Nanotechnology for Solar Energy

Responsible Research and Innovation www.irresistible-project.eu

Colophon

IRRESISTIBLE is a project on teacher training, combining formal and informal learning focused on Responsible Research and Innovation. It is a coordination and support action under FP7-SCIENCE-IN-SOCIETY-2013-1, ACTOVITY 5.2.2. Young people and science: Topic SiS.2013.2.2.1-1 Raising youth awareness to Responsible Research and Innovation through Inquiry Based Science Education. The project IRRESISTIBLE is funded by the EU as FP-7 project number 612367

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The Module

This is an educational module targeted for Secondary-school students and developed by teachers in physics and chemistry, together with educational professionals and scientists of the University of Bologna.
The module is developed within the framework of the European project IRRESISTIBLE – *Engaging the Young with Responsible Research and Innovation* – www.irresistible–project.eu.
In this project, awareness about Responsible Research and Innovation (RRI) is raised by bringing topics of cutting edge research into the teaching program and fostering a discussion among the students on RRI issues about the topics that are introduced. The features of Responsible Research and Innovation can be summarized in the following issues: Engagement; Gender equality; Science education; Ethics; Open access; Governance. Example of how these issues prove to be relevant in contemporary science research are given later in this guide.
In this module the cutting-edge field is "Nanotechnology"; in particular it is focused on the nanotechnology studies carried out to convert sunlight into electric energy and on the RRI aspects relevant to this specific field of research.

This module is organised in 6 chapters, named *Engage, Explore, Explain, Elaborate, Exchange* and *Evaluate*. This organization derived from the *5E-model for Inquiry-Based Science Education.* This is a method for inquiry-based science learning, that we adapted adding a 6th E (Exchange). By using this method, students are actively involved in the subject and are stimulated to search for information themselves.

A basic feature of the project is to combine formal (at school) and informal (at an exhibition, science centre or festival) teaching to familiarize schoolchildren with science. For this purpose, an expert from science museum is also part of the CoL (community of learners) working at the module.
During the module, with the help of science centre staff, students elaborate an exhibit for the general public highly focused on RRI.

Sources:

- www.irresistible–project.eu
- Attachment 1: "Presentation of the project" (link: https://www.dropbox.com/sh/jiivhvxcf9aoave/AABXnFMs8B0IH0a_TDZK2YeJa?dl=0)

1.1. The 6 dimensions of RRI

In the project, the underlining idea is that both research and innovation should be closely linked to society and societal needs. Six key concepts that are indicated in the leaflet are used as starting point in order to provide a solid base to discuss how the research that is being introduced to the students links to these issues.

1. Engagement

The first key to RRI is the engagement of all societal actors - researchers, industry, policymakers and civil society – and their joint participation in the research and innovation process, in accordance with the value of inclusiveness, as reflected in the Charter of Fundamental Rights of the European Union. A sound framework for excellence in research and innovation entails that the societal challenges are framed on the basis of widely representative social, economic and ethical concerns and common principles. Moreover, mutual learning and agreed practices are needed to develop joint solutions to societal problems and opportunities, and to pre-empt possible public value failures of future innovation.

2. Gender Equality

Engagement means that all actors –women and men – are on board. The under-representation of women must be addressed. Research institutions, in particular their human resources management, need to be modernized. The gender dimension must be integrated in research and innovation content.

3. Science Education

Europe must not only increase its number of researchers, it also needs to enhance the current education process to better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process. There is an urgent need to boost the interest of children and youth in maths, science and technology, so they can become the researchers of tomorrow, and contribute to a science-literate society. Creative thinking calls for science education as a means to make change happen.

4. Open Access

In order to be responsible, research and innovation must be both transparent and accessible. This means giving free online access to the results of publicly-funded research (publications and data). This will boost innovation and further increase the use of scientific results by all societal actors.

5. Ethics

European society is based on shared values. In order to adequately respond to societal challenges, research and innovation must respect fundamental rights and the highest ethical standards. Beyond the mandatory legal aspects, this aims to ensure increased societal relevance and acceptability of research and innovation outcomes. Ethics should not be perceived as a constraint to research and innovation, but rather as a way of ensuring high quality results.

6. Governance

Policymakers also have a responsibility to prevent harmful or unethical developments in research and innovation. Through this key we will develop harmonious models for Responsible Research and Innovation that integrate public engagement, gender equality, science education, open access and ethics.

Sources:

– http://ec.europa.eu/research/science-society/document_library/pdf_06/responsible-research-and-innovation-leaflet_en.pdf
– EU (2012). Responsible Research and Innovation: Europe's ability to respond to societal challenges

1.2. Learning goals and outcomes

The module described in this guide aims at raising students' awareness of RRI aspects in contemporary research and innovation by focusing on nanotechnology studies carried out to convert sunlight into electric energy.
The module is composed of a basic core where both content and RRI aspects are developed and an optional extension where further content knowledge is addressed.

a) Basic learning outcomes related to nanotechnology of the module

At the end of the module, a student should be able to:

- describe natural and artificial ways of exploiting and storing solar energy
- explain how nanotechnology can be applied to addressing the problem of energy supply and, in particular, the production of photovoltaic energy

b) RRI learning outcomes of the module

At the end of this module, a student should be able to:

- describe ethical and social implications raised by the development of alternative/renewable energy sources

(e.g.: in spite of its potential benefits for society, the production of, for example, photovoltaic energy is constantly exposed to the risk of becoming a big business)

- discuss whether or not gender equality can have a positive effect on research and innovation concerning the global challenge of energy sources
- consider the importance of open access to the results on the applications of nanotechnology for solar energy conversion to strength the collaboration between research, industry and government
- understand that science education is essential for developing in the society the scientific literacy that enables a sensible approach to the problem of energy, based on the awareness that no form of energy is completely free and clean
- recognize that engagement of different actors to face the energy problem is important because it requires to balance the needs, opinions and aims of scientists, entrepreneurs, politicians and citizens
- understand and compare the choices made by the governance of different world regions and countries to address the problem of energy supply

c) Optional extension of the module

At the end of this option, a student should be able to:

- describe a p-n junction and how the photoelectric conversion takes place in it
- describe what is a solar cell (Graetzel cell) and what it can be used for
- discuss advantages and disadvantages of using natural dyes in the Graetzel cell
- describe the reactions occurring within a Graetzel cell illuminated by light
- assemble a Graetzel cell by following a specific protocol
- analyze images of the photoelectrode from an Atomic Force Microscope

1.3. IBSE and the 6E model

Engage

This phase has as the purpose of awaken the interest of students – motivating them to engage in subsequent tasks – and identify their prior knowledge about the topic(s) under study. Teacher must use problems that can awaken student's curiosity and lead them to formulate research questions.

Explore

This phase is intended to allow students to get actively involved into topic(s) and build knowledge –performing tasks such as research and experimental activities, formulate hypotheses, plan and execute preliminary investigations. At this stage students have the opportunity to be directly involved with the phenomena and materials related to the topic(s) of research – questioning, analyzing data and reflecting on the results. The teacher should act as a facilitator, providing materials and helping students to keep focus.

Explain

This phase aims at creating the opportunity for students to share with their peers and/or with the teacher what they have learned so far - making use of an appropriate scientific language. It is intended that during this process students reflect on their scientific misconceptions, being able to build new correct ones. This time is an opportunity for teacher to introduce and explore further the scientific concepts - by promoting a greater understanding on students, which will allow them to explain with greater ease and accuracy what they have learned.

Elaborate

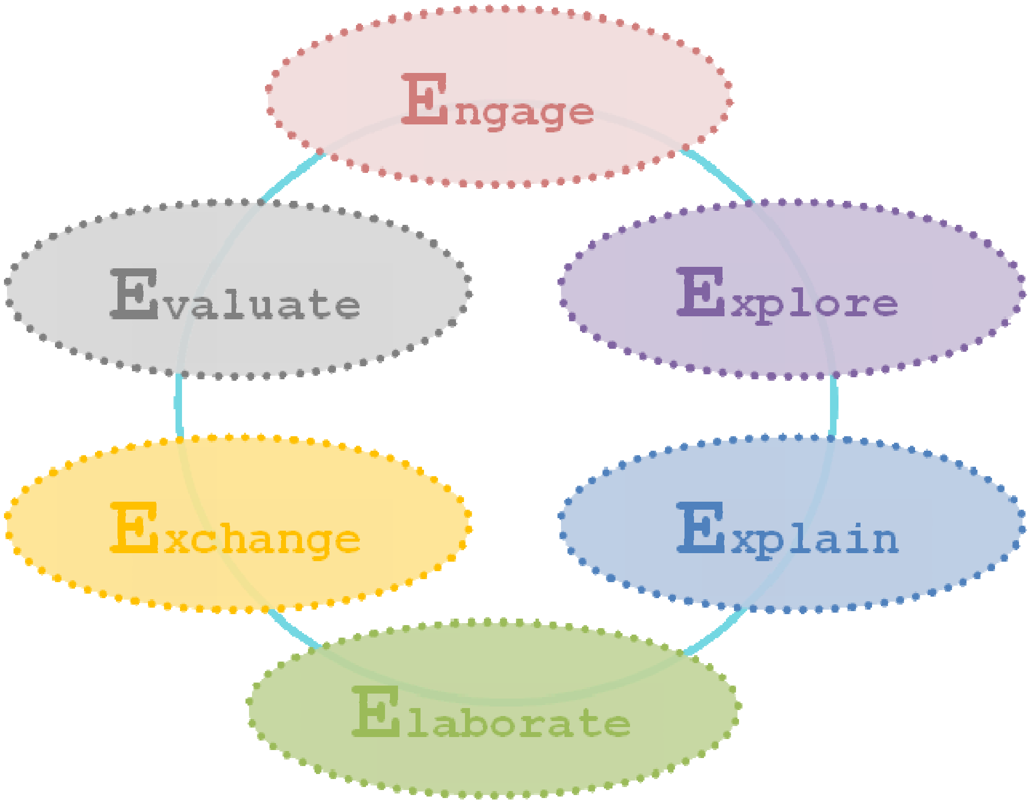
This phase aims at shifting to RRI-questions. Students will confront researchers with challenges to be answered by the scientists. The teacher should stimulate students to use their acquired competences for confronting themselves with scientists and then to work in peer-to-peer situations.

Exchange

This stage involves planning and building an interactive exhibition of the products of research. It is intended that students share with the community the results of their investigations – products may take different formats (poster, game, video, among others). It is an opportunity for students to communicate to a wider audience the new knowledge built. This phase is in close relation with the Empowerment phase, since it is aimed at promoting awareness and sensitizing others to the topic through the exhibition.

Evaluate

At this stage students have the opportunity to assess their knowledge and skills; teacher has the opportunity to assess the progress of their students in relation to the learning objectives established. The evaluation process focuses, in particular, in the students and in the creation of opportunities for them to reflect on their performance – making use of self-assessment. This stage goes along all the phases of the module. Indeed, students have multiple opportunities to reflect on their performance, difficulties and results.



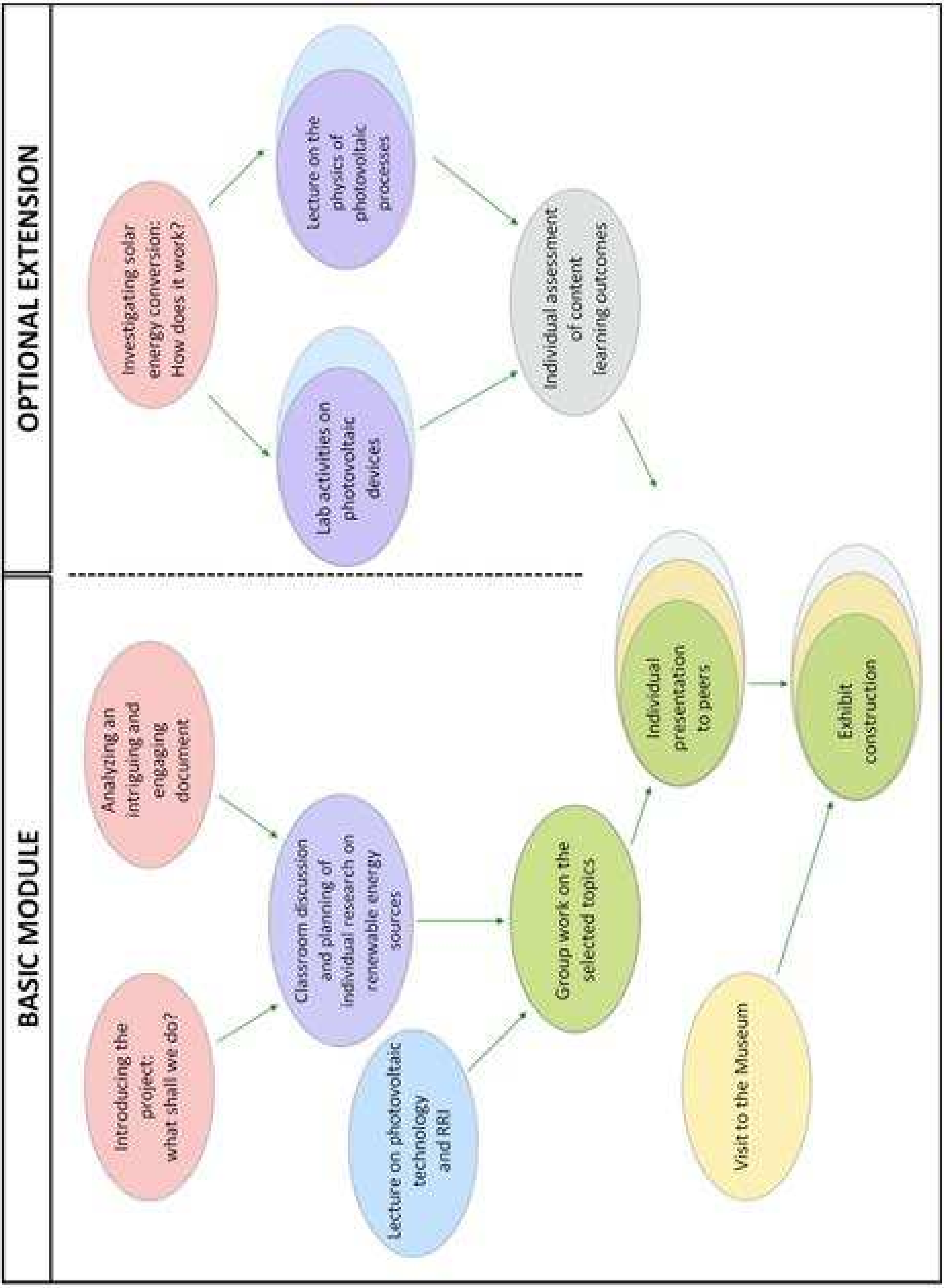
Map of the module

In the following map both the basic and the extended versions of the module are synthesized by identifying the flow of different activities. The activities are labelled according to the 6E Model as indicated in the map caption. Some activities play a multiple role according to the 6E Model and, for this reason, in the map the activities are marked with more than one colour; however, for the sake of simplicity, in the following description each activity is assigned to only one of the 6E.

Legend of the colour:

- ***Engage***
- ***Explore***
- ***Explain***
- ***Elaborate***
- ***Exchange***
- ***Evaluate***

The map of the module



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Engage

“Introducing the project and analyzing an intriguing document”

The features of the IRRESISTIBLE project, in general and in the module in particular, are introduced to the students. The topic of the importance of solar energy for producing electricity is put forward by presenting the video of the TED lecture “My solar powered adventure” by Bertrand Piccart, where the challenge of getting rid of our dependency on fossil energy is addressed.
The students are asked to answer individually some questions about the lecture (see Assignment 1) and a discussion should follow aimed at engaging the whole class.

Figure 2.1 – The Swiss solar-powered aircraft Solar Impulse

Sources:

– https://www.ted.com/talks/bertrand_piccard_s_solar_powered_adventure

Box 2.1: Summary: “My solar-powered adventure”

1) *The conduction of a balloon through the atmosphere as metaphor of living*. In the balloon, like in life, we must go often in unforeseen directions: we want to go in a direction, but the winds push us in another direction. As long as we fight against the winds horizontally, life is a nightmare.
For steering a balloon we understand that the atmosphere is made out of several different layers of wind which all have different directions; so, for changing our trajectory, in life, or in the balloon, we have to change altitude and raising to another psychological, philosophical and spiritual level.

2) *The pioneering spirit*. Pioneers are not people who have new ideas; rather, they are people who help us to explore this vertical axis, that means to explore all the different ways to do, all the different ways to behave, all the different ways to think, before finding the one that goes in the direction we wish.

3) *How to perpetrate the pioneering spirit today and to make the most incredible thing possible?* It is not a matter of conquering the planets or space since it has already been done. The question, today, is to improve the quality of life by getting rid of our dependency on fossil energy. For example, the Solar Impulse project, flying around the world in a solar powered airplane, can be seen as a right answer to the above question.

4) *The Solar Impulse project is a symbol*. It shows that it is not anymore completely stupid to think about getting rid of the dependency on fossil fuels.
However, if our airplane is too heavy, and if the pilot wastes energy, we will never fly until the next sunrise. At the same way, if we keep on wasting our energy resources, and if we keep on building things that consume so much energy that most of the companies now go bankrupt, we will leave several problems that should be solved by the next generations.

5) *The wings of the future*. When Charles Lindbergh crossed the Atlantic for the first time, the payload of his airplane was also just sufficient for one person and some fuel. Twenty years later there were 200 people in every airplane crossing the Atlantic. Let’s go for it, for an excellent adventure in the wings of the future!

Assignments 2 –

Engage

Questions on TED lecture to be answered by the individual students and discussed with the whole group:

- Do you find the metaphor of the balloon appropriate? Why?
- Do you find the pioneering spirit described in the lecture attractive? Why?
- The Solar Impulse adventure is very expensive and risky. Do you think it is worth all this efforts?

3

Explore

“Classroom discussion aimed at planning the individual researches on renewable energy sources”

The students are invited to put forward topics for individual research on energy sources that will contribute to a group presentation (see Assignment).

Examples of research topics:

- Review of the energy sources (renewable and non-renewable) with special focus on their environmental and social impact as well as on their energy performance;
- Framing of the energy problem by investigating: i) the historical development with special attention to the national context (see, for example, the period called “Austerity” occurred in Italy during the ‘70s); ii) current international protocols to reduce energy consumption; iii)

problems in the use of conventional sources (pollution and shortages)

- The current situation in the use of energy sources and future perspectives (e.g., the students visit and interview the managers of a farmhouse, aimed at reaching the energy independence beyond the usual recycling of water and waste)

Sources:

– http://www.ipcc.ch/
– http://www.bp.com/content/dam/bp/pdf/Energy-economics/statistical-review-2014/BP-statistical-review-of-world-energy-2014-full-report.pdf
– http://www.greenpeace.org/seasia/ph/Global/international/publications/climate/2010/SolarGeneration2010.pdf

Assignments 3 –

Explore

Each group of students will put together the results of the individual researches on energy sources for constructing a map or a presentation on the topic addressed.

4

Explain

“Lecture about the use of photovoltaic technology and RRI”

A lecture about the photovoltaic technology suitable to be analysed in terms of RRI concepts is delivered by the teacher and/or the university expert.

An example of slides for this lecture is given in “Attachment 2”, where the specific topic addressed are:

- Is solar energy a good idea and why? Some motivations (slides 1-2)
- How much energy comes from the sun? (slide 3)
- How much does it cost? (slide 4)
- The grid parity concept (slides 5-6)
- Which countries produce solar converters and where are they installed? (slides 7-8)
- Solar photovoltaic industries bankrupt. Solutions? (slide 9)

- The research concerning development of new solar cells, new materials, low cost or high efficiencies. Some examples/solutions are tandem cells, new generations of solar cells based on quantum dots (slides 10-13)
- How can we select the “perfect material” for solar cells? As an example the life cycle assessment (LCA) can be discussed (slides 14-15)

Sources:

– Attachment 2: “References for the lecture” (link: https://www.dropbox.com/sh/jiivhvxcf9aoave/AABXnFMs8B0IH0a_TDZK2YeJa?dl=0)

Assignments 4 –

Explain

Individual analysis of the lecture in which the students try to identify the aspects of RRI in the specific topic presented.

Classroom discussion of the students' analysis.

5

Elaborate

“Group work on the RRI aspects”

The RRI aspects of the sunlight conversion into electricity, identified by each student in the previous phase, will be discussed with the whole class. Of course, the teacher can select the teaching method that in her/his opinion is the most suitable one, although an active form and an equal distribution of roles to male and female students (classroom debate, work group, etc.) are highly recommended.
The peer-to-peer work can be organized according to the following steps:

- Identification of 4 or 5 crucial topics concerning RRI key concepts
- Distribution of the identified topics (one for each group of students)
- Time of working in the group aimed at designing a group presentation on the selected key concept

Each group of students reports to the whole class on the selected topic, each component of the group should have at least a small part in the presentation to the class (Attachment 3).

Sources:

– Attachment 3: "Results from the group work" (link: https://www.dropbox.com/sh/jiivhvxcf9aoave/AABXnFMs8B0IH0a_TDZK2YeJa?dl=0)

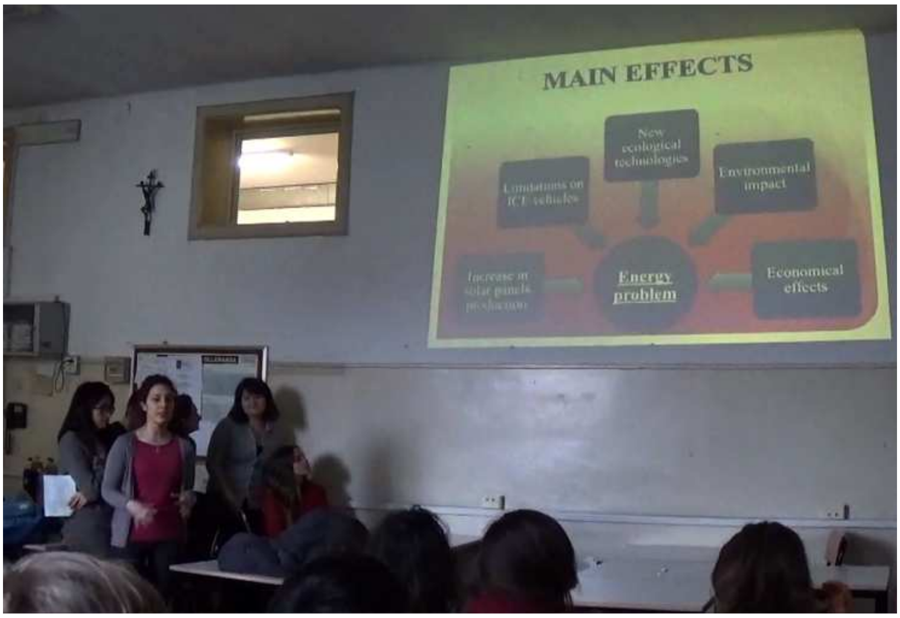

Figure 5.1 - *Students in action during the peer-to-peer work*

Assignments 5 –

Elaborate

Design and development of a presentation in which all the group contributions are combined.

- The class is divided in 5 groups
- Each group identifies the topic
- Each group works on a topic and prepares a presentation for the other mates
- Each component of each group explains to the class what he/she had learnt about the selected topic

6

Exchange

"Visit to the museum and exhibit design"

The students are asked to exchange the results of their work with other students in the school and occasionally with a general audience.

This will be done through an oral presentation and the construction of an exhibit.

In order to design the exhibit, a visit to a museum and the interaction with the museum staff is likely to result very helpful (see Attachment 4).

An example of exhibit designed and constructed by the students involved in this module is given in "Attachment 5".

Sources:

- Links to movies:
  https://drive.google.com/folderview?id=0B2pxYfFciFzqeDJOS283eUpFRXM&usp=sharing
  https://www.dropbox.com/sh/uble85yp40pbdqg/AAC47uurFngwy8d8M26-DsJha?dl=0
- Attachment 4: "Exhibit presentation"
- Attachment 5: "Ecolopoly presentation"
- Link to the attachments:
  https://www.dropbox.com/sh/jiivhvxcf9aoave/AABXnFMs8B0IH0a_TDZK2YeJa?dl=0

Figure 6.1 – Students playing with the Ecolopoly exhibit

Box 6.1: “Ecolopoly” rules

The students established the following rules:

- each president chooses his country’s structure: he has to decide about ethical problems such as the gender equality, the science education and the open access (for example by choosing the number of males and females ministers or by choosing if his governament will invest in renewable or non-renewable energy sources (Nuclear energy, Fossil Fuels or Renewable sources).
- each president starts the game with 100 money (100 Z) and 25 ethical points (25 E), but the increase or decrease of this money and ethical points depend on: i) the type of energy source selected (Nuclear: +50Z, Fossil Fuels: +20Z, Renewable sources: +10 E); ii) the investment in science education and public-funded research (not invested + 20 Z and -5 E, invested – 20 Z and +5 E); iii) the integration of the gender dimension in research and innovation content (not integrated + 5 Z and -2 E, integrated -5 Z and +2 E).
- the first player shoots and every box on the board represents a situation that he/she has to face.
- the players who loose all their money or ethical points loose the game, and the one who survives is the winner.

Figure 6.2 – Panel of the game board

7

Evaluate

“Evaluation of the module activities”

Self and hetero evaluation will be present at different moments of the module. At least three aspects concerning the module activities need to be evaluated:

- Features of the group’s work (exhibit, power point presentation, etc.)
- Single students reflections and learning (focus groups)
- Cooperation of the students to the whole process

The following grids are examples of evaluation tools concerning of these three aspects.

Table 7.1

Rubric to evaluate the presentation

Dimension	Excellent		Good		Sufficient		Insufficient	
Text	Rich in information; clearly and logically explained	4	The most important information is present	3,5	Only basic information is contained	3	No information or /and major errors	1
Graphic and animations	Graphic clear and consistent with the text. Effective animations	3	Partially clear graphic and partially consistent images	1,5	Poor graphic, misspellings	2	A lot of errors	1
Punctuality	Delivery on the agreed day	1	1 day late	0,5	2 days late	0	Later than 2 days	0
Exposition	Confident and effective communication	2	Fairly confident communication	1,5	Not confident communication	1	Ineffective communication: the student reads the slides and/or parts are missing	0

Table 7.2
Rubric to evaluate the exhibits

	Level 1	Level 2	Level 3
Scientific Content	No basic science concepts are presented	Only some basic science concepts are presented	The exhibit is strongly based on the scientific concepts
RRI	There is no mention of RRI	There is a weak connection of RRI to the exhibit (only 1 or 2 key concepts are addressed)	There is a strong connection of RRI to the exhibit
Interactivity	The object is static	The object is moderately interactive	The object is highly interactive
Creative/Original/ aesthetic aspect	Not very appealing and original	Moderately appealing and original	Very appealing and original exhibit
Design and selection of exhibit	The selection is made by the teacher	The design of exhibit is selected by majority	A consensus is reached about the design of the exhibit
Cooperation among the students	The exhibit is realized by few students	There were two or three leaders in the class who distributed the roles	The role of each student in the realization of the exhibit is assigned by exploiting the specific competences of each one

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Assignments 7 – Evaluation of the cooperative project on Energy and RRI

Class .... Date ....

Name .... Role in the group ....

Title of the project ....

Short description of your contribution to the work

....

Signature of all the group-mates for agreement

Signature ....

Signature ....

Signature ....

Signature ....

If you have to redo this project what would you change to get better results?

....

....

How could the group work more effectively next time?

....

....

8

Annex

“Optional extension of the module”

This module is comprised of an optional extension targeted only for the last two year of the upper secondary school (12^{th} and 13^{th}). The extension is organized by following the 6E-model, as for the basic module.

Engage

Investigating the conversion of solar energy into electric energy. How does it work? (2 hours)

The activity is a presentation focused on the operation of the Graetzel cell.

Explain

Lecture on the physics of the photovoltaic process (3 hours).

In order to prepare the lecture, we provide a document (Attachment 6) where the following issues are addressed:

- Resistivity of materials and their classification in insulators, semiconductors and conductors
- Band model
- Conduction model for semiconductors (electrons and holes)
- Doping

- *pn* junction
- Photovoltaic cells
- Efficiency of a photovoltaic cell
- Graetzel cells

Explore

Laboratory activities on photovoltaic devices (5+2 hours)

As an example of the laboratory activities, we provide documents on the construction of the Graetzel cell and its analysis with Atomic Force Microscopy carried out by the Italian students:

- phycics of the photovoltaic process (Attachment 7)
- protocol for the construction of the Graetzel cell (Attachment 8)
- presentation where the fundamentals of the Atomic Force Microscopy are presented together with some typical images and measurements (Attachment 9)

Evaluate

Individual assessment of learning outcomes (2 hours)

As an example we provide the individual test submitted to the students at the end of the module (Attachment 10).

Sources:

- Link to the attachments:
https://www.dropbox.com/sh/jiivhvxcf9aoave/AABXnFMs8B0IH0a_TDZK2YeJa?dl=0

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