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# INQUIRY BASED LEARNING: WHY BUYING A CAR WITH A TREE INCLUDED? ENHANCING SCIENCE AND MATHEMATIC LEARNING

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## Abstract

International reports reveal a deficient situation in relation to science and mathematics learning, which can be considered as an obstacle for the education of literate and informed citizens and the qualification and the preparation of future scientists and engineers. This situation may be partly attributed to the way science and mathematics are taught at school.

Research on effective teaching approaches shows that inquiry based learning (IBL) improves students' engagement and motivation for science and mathematics learning and promotes the development of process skills, critical thinking and conceptual understanding of some science and mathematics topics.

The present work describes the design and implementation of an instructional approach for enhancing science and mathematics learning through IBL. The instructional approach is based on the design of an interdisciplinary task which starts by challenging students through the analysis of an advertisement. The initial scenario engages students in an investigation process to look for evidence and understanding while acquiring meaningful learning of key science topics and mathematical tools. The task also takes advantage of current technological resources to facilitate and support the overall inquiry process.

## 1 INTRODUCTION AND BACKGROUND

Recent reports by experts [1] highlight a decrease in students' interest in science and mathematics at school, with a significant effect on the numbers of young people choosing scientific studies and careers. The negative impact of this situation on individuals' preparation for taking an active and informed role in modern, knowledge-based societies raises a serious concern [1]. Additionally, this trend may be interpreted as an important threat to our societies' capacity for innovation and development [2], [3].

The key relationship between teaching methods and students' attitude to science and mathematics learning has been repeatedly reported [2], [4] and is explicitly addressed by the European Union in its call for proposals within the 7th FP Capacities Work Programme, Science in Society:

*'Falling interest in key science topics and mathematics has been linked to the way they are taught from the earliest age. Therefore, greater emphasis needs to be placed on the development of more effective forms of pedagogy; on the development of analytical skills; and, on techniques for stimulating intrinsic motivation for learning science' [5], p. 18.*

Transmission-based pedagogies where students are considered as passive receivers and reproducers of information do not support the development of skills and competences. Society is currently demanding critical thinkers, able to efficiently select and use information, solve problems, adapt to new situations and keep on learning in an increasingly complex and rapidly evolving society. Therefore, there is an urgent need to support those teaching approaches which foster students' active learning in science and mathematics, and which promote not only conceptual understanding of key curricular topics, but also the acquisition of skills and competences.

Inquiry Based Learning (IBL) is the pedagogy being promoted as a key approach to address these challenges [5], [6], [7]. Furthermore, on a European level most educational documents, such as educational policy documents or curriculum guidelines, support and require an introduction of IBL to school subjects [8].

Taking into account the outlined background, this paper describes the development of an interdisciplinary task for enhancing science and mathematics learning through IBL. The main pedagogical objectives of our instructional approach are:

- Increase students' motivation and positive attitude towards science and mathematics learning.
- Provide scenarios and contexts for meaningful learning from an integrated and interdisciplinary perspective.
- Promote the development of critical thinking, informed decision making, process skills and competences.
- Offer opportunities for collaboration and autonomous learning through a student centred pedagogical approach.
- Take advantage of information and communication technologies and other technology-based resources to increase the opportunities for inquiry and efficient mathematics and science learning.

## 2 THEORETICAL FRAMEWORK

The American National Science Education Standards [7] describe inquiry in education as '*a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in the light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations*'. (p. 23)

Therefore, in a narrow sense IBL may be defined as a teaching approach which intends to promote learning by engaging students in any of the processes or activities typically involved in scientific research, such as:

- Observation making.
- Hypothesis formulation.
- Definition of problems and key guiding questions.
- Design and performance of experiments.
- Data handling (acquisition, gathering, representation and analysis of data).
- Draw of conclusions based on the available evidence.
- Communication and discussion of results.

Within the PRIMAS project there is a multifaceted understanding of IBL which does not only focus on the processes related to scientific inquiry, but on other key aspects considered as essential for an efficient IBL implementation. These IBL characteristic features may be outlined as follows:

### 2.1 Students' activity

Students are expected to pose questions, make decisions, design plans and experiments, discuss, collaborate, communicate results and provide justified answers and explanations when engaging in the inquiry process.

### 2.2 The teacher's role

Teachers are not considered as knowledge providers but as motivators and facilitators of students' learning. For this purpose, specific teaching competences are required to subtly guide students and help them to work in profitable ways. The use of questioning for triggering students' reflection, critical and logical thinking and self-regulation through their own learning process is one of the teacher's skills, necessary for playing a suitable role as student guide. In this line, the ability to prompt constructive interaction between students when holding a discussion is crucial for ensuring the social construction of knowledge. Teachers should also know how to design and use unstructured tasks which offer appropriate challenges and provide rich contexts and scenarios to facilitate learning.

### 2.3 The classroom atmosphere

The classroom atmosphere is considered as a key feature of an efficient IBL implementation. It is important to establish a culture where there is not a knowledgeable authority but instead, ideas are respected and accepted according to their foundation and how they are supported by evidence and

logical thinking. In this atmosphere mistakes are considered as opportunities to learn and there is a shared sense of ownership and purpose.

## 2.4 The expected learning outcomes

Students are expected not only to acquire conceptual understanding of science and mathematics topics, but also to develop process skills and competences. Since IBL requires a student-centred approach it promotes more autonomous learners and lifelong inquirers.

The briefly described theoretical framework has shaped our pedagogical proposal. In the next section we will present and analysed the task entitled 'car pollution: buying a car with a tree included' highlighting its potential pedagogical benefits from an IBL perspective.

## 3 OUR PROPOSAL FOR ENHANCED SCIENCE AND MATHEMATICS LEARNING

### 3.1 Car pollution: Buying a car with a tree included?

The starting point of the 'Car pollution' task is an advertisement of a well-known German car manufacturer. The advertisement, that can be seen on TV and on the car manufacturer webpage, is related to an ecological-friendly program called 'CO<sub>2</sub> neutral' program (Fig. 1).

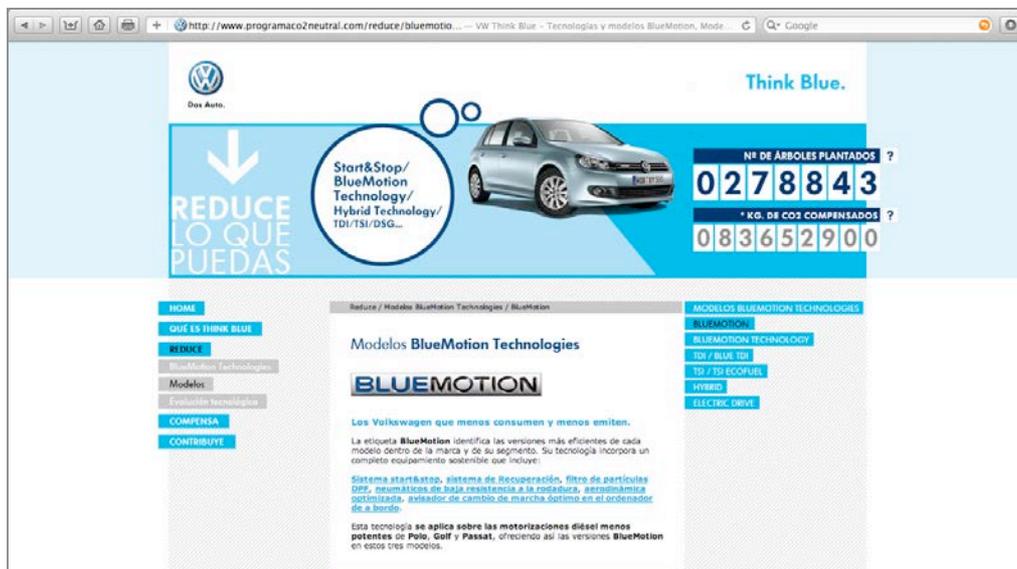


Fig. 1. The CO<sub>2</sub> neutral program site.

Briefly, the program involves planting trees to compensate for the carbon dioxide emitted by the cars sold in their first kilometres. For instance, if you are a customer and you surf in the configuration tool of the manufacturer's webpage, you will find that every car includes one tree for free. As it is explained in the webpage, this tree will compensate for the CO<sub>2</sub> emitted by the car in its first 2000 km (Fig. 2).

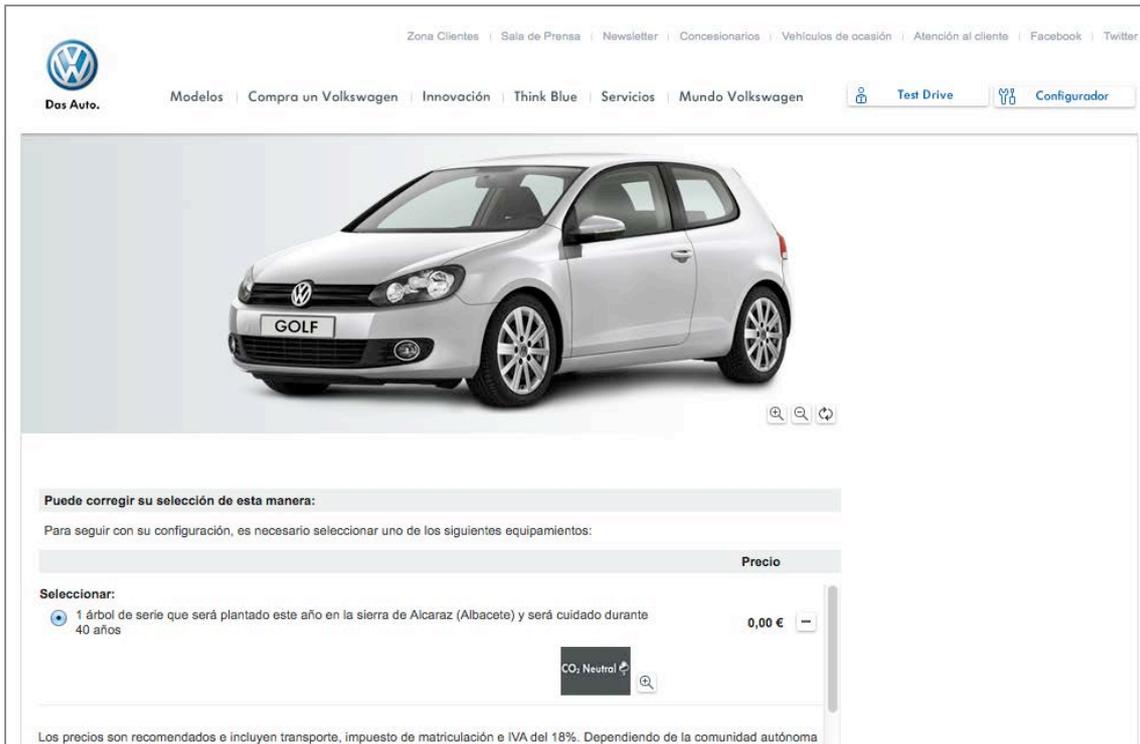


Fig. 2. One tree included in your new car.

If you continue selecting options for your new car (like the colour, the engine, or the equipment), you will find that you can pay for a extra 'CO<sub>2</sub> neutral pack'. The price depends on the car and the engine. The pack includes a number of trees that will be planted in the Alcaraz mountains (Albacete, Spain) to compensate for the CO<sub>2</sub> pollution caused by your car in its first 20000 km. You can buy as many packages as you want, depending on the pollution you would like to compensate for.

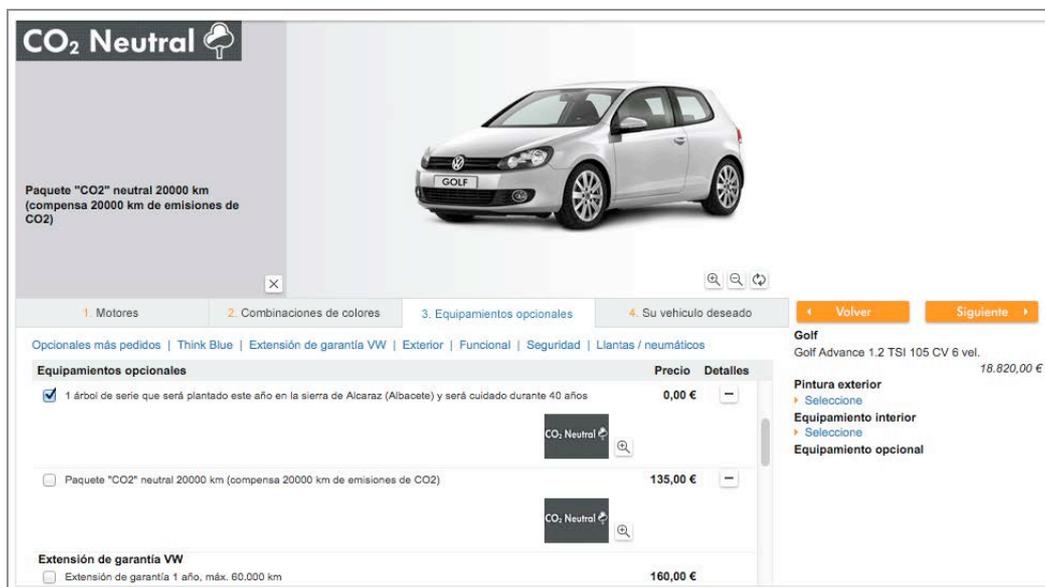


Fig. 3. Trees as an optional equipment.

We consider this context to be engaging and meaningful, since it is a real and authentic situation students can explore themselves surfing on the web. Besides, students can find similar initiatives in other countries, as well as some controversial news about the reliability and the efficacy of this kind of actions<sup>1</sup>.

The starting point is rich enough to give raise to many different questions that could lunch an inquiry process. Teachers can tailor it according to their students' potential and decide whether they would like students to pose the questions they want to explore, or they would rather provide them with a set of guiding questions. Some of them were offered within the COMPASS materials (Fig. 4).

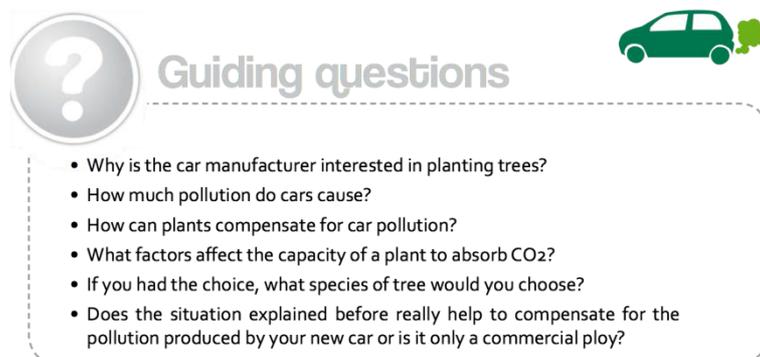


Fig. 4. Suggestions of guiding questions for the 'Car pollution task'.

If the teacher chooses a project-based learning approach, there are many directions students might follow. It depends on the way teachers would like to shape and guide the project. One option is that students decide about the issues they want to explore, and then the whole group carries out the inquiry process. A different option is that each group inquiries about one different issue in the task, and later they put their findings together. At the end, there is a final product students should develop (Fig. 5): a report about the 'CO<sub>2</sub> neutral program', based on their findings, to be submitted to an appropriate audience: other car manufacturers if the 'CO<sub>2</sub> neutral program is worthy; press, consumers associations or authorities, to denounce a fraud.

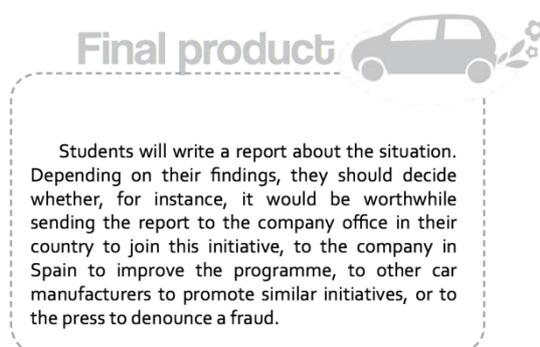


Fig. 5. Final product for a project-based learning approach to the 'Car pollution task'.

### 3.2 Inquiry processes in the 'Car pollution' task

There are two systems co-existing in the activity that students should explore, inquiry, model and connect, that we call the 'car system' and the 'plant system'. When working within these systems, students will need to activate different inquiry processes (Fig. 6).

<sup>1</sup> For instance, the case of another car manufacturer in Australia (<http://www.accc.gov.au/content/index.phtml/itemId/843395> )

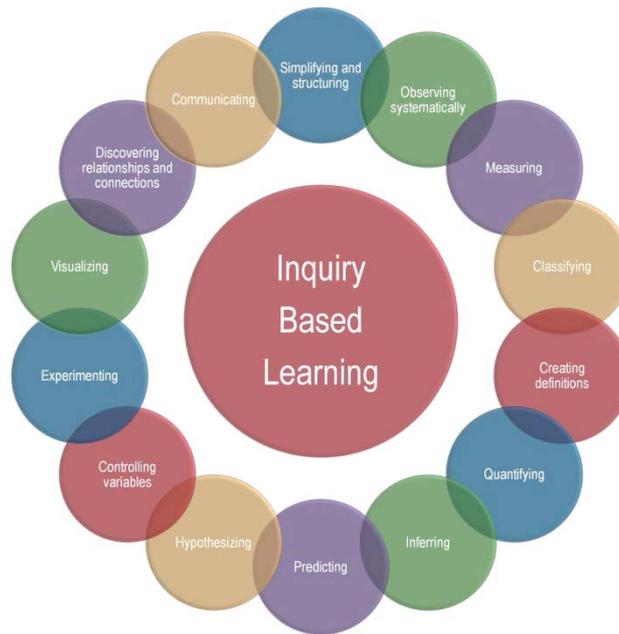


Fig. 6. Inquiry processes.

In the 'car system' ( $S_C$ ) students will inquiry about car pollution. The aim is to **quantify** the amount of  $CO_2$  a car will emit. In this activity students have to **simplify and structure** the situation. Firstly, because the great diversity of data: many different car models with different engines. Secondly, to **identify and control the variables** involved (distance, amount of  $CO_2$  and emission rate), ignoring other factors that are normally not considered (for instance, the weight or the length of the car). **Hypothesizing** that the pollution a car emits depends proportionally on the distance, students will create models to **quantify** the  $CO_2$  emitted by different cars. According to the proportional hypothesis, the pollution could be modelled by a linear function just using the emission rate provided by the car manufacturer. However, if students want to evaluate the whole 'CO<sub>2</sub> neutral program', they will find that there is a great diversity of car models and engines, and that there is often little difference in  $CO_2$  emissions for some of them. Once again, the necessity to **simplify and structure** the situation emerges. To do this, one option might be using the arithmetic mean (or the median, or the mode) of the different emission rates. This will **simplify** the situation drastically, but it will entail a significant lost of information. Another option might be to group the car models in different intervals according to their emissions. Considering the data provided by the car manufacturer, students might group the cars in different categories. For instance: low emissions (less than 100 g/km), medium emissions (between 100 g/km and 150 g/km) and high emission (more than 150 g/km) (Fig. 7). A meaningful distribution of cars models in different intervals might need the use of some statistical parameters.

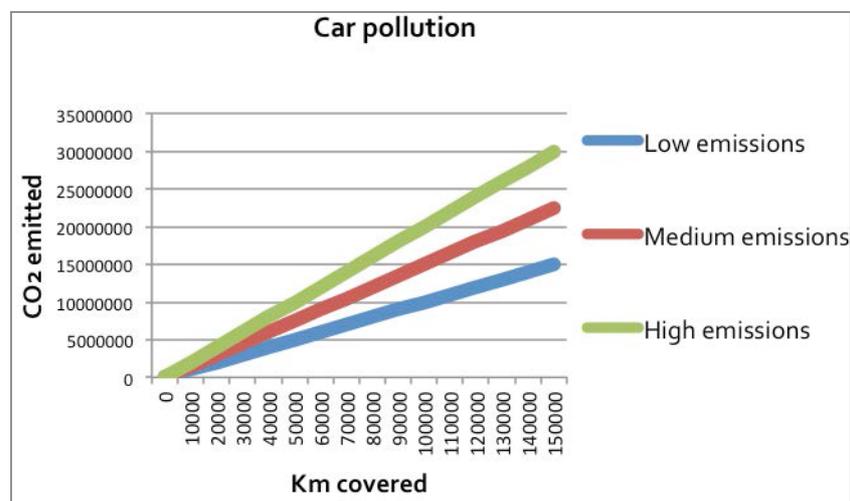


Fig. 7. Simplifying and structuring the situation: grouping cars in different intervals.

Besides, students might inquire about the combustion process and the kind of pollution cars emit. Although this part is not explicitly developed in the COMPASS materials, it is given as suggestion teachers might want to explore.

In the 'plant system' ( $S_T$ ), students will inquire about the relation between carbon dioxide and plants. From a qualitative perspective, they will inquire about the photosynthesis process and how it works. They will **discover relationships and connections** between the photosynthesis and the factors that affect plants' photosynthetic efficiency, like  $CO_2$  concentration, temperature or light intensity. For some of these factors, classical lab **experiments** might be introduced (like the well-known one with the water plant *Elodea canadensis*, with different concentrations of  $CO_2$  in the water, or with a light focus in different distances).

An interactive research environment has been developed for students to inquire about the dependency between light intensity and photosynthetic efficiency (Fig. 8). Student will **control variables** and interpret graphs. They will **classify** graphs depending on their growth, which is connected with the leaves' physiognomy of the plants<sup>2</sup>.

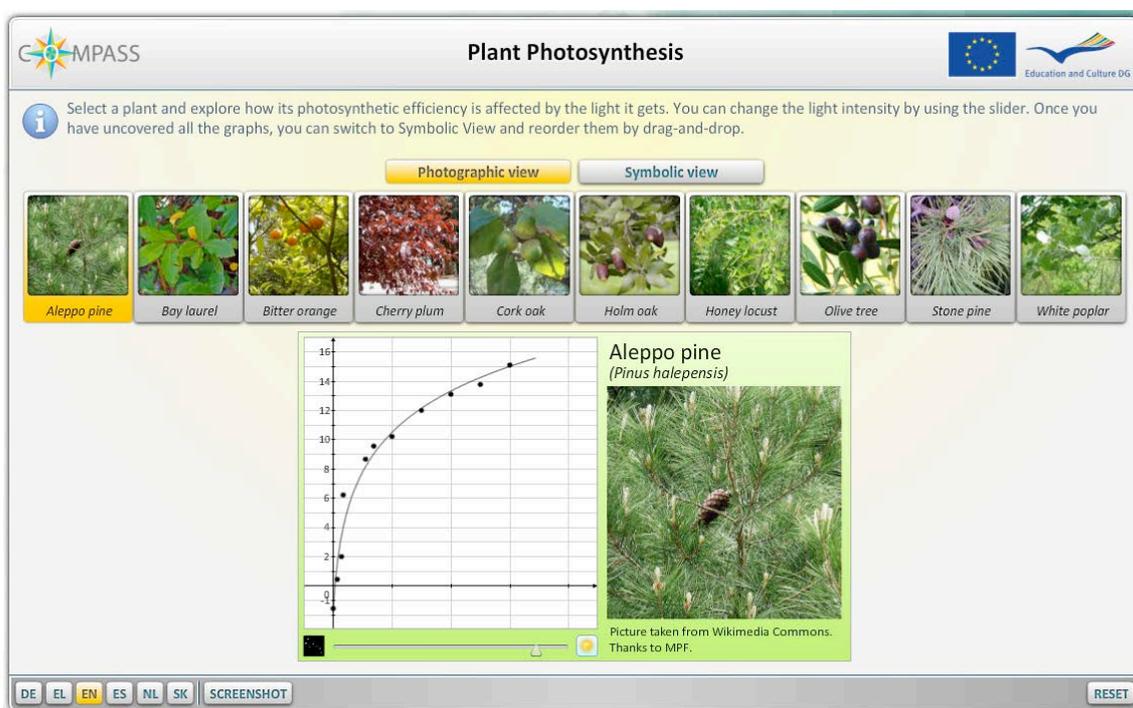


Fig. 8. Interactive applet to inquire about how light intensity affects the photosynthetic efficiency.

From a quantitative perspective, students' work will be to **quantify** how much carbon dioxide can a plant compensate for. This is an interesting but complex modelling task, which could be approached in different levels. In the most difficult approach, students will need to **measure** the leaf surface of each plant they want to work with. The difficulty of a real measurement of the leaf surface of a plant will provoke the necessity of adopting approximate models. Students might look for methods to do that<sup>3</sup> or they can use rough estimation depending on the form of the tree (conical, cylindrical, spherical), which involves both a new **simplification** and **hypothesising** process but also a **visualizing** process (e.g., assuming that a tree canopy is spherical, and estimating a ratio of 2 metres, then...). Later students will use some data already provided by the materials to get to some final measures of the amount of  $CO_2$  compensated by each plant.

If teachers find this activity complex, a simpler option is offered in the COMPASS materials. Based on Figueroa & Redondo (2007) work, data about the capacity of different plants to compensate for  $CO_2$  pollution is offered. This simplifies the situation significantly. Since these data offer the amount of  $CO_2$  a plant can compensate per day, student still need to **structure** the situations and make some **hypothesis** in relation to how many days will it take for a car to run a number of kilometres.

<sup>2</sup> For a detailed description, visit the complete version of the task at <http://www.compass-project.eu>

<sup>3</sup> Figueroa & Redondo (2007) describe different models engineers use to carry out this task.

Finally, students will put together their findings about the pollution cars emit (system  $S_C$ ) and the plants capacity to compensate for  $CO_2$  (system  $S_T$ ) in order to produce their final report. This will involve students in a **communicating** activity, scientifically mediated. It is very important to stress that students will have to produce their reports based on scientific facts and their mathematical calculations, and not just on their beliefs or their preconceptions about the whole situation.

### 3.3 Car pollution task': the case of a teacher and his students

Different teachers in the COMPASS countries have implemented the car pollution task<sup>4</sup>. We will report in this section the work of a Spanish teacher with his students. We invited the teacher to write about *'his case', which gave us the opportunity to have a deeper insight about the implementation process.*

The task was implemented in March 2011 with 15 years old students (3<sup>rd</sup> level of the Compulsory Secondary Education). The reasons offered by the teacher for the election of this group were the following: the whole group is studying biology (which is optional in the 4<sup>th</sup> level), the photosynthesis process fits within the curriculum and also with trending topics like global warming and climatic change and, finally, their students have worked in project-oriented activities before and they enjoy to be involved in this kind of teaching.

However, the teacher expresses his initial concern about: the managing of the classroom and if their students will really learn what they are supposed to learn. These concerns normally rise from the shift in the teaching paradigm. Although it is not the first time this teacher experiences IBL activities, he still feels the lack of professional competencies to deal with the complexity of this teaching situation. Dealing with unstructured problems, supporting students' inquiry, monitoring students' group work and discussion, using assessment for learning, or institutionalizing students' learning, are new professional competencies this teacher is just starting to explore<sup>5</sup>.

Besides, in this case the interdisciplinary character of the activity is an added difficulty teacher will have to sort out. However, this teacher, probably because of his personal background, does not conceive it as a major challenge. He has a degree in physics, he works as a science teacher in his school, but he normally teaches mathematics as well.

When describing his experience with the activity, the major difficulties expressed by this teacher are related with the rupture of the didactical contract and the management of the new one. As he writes, pupils felt lost in many cases during the task. They expected a single and correct answer for each activity, and felt confused when several answers might be considered correct (like, for instance, different amounts of  $CO_2$  compensated by trees). They felt also disoriented about the openness of some tasks and the diversity of data. For instance, when they have to quantify the pollution provoked by cars, they found difficult to deal with the diversity of models and engines provided by the car manufacturer's site. On the one hand, this is connected again with a rupture in the usual didactical contract, in which problems are supposed to come just with the data students' will needed to get to the solution. But, on the other hand, this is also connected with a meaningless learning of statistic concepts: confronted with a situation in which some statistical parameters will help them to structure and simplify the situation, they do not use them spontaneously<sup>6</sup>.

In the management of the situation, the teacher expresses the difficulty he found to manage and support students' group work. Also to support their students in an inquiry process in which they get stuck quite often.

Despite the difficulties, the teacher finds the activity quite interesting and motivating for their students. He also stresses the power of the situation to provoke meaningful situations in which students can use the knowledge they already have, or learn new one. He finds the activity interesting to be recalled when working in other parts of the curriculum like, for instance, when working with functions in their mathematics classes in the third term.

Finally, he is convinced that a regular use of this kind of activities will provoke an evolution in the dominant didactical contract, which will lead to a reduction of students' confusion. They will develop

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<sup>4</sup> Germany, The Netherlands, England, Cyprus, Slovakia and Spain.

<sup>5</sup> The PRIMAS Project aims at supporting teachers in the acquisition of these competencies through the implementation of professional development actions. For more information, please visit <http://www.primas-project.eu>

<sup>6</sup> Indeed, this should be interpreted as a limited development of their mathematical competency, assuming that it is defined as the capacity of students to identify and use mathematics in a diversity of situations in which they are needed.

their own strategies to initiate and maintain an inquiry process, to formulate hypothesis and work over them.

#### 4 FINAL CONSIDERATIONS

The analysis of current educational demands reveals a need of teaching approaches which increase students' motivation and engagement in science and mathematics learning and promote not only knowledge acquisition, but also the development of competences. Taking into consideration this situation and deeply grounded on research evidence about efficient teaching and learning approaches, we present a versatile interdisciplinary task to facilitate meaningful and motivating science and mathematics learning.

The task here described have been refined and improved on the basis of the analysis made by several educational researchers working within the COMPASS project and the feedback received from the teachers who have implemented it in different European countries. Teachers' written reflections after the implementation of the car pollution task into their classrooms repeatedly highlight its pedagogical potential. Particularly, they value its focus on the development of process skills and critical attitudes and stress the opportunity to make students think, make decisions and communicate in a justified and convincing way.

Taking this into account, we think that the task presented here may be considered as a useful resource for anyone interested in enhancing science and mathematics learning and in promoting critical thinkers, responsible and engaged decision makers and more autonomous and motivated learners

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