composition of animals feed. Then the teacher can discuss other options, like feeding farmed fish micro-seaweed or artemia (zooplankton); fish feeding on these species are situated in lower trophic levels than carnivorous fish such as salmon.

The aim of this activity is to encourage students to reflect on how the consumption of fish products to produce animal feeds would affect marine ecosystems. There is a need for teacher's support in encouraging students to compare different alternatives (rather to decide on the first one) and in promoting the debate.

14. Concluding comments: The challenges for promoting argumentation

These teaching units were designed with the purpose of promoting argumentation in secondary science classrooms. They combine tasks focusing in the use of evidence with others focusing on modelling. The tasks about use of evidence address different dimensions: drawing claims from data or from texts, choosing explanations or courses of action on the basis of evidence, and evaluating claims in the light of evidence.

In all the cases the students need, for instance, to make sense of data, to select data relevant for a claim, or to identify patterns. For these purposes, and for all the operations related to the use of evidence, it is necessary the articulation with the relevant models, gene expression in the first sequence and energy flow in the second one. Science learning and development of argumentative competences are interconnected. To engage in argumentation is for students to experience, as Roberts (2008) advocates, the epistemic practices of particular science discourses and reasoning patterns.

To engage in these practices, to use evidence, to build arguments is not devoid of difficulties, some of them discussed in the comments to each task. This engagement requires constant support on the part of the teacher. For this to occur, teachers' ownership is crucial, and it is suggested to cooperate with teachers in the design of the tasks, to incorporate their suggestions, to discuss the purposes of each activity, to support them in understanding why some students experienced problems in carrying them out. In summary, teachers and researchers collaborate in making sense of the challenges involved in taking a complex practice to the classroom. The authors are grateful to all the teachers who collaborated in this work and who granted researchers access to their classrooms. Thank to them it is possible to understand better the complex challenges involved in using evidence and in modelling.

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These teaching sequences have the purpose of providing resources and strategies for teachers interested in creating learning environments for argumentation and inquiry in science classrooms. The tasks are designed in order to engage students in using evidence, building arguments and modelling about two topics: the model of gene expression and energy flow in ecosystems. Both issues are socio-scientific, gene expression is related to the understanding of gene-environment interactions shaping traits and performances, and so to being able to criticize determinist approaches. Likewise, understanding energy flow in ecosystems is necessary in order to discuss and decide about sustainable resources management, for instance issues related to the depletion of fishing resources.

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