Nanotechnology for solar energy conversion

RRI aspects of environment friendly energy production

Irresistible Project Module prepared by the Università di Palermo, IT, Community of Learners

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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Nanoscienze per l'energia

Introduction

The topic selected for the present teaching module is related to the important issue of energy transduction, with particular reference to solar energy and its responsible and conscious use in our society. It was chosen after several discussions in the Community of Learners (CoL) of the University of Palermo, IT on the relevance for students and citizens of an informed awareness on the energy sources and their importance for all. The difference between renewable and non-renewable energy sources and the role of science and technology to try to overcome the problem of the limited availability of raw materials (oil, gas, …) used to produce energy are a central point in the Module. Moreover, this Module aims at making young people aware of the relevance of scientific knowledge in their everyday life and at making clear that, only by possessing some form of basic scientific understanding and knowledge, it will be possible for them to make responsible choices in their future and, hopefully, influence the decisions of policy-makers.

This Module involves disciplinary concepts usually introduced in all Italian school curricula. It can be introduced in the last three years of Upper Secondary Schools (16-18 years old students) or, with some simplifications, in the first two years (14-15 years old students).

This teaching Module mainly deals with Chemistry and Physics contents. The two disciplines are dealt with harmonically, and can be integrated with contents from Biology to allow students to have a unified vision of Science, depicted as a single piece of human knowledge. Many activities are designed to be developed together by two or more teachers, of different disciplines.

MAIN CONTENTS

- Different energy forms and transformation from one to another
- Renewable and non-renewable energy sources
- Photovoltaic effect
- First generation solar cells
- Organic solar cells
- Photo-activation of organic dyes
- Redox reactions
- Properties of nanomaterials

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Pedagogical background: The 6E-method

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This teaching module is based on the 6E-model (Engage, Explore, Explain, Elaborate, Exchange and Evaluate) for Inquiry-based Science Education (IBSE), a method for inquiry-based learning of the natural sciences developed by Bybee et al (Bybee, Powell & Towbridge, 2007). The original method is used in the IRRESISTIBLE project with an added E: Exchange.

In the table on the next page, the different steps are explained in the context of this project.

table 1
Steps in the 6E-method

Step	Description	Examples of activities	Goal
Engage (involve)	Making the students interested in the topic.	Visit to science center, university or factory; lecture by scientist; video, discussion with the students	**In these steps, the research that is performed at the university is discussed and put in a framework that understood by the students**
Explore (investigate)	Students formulate questions, perform introductory experiments and search on the internet	Students work independently; discussion with students, asking questions that will be answered	
Explain	In this step, the questions are answered, the science is introduced	Together with students, teacher discusses the science	
Elaborate (broaden)	In this step, the six key messages of RRI can be introduced	Students match the ethical issues with the science and innovation from the engage; debate	**In these steps, the students learn about RRI-aspects and apply them to the science**
Exchange	Students make an exhibition of the science and the RRI-aspects of the topic	Students work together to build the exhibition, topics are divided among student/group	
Evaluate	Students make a test/exam on the contents of the module. Together with the teachers and/or scientists, they evaluate their new knowledge	Test and evaluation, questionnaires.	**Part of the evaluation is our own research around this project, with teachers and students**

2

Responsible Research and Innovation (RRI)

Responsible Research and Innovation (RRI)

Responsible Research and Innovation is a term coined by the EU, with the goal of bridging the gap between the scientific community and society. Science and industry need to question whether certain innovations are always desirable for society. An example of an innovation that failed because there was not enough support from society is genetic engineered corn (von Schomberg, 2013). Another example of an innovation that was not directly accepted by society is the vaccination against HPV (human pappiloma virus) (Humacare 2015).

On the other hand, the EU wants scientists to have a better eye for problems in society, in order to be able to find solutions from science.

The six key issues of RRI are reported in the table in the following page:

table 2
Six key issues of RRI

Key issue	
Engagement - "choose together"	Engagement of all societal actors – researchers, industry, policy-makers and civil society – with the research and innovation process.
Gender equality – "unlock the full potential"	All actors – women and men, are on board. The under-representation of women is addressed
Science education – "creative learning, fresh ideas"	Europe needs to enhance the current education process to further equip future researchers and other societal actors with the necessary knowledge
Ethics – "do the right thing and do it right"	Society is based on share values. In order to adequately respond to societal challenges, research and innovation must respect fundamental rights and the highest ethical standards.
Open access – "share results to advance"	In order to be responsible, research and innovation must be both transparent and accessible.
Governance – "design science for and with society"	Policy-makers have a responsibility to prevent harmful or unethical developments in research and innovation.

3

Overview of the module

Overview of the module

The table below is a suggestion for the distribution of the activities over the lessons. A detailed description of each activity is reported in chapter 4.

table 3
Overview of the module

Lesson	What	Number of activities	IBSE 6E phases	RRI topics*
1	Student pre-test	1	Engage	
2	Introduction to RRI	1	Engage	En, Ge, Se, Et, Oa, Go
3	Thermal and electrical effects of light	4	Engage, Explore, Explain, Elaborate	En, Ge, Oa, Se
4	Investigation of different energy sources	2	Engage, Explore	En, Se, Et, Oa, Go
5	Produce presentation material	1	Elaborate	Se, Et
6	Assembling a DSSC cell	1	Explore	
7	Preparation and presentation of the exhibit	3	Elaborate, Exchange, Evaluate	En, Ge, Se, Et, Oa, Go
8	Student post-test	1	Evaluate	

*En = Engagement, Ge = Gender Equality, Se = Science Education, Et = Ethics, Oa = Open Access, Go = Governance

Requisites

For an effective teaching of this Module, the students are supposed to have a basic knowledge of the following topics: eenergy in its different forms, temperature and heat, electric current and voltage, chemical properties of metals and semimetals, chemical bonding, data collection and graphical representation.

Learning goals

Learning outcomes (science)

At the end of the Module, students will be able to:

- Describe different effects of radiation on matter
- Describe the parameters affecting the extent of heating induced by radiation
- Describe the conversion of solar energy into electricity
- Describe the operation of a DSSC cell
- Explain the photovoltaic effect
- Explain the conduction properties of organic molecules
- Explain the behavior of matter on a nanometric scale
- Recognize natural phenomena involving the conversion of solar radiation

Learning outcomes (RRI)

At the end of this Module, students will be able to explain:

- How the use of fossil-fuels as energy sources has led to economic and environmental problems
- The environmental impact of different energy sources
- Why renewable resources are preferable
- How the government promotes renewable resources

Learning outcomes (practical)

At the end of this Module, students will be able to:

- Measure the extent of heating of an object exposed to sunlight
- Measure the electrical output of a photovoltaic panel
- Work with Real-Time online transducers
- Use tables, graphs and multimedia presentations to organize experimental results
- Discuss/debate the ethical aspects of renewable and non-renewable energy sources
- Build an exhibition about the scientific and ethical aspects of the topic

Resources

On the IRRESISTIBLE website **www.irresistible-project.eu/** a selection of introductory material on the 6E-method, RRI topics and guidelines on exhibit preparation can be found.

3-Overview of the module

Remarks

The interdisciplinary nature of this teaching Module is best seen when it is taught during physics and chemistry-lessons at the same time. That also makes it easier to find the necessary hours and reserve more time for experiments, debates and the exhibition.

However, you can also choose to teach only the chemistry- or physics -part, or to leave out certain parts that do not match the current knowledge of your students. It is important to underline constantly how scientific research can lead to societal innovations. Also, the relation between RRI and these innovations have to be made clear. Finally, the exchange of knowledge in running the exhibition is a very important part of the project. These three aspects have to be dealt with while teaching the module.

Furthermore, make sure you have read the whole module before teaching, especially the part that is not about your own subject.

4

Planning of the lessons

Planning of the lessons

Table 4 is an example of how the lessons were planned at one school, where a chemistry and a physics teacher taught the module together. In this chapter, a detailed planning for each lesson is also reported.

table 4
Planning of the lessons

Week 1			Lesson	Activity
1 hour	Student pre-test	Assess students prior knowledge	1	1.1
1 hour	Introduction to RRI	Induce reflections on links between science and society	2	2.1
Week 2				
1 hour	Fill worksheet and group discussions	Reflection on the radiation-matter interaction	3	3.1
1 hour	Plan and perform experiments	Identify relevant parameters about light-matter interaction	3	3.2
1 hour	Analysis of results	Find relations among the investigated parameters	3	3.3
1 hour	Examine conventional photovoltaic panels	Investigate on light electricity conversion	3	3.4
Week 3				
1 hour	Examine different energy sources	Reflections on renewable and non-renewable energy sources	4	4.1
homework	Search information	Find appropriate literature for different energy sources	4	4.2
2 hours +homework	Production of presentation material	Select and organize information on different energy sources	5	5.1
Week 4				
2 hours	Assemble a DSSC cell	Consider parameters affecting the operation of a DSSC cell	6	6.1
Week 5				
1 hour	Pre-production	Organize material and plan exhibit	7	7.1
2 hours +out of class work	Production and staging of the exhibit	Run the exhibit in suitable environment	7	7.2
1 hour	Post-production	Analyze and discuss exhibit outcome	7	7.3
1 hour	Student post-test	Evaluate impact of the learning sequence	8	8.1

4.1 Lesson 1 – Student pre-test

Any inquiry-based teaching protocol or procedure should always start with the assessment and evaluation of the students' prior knowledge about the specific content to be dealt with. This prior knowledge might arise from different sources such as common experience, previous courses or from media. In any case, since new knowledge is always built on top of pre-existing notions, it is very important for the teacher to assess the existence of concepts and also misconceptions by the students.

It has been demonstrated that a good way to achieve the above goal is to implement a questionnaire aimed at probing competence rather than simple content knowledge about the relevant topics. The same questionnaire can be used at the end of the module in order to assess the performance of students before and after the teaching sequence has been implemented. As a consequence, some of the questions will deal with specific learning goals to be achieved in the module although direct reference to them should not be explicitly made. his implies that students may be puzzled at the beginning of the module in having to answer questions on topics that they have not studied before. However, the purpose of those questions will become clear when they will have to fill the same questionnaire at the end of the module.

As far as the present Module is concerned, topics to be covered by the questionnaire include: the effect of the interaction of radiation and matter, energy and its conversion, renewable and non-renewable energy sources, effect of surface area on reactivity.

In order to encourage familiarity with web 2.0 tools, the tests can be administered by using platforms such as Edmondo or Socrative.

Since its purpose is to assess the impact of the teaching sequence on the whole class, the questionnaire can be anonymous. In this case the teacher should ask the students to mark their answer sheet with a nickname. It is important that the students write this nickname down since they will use it again when they fill the post-test.

Duration: 1 hour

<u>Activity 1.1</u>: **Engage – elicit prior knowledge by students**

In this phase a questionnaire is filled by students according to the features underlined above. A prototype example of a possible test that was actually used in the development of the present module in Palermo, IT, is reported in the Appendix (A4.1).

4.2 Lesson 2 – Introduction to RRI

Duration: 1 hour

Activity 2.1: **Engage – reviewing RRI principles**

During this lecture, a discussion about RRI topics is initiated by using appropriate videos and/or power point presentations. The basic ideas about RRI are summarized in chapter 2 and suitable material can be found on the IRRESISTIBLE project website.

4.3 Lesson 3 – Thermal and electrical effects of light

Electromagnetic radiation coming from the Sun, can be converted to another form of energy, such as thermal, electrical or chemical energy depending on the kind of interaction between solar radiation (photon) and matter. In the case of solar to thermal energy conversion, photon interaction with matter results in an increase in kinetic energy of atoms and molecules that, in turn, increases the internal energy and raises the temperature of the material. The heat that is produced can be used directly for domestic or industrial heating purposes or by concentrating the light from the Sun and producing steam which makes an electrical generator turn.

However, there is a way of producing electricity from radiation directly by exploiting the photoelectric effect. Photon-matter interaction in photovoltaic energy conversion involves excitation of electrons to a higher potential energy level and subsequent separation of charges. By applying a voltage to the material, these charges can move thereby producing a current. In traditional semiconductor based photovoltaic solar-cells the valence and conduction bands are separated by an energy gap that the electrons are able to overcome, if the material is exposed to radiation of appropriate wavelength. Conventional first generation cells are made of crystalline silicon, the commercially predominant technology, that includes materials such as polysilicon and monocrystalline silicon. Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small stand-alone power system. In the above cells, and therefore, in commercial solar panels (made up of a large number of solar cells connected to each other), current intensity and voltage depend on many variables such as wavelength and intensity of incident light, size of the panel and orientation with respect to the Sun.

In the activities of this section the effect of different parameters is studied. The amount of heat or electric output produced by a given radiant energy source depends on many variables (light intensity, distance from the source, time of irradiation, nature o the material etc.). The amount of heat can be determined by measuring the change of temperature of a suitable material, for example a certain volume of water.

Students are encouraged to identify by themselves possible parameters and to device experimental procedures to test their ideas.

The work can be performed in a school laboratory, as the instruments requested are today readily available. However, the possibility to perform the experimental activities in a research facility and/or university laboratory may be an added value. In fact, one of the aims of this Module is to develop the topics in an environment different from that students are accustomed to, and with the support of researchers, in order to stimulate the student learning. In this way one of the RRI Issues, Open Access, is highlighted.

In case research/university laboratories are not easily accessible, communication tools such as Skype can be used to have researchers taking "virtually" part to the experimental phases.

Duration: 4 hours

This lesson consists of 4 activities which can be performed in a single time slot, or in distinct successive meetings.

Activity 3.1: **Engage**

Students are divided in small groups. The way the groups are organized is discussed in order to stress the importance of gender issues in working groups and to underline the role that women play in scientific research and innovation (RRI – Gender Equality).

A worksheet containing questions aimed at identifying typical student ideas about the conversion of light in thermal energy is presented. A typical worksheet used in Palermo is reported in the Appendix (A4.3.1)

Activity 3.2: **Explore**

Students are asked to think about measurable factors that can influence the conversion of light in thermal energy, as summarized in a worksheet similar to that used in Palermo and reported in the Appendix (A4.3.2). Then, students are asked to design experiments that can demonstrate the effects of those factors and to try to perform them.

Among the factors which the students will probably identify, one might expect: a. How strong the light source is (intensity and type of light source); b. How far the light source is (distance); c. Time of exposure; d. Nature, color and quantity of the material of the heated object.

Each group is asked to plan experimental procedures aimed at finding a (semi)quantitative relation between each factor and the temperature increase. To do this, students are presented with simple instruments, also easily found in real-life situations, that they can choose to plan and implement their experiment.

As an example, the student group that chose to study the dependence of temperature increase on distance from the heat source will be asked to report their results in graph and table forms, but also find a simple analytic expression relating distance and temperature increase. Moreover, the students should also be able to understand that, as several factors can influence the temperature increase, in order to study the dependence of temperature increase on distance, all other factors must be fixed and kept constant.

The students will report in the worksheet all their considerations, the experimental set-up and the results. All the experimental activities can be performed by using thermal sensors linked to Real-Time Laboratory equipment. More traditional lab instruments can be used (conventional thermometers), but in this case, the possibility to follow in real time the temperature variations with respect to the variations of the factor in study would be lost.

The collected data are analyzed by the student groups by using a data logger or a spreadsheet program, or other web 2.0 tools, in order to allow the students to gain, or improve, skills in collecting and handling data, constructing tables and graphs and interpreting their results.

Materials:

- Light sources of different type (incandescent, fluorescent, led, halogen) and power
- Empty soft drink cans painted on the outside in black or white
- Rulers (stick or ribbon type)
- Graduated cylinders or beakers
- Tap water
- Thermometers or real-time thermal sensors

<u>Activity 3.3</u>: **Explain - Elaborate**

Explain

The students analyze their results and find the physical variables that can be used to describe/explain the experimental results and try to deduce typical behaviours and laws. This will be done alternating small- and large-group work, with each small group represented by a spokeperson that presents his/her group results to the other groups.

This activity resembles the work of a scientific community and the possibility to access all the results of various researchers (RRI – Open access).

Elaborate

In this phase the teacher helps students to consolidate their findings, also introducing them to specific scientific terms and presenting relevant aspects neglected or unobserved during the experimental phase.

The students are also asked to find analogies and differences between the phenomena first discussed and then experimentally studied and the Natural World (see relevant questions in A.4.3.2. For instance, it is asked them if it is possible to have a shower with water heated up by the Sun, and how (and if) it would be possible to optimize the results (reducing the winding volume in thermal solar panels, colour of the panel and hot water reservoir, light incident angle, etc.).

As a conclusion of the current activity, the teacher invites the students to think about other possible effects, in addition to heating, that radiation might induce on matter. This can be done by the use of an appropriate worksheet (see example in A4.3.3).

Several ideas might arise from students (for example the colour of objects, photosynthesis, fluorescence…). During the discussion, the teacher will guide students to recognize that light can also induce electrical effects. This idea will be further developed in Activity 4.

<u>Activity 3.4</u>: **Engage – Explore - Explain**

Engage

In this activity the teacher will guide the students through an investigation on the production of electricity by using small commercially available photovoltaic panels, such as those available for camping vehicles or other recreational applications. It is important that these panels are powerful enough to light a small LED lamp when illuminated with the commonly available light source (such as incandescence or halogen bulbs).

The activity is guided by the use of an appropriate worksheet (see example in A4.3.4) handed out to students at the beginning of the demonstration.

At first, the teacher will demonstrate that the LED bulb will light up when the photovoltaic panel is illuminated. The students are asked to sketch the experimental set-up and write down their observations.

Explore - Explain

At this point the teacher will state that the light coming from the source is converted into electricity capable of lighting the LED up. The teacher will also state that, in order to investigate about the process of converting radiation into electricity, instead of the LED bulb, specific instruments must be used to measure current and voltage of the electric output of the panel. Therefore, the LED bulb is replaced with a digital multimeter and both current and voltage drawn from the panel are measured under different illumination conditions. Once again, as mentioned in Activity 2.1, the use of computer interfaced transducers is useful for displaying and storing the results.

Once a proper measuring procedure is established, the teacher will ask the students to think about factors that can influence the electrical output of a specific photovoltaic panel as that used in the experiment. Also based on the experiences in Activity 2.1, it is expected the students will suggest different possibilities such as: a. How strong the light source is (intensity and type of light source); b. How far the light source is (distance); c. Orientation of the panel with respect to the light source (illumination angle).

Depending on the time available, the teacher might ask the students, once again divided in small groups, to investigate experimentally on systematic changes of selected variables on the electrical output of the panel (see optional questions in A4.3.4).

Materials:

- Light sources of different type (incandescent, fluorescent, led, halogen) and power
- Small LED bulb
- Rulers (stick or ribbon type)
- Digital multimeter or real-time voltage and current transducers

4.4 Lesson 4 – Investigation of different energy sources

In this section a general discussion about ways of producing energy, in particular electricity, to be used in practical everyday life applications, is initiated.

There are many ways to produce electricity. In modern society, the most common ways to produce the large amounts of electricity that is required, is by the use of generators which are made of two sections: the rotor (which rotates) and the stator (which remains stationary). Generators use the principle of electro-magnetic induction. As a consequence, in order to produce electricity, the rotor must be put into motion. There are two types of generating plants, depending on the energy source they use to put the rotor into motion: thermal plants and kinetic plants. In thermal plants heat is used to raise the temperature of water in a boiler in order to obtain high-temperature steam. This steam is then channeled to a spinning turbine, connected to the rotor of the generator. In these plants, heat is mainly produced by combustion of fossil-fuels: oil, coal or natural gas. Under this category, nuclear power plants should also be mentioned. In this case, a large amount of heat is released when nuclear fission reactions of heavy radioactive nuclei take place. Once again, the heat can be used to generate electricity.

Kinetic plants, instead of heat, use kinetic energy. Moving wind or water spin a turbine, which in turn spins the rotor of the generator.

Other means of obtaining heat for producing electricity include geothermal energy, where heat of the Earth originating in the underground from the nuclear decay processes of radioactive elements is exploited, or that produced by direct heating from solar irradiation (see previous section).

In addition, as described in more details in the introduction of section 4.3, solar radiation can be turned directly into electricity in solar photovoltaic panels.

In all conversion processes described above, a specific energy source is required which, in the conversion process, is consumed. Depending on the time scale required for the specific energy source to run out, compared to average human life, *renewable* and *non-renewable* energy sources can be identified. The amount of fossil-fuel which is available, in spite nature took several millions of years to make it, is limited and, at the current rate of consumption, it will definitely run out quite soon. Fossil-fuels are typical examples of non-renewable resources.

On the other hand, also the material (hydrogen) undergoing nuclear reactions in the Sun and producing radiation will also run out. However, the estimated life-time of the Sun, compared to human time scales, is so long that solar energy can be considered limitless and therefore it is a renewable energy source. On the same basis, other forms of energy more or less directly related to solar energy such as the wind or hydropower, can be considered renewable sources.

When discussing the features of possible energy sources, however, one should also take into account the environmental impact that the conversion processes might have. In particular, the production of by-products and wastes should be carefully considered. In burning fossil-fuels large amounts of CO_2 and other polluting substances (SOx and NOx) and, particularly in the case of coal, also large amounts of soot, are released in atmosphere. In order to reduce the massive emission of CO_2 in atmosphere caused by the combustion of fossil-fuels, in 1997 the Kyoto Protocol, an international treaty on the environment concerning global warming, was drawn up in Kyoto, a Japanese city, by more than 180 countries. Subscribers countries have committed themselves to a quantitative reduction of their emissions of greenhouse gases (that warm the Earth's climate) below their 1990 emission levels (baseline), as a percentage different from state to state.

From what it has been said above, it seems evident that using the combustion process to produce energy has several drawbacks: it will quickly cause the fuel to run out and it causes heavy environmental pollution problems. Also the generation of heat by nuclear reactions has raised several concerns because of possible safety problems and because radioactive waste are produced. On the other hand, the exploitation of solar energy for producing heat or electricity via the photovoltaic effect seems to be a viable alternative. However, it should be kept in mind that also in this case issues related with the production of the necessary equipment and the disposal of exhausted materials should be analyzed.

In this activity students are encouraged to reflect on energy production issues also producing presentation material to be discussed with the teacher and their peers.

Duration: 1 hour + homework

Activity 4.1: **Engage**

The teacher asks the students the following question:

"Where does the electric energy we normally use at home come from?"

All student answers are written on the blackboard, in a single column. Another column is used to group answers per type and to distinguish between renewable and non-renewable energy sources.
The main goal is to highlight the student common ideas on the difference between renewable and non-renewable energy sources.

Appropriate videos are shown to students, also in order to help them to acquire proper scientific terminology. Typical videos that can be used are:

http://m.youtube.com/watch?v=KV7SNveb1Is

https://www.youtube.com/watch?v=PhLA6kuZSa0

www.eniscuola.net/argomento/solare

After watching the videos, the students are asked if they want to change, or modify, the answers given to the previous question. Finally, teacher summarizes the main features of the various energy sources discussed so far, also from a sustainability viewpoint.

Activity 4.2: **Explore** (homework)

Student groups are formed and students are invited to research at home documents, web site and related articles about the following topics:

Group 1: Kyoto protocol and rational use of energy
Group 2: Renewable energy sources (advantages and disadvantages)
Group 3 : Solar thermal energy and traditional technology photovoltaic panels
Group 4 : Last generation photovoltaic panels
Group 5: Environmental impact of photovoltaic technology

4.5 Lesson 5 – Produce presentation material

Duration: 2 hours + homework

Activity 5.1: **Elaborate**

The collection of information gathered in the previous activity by each group is organized in a structured product, such as a Power Point presentation, a video, an interactive Prezi like presentation or a series of conceptual maps.

These products can be used in a Science Exhibit and for self evaluation and student assessment by the teacher.

Student share their results (also by using IT technologies such as Facebook and WhatsApp).

The ethical aspects of research and innovation are highlighted and discussed. The aim is to make students aware of advantages and disadvantages of the various energy sources and of the effect that the technology can have on the environment and on their own lives (RRI-Science Education and Ethics).

The teacher can follow and coordinate the student discussions by means of the same IT technologies used by them.

4.6 Lesson 6 – Assembling a DSSC cell

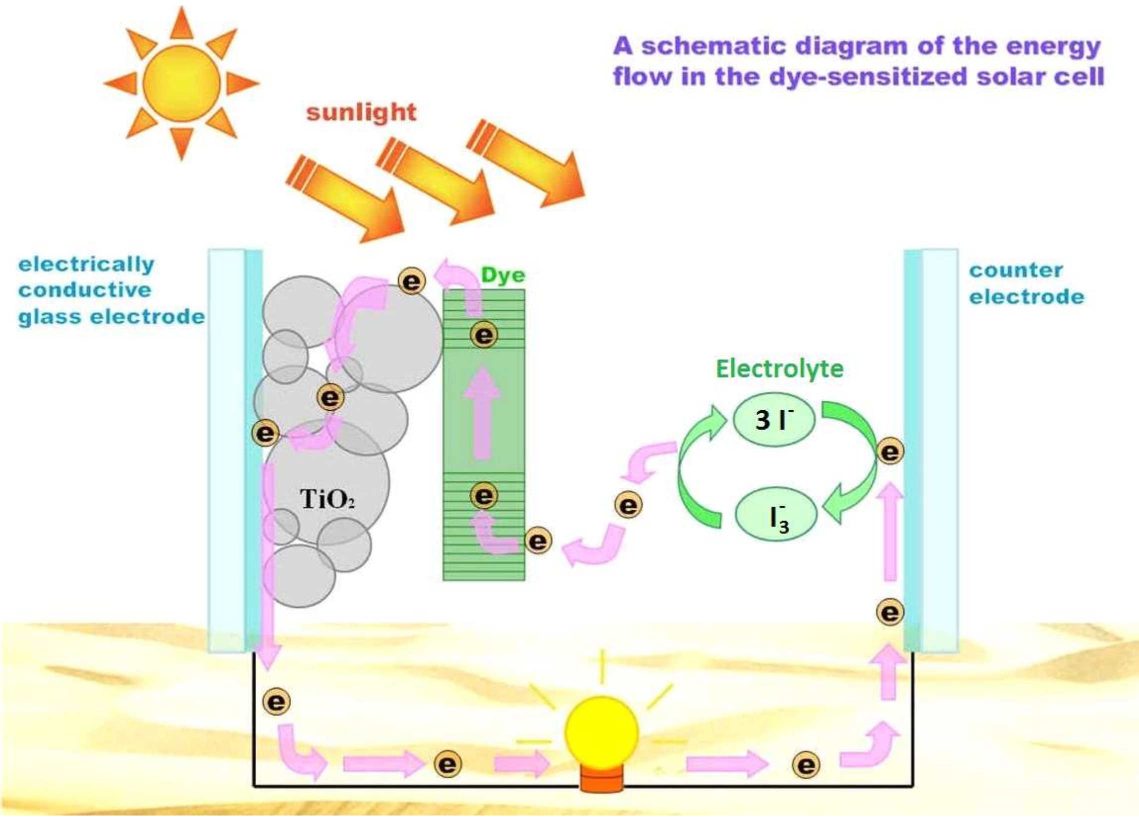
In addition to first and second generation semiconductor-based photovoltaic panels (see section 4.3), research is progressing on the development of more efficient and also more versatile cells.

The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics. Most of them are not commercially available yet and they are still in the research or development phase. Many of these applications use organic materials, such as dyes or polymers. Plastic solar cells are flexible and use polymers such as polyphenylene vinylene.

The use of natural or artificial pigments in the design of electrochemical cells was originally proposed by M. Grätzel in 1991. This kind of organic solar cell is known as Dye Sensitized Solar Cell (DSSC). The active material is constituted by a dye, often anthocyanins, a class of water-soluble pigments whose colors might range from red to blue, contained in some fruits such as blackberries, raspberries, blueberries etc..

The cell (see diagram in Figure) consists of two conducting glass slides, which serve as electrodes, one of which is coated with a layer of TiO_2 nanoparticles and the other with graphite, the active material (anthocyanins) and the electrolytic solution, containing the pair iodide/triiodide that acts as a mediator in the operation of the cell process.

As schematically depicted in the Figure, the dye, upon absorption of the visible portion of the incident light, forms an excited electronic state. Due to the energy contiguity, excited electrons can move in the conduction band of the TiO_2 layer, and then flow in an external circuit to the counter electrode, another conductive glass slide covered with a layer of graphite. The electrons can then be returned to the dye by the mediator compound iodide/triiodide. Nanoparticles play an important role in the operation of the DSSC cells by providing a high surface area thus maximizing contact between the dye and the semiconductor. In this way the amount of charge transferred will be maximized and, as a consequence, the efficiency of the cell will improve.



Schematic diagram of a DSSC cell. The arrows indicate the electron flow generated by the photoexcitation of the dye (green rectangle)

In this activity, students will assemble and test a DSSC cell. The result of their work will be displayed and demonstrated, along with presentation material from the previous activities, in the final exhibit.

Duration: 2 hours

Activity 6.1: **Explore**

The teacher introduces the basic principles of operation of a DSSC cell, as an example of innovative photovoltaic system, and guides the students to assemble their own cell.
In order to assemble the cell, a preliminary phase is needed for the preparation of the TiO_2 coated conducting glass electrodes.

Full details about this procedure are reported in:

https://www.youtube.com/watch?v=Qbsl1NP5uZI

The text of the above video can be found in the Appendix (see A4.6.1).
However, it is possible to find ready-made TiO_2 coated glass slides from different commercial vendors. In many cases these electrodes are supplied in kits containing all the necessary equipment and also test and measuring tools such as LED lights, small battery powered calculators, multimeters that can be used to test the cell.
In what follows, it will be assumed that TiO_2 coated electrodes are available to the students.
The students are divided in small groups and a worksheet is supplied (see example in A.4.6.2) to be used during the activity.
The cells are then exposed to sunlight and the obtained voltage and current are measured. A LED is lighted by using the electric energy extracted by the cell. The students are, finally, asked to highlight the analogies and differences between traditional photovoltaic cells and organic ones.

Materials:
- TiO_2 coated conducting glass slides
- Ethanol
- Raspberries or other berries
- Distilled water
- Iodine electrolyte solution

Equipment:
- Mortar and pestle
- Petri dish
- Glass stirring rod
- Conducting glass slides
- Candles
- Cotton swab
- Multimeter

4.7 Lesson 7 – Preparation and presentation of the exhibit

This section deals with activities in which the students transfer their knowledge about the topic to other (other students, parents, the general public). This will be done in an exhibition for which the students make posters, exhibits or other presentation tools.

There are many possibilities on how students can use an exhibition to show what they learned in the module. Posters, objects, movies, all presentation forms are allowed. The DSSC cell that students made in the previous section can be used. Furthermore, students can report the results of the experiments performed in their lab work about the conversion of solar radiation into heat and electricity.

Also, showing the aspects of Responsible Research and Innovation is important in the exhibitions. You can think about statements about renewable and non-renewable energy sources and the connection to the environment that induce visitors to start a discussion on the topics.

The production of an exhibition has three phases, that are equally important: pre-production (design), production (the actual implementation) and post-production (evaluation). Also, you need to think about how to make your exhibition *interactive*, which means that visitors actually do something with the exhibition and not just look at it. Texts must be clear, readable and most importantly not too long.

Duration: 4 hours + out of class work

Activity 7.1: Pre-production (***Elaborate***)

In planning how the exhibit will be organized, please make reference to the "Interactive exhibitions development guide" available in the IRRESISTIBLE project website.

- Divide students into groups so that every topic of the module will be dealt with in the exhibition. In particular, invite the students to organize and elaborate the experimental data they have collected about the conversion of solar energy into heat and/or electricity as well as the material collected about the implications of using different energy sources
- Invite the groups to discuss with each other in order to agree on a shared plan for the exhibit
- Make very explicit that the RRI-issues need to be addressed in the exhibition as well

Some students don't find interesting to making an exhibition. Try to find a way to make it relevant for them, for example by using it in open days at school, in presentations to lower level students or a suitable science fair. Make sure that every group has a plan on what to do.

<u>Activity 7.2</u>: Production (***Exchange***)

In this activity the students will actually put together their exhibit. Most of this work will be done during off class hours. However, in order to get the students more involved, it is advisable to find space at school for work after hours.

In the final exhibit, products prepared by students are shown and described to visitors of the event, the main phases of the learning path are described and practically demonstrated (heating/cooling of bottles of different colors exposed to the light, generation of electric energy by means of inorganic and organic solar cells, influence of the angle of incidence of light on the heating due to the light, etc.).

Thus, the students behave as young researchers, sharing their results with other people and involving them in their study.

<u>Activity 7.3</u>: Post-production (***Evaluate***)

After the exhibition, the teacher will ask the students to summarize their opinions.

The evaluation phase might address questions like:

Did everything go as planned? What went wrong, what could have been better? What could be done differently?

It must be stressed that holding the exhibit also represents an evaluation tool. In fact, both the students and the teachers can assess how effective was the interaction with visitors and, therefore, how solid was their background developed during the preparation phase and through the learning sequence.

4.8 Lesson 8 – Student post-test

In this phase, students are asked to fill the same questionnaire that was used in 4.1 (see example in A4.1). Once again, the questionnaire is filled anonymously but the teacher will ask the students to mark their answer sheet with the same nickname they used in 4.1. In this way, it will be possible to monitor performance and attitude changes on an individual basis.

Duration: 1 hour

Activity 8.1: **Evaluate**

5

Appendix

A4.1

Prototype example of pre/post questionnaire

1) When exposed to sunlight, all materials warmed up, but in some cases the radiation causes other phenomena. Can you mention some of these?

2) Two equal bricks were placed on a table and they were exposed to sunlight from the top for the same time. One of the bricks was set vertically while the other one was laying flat on the table. What can you observe?

a) the brick placed vertically was warmer than the other
b) the brick laying flat was warmer than the other
c) the bricks did not warm up
d) the bricks had the same temperature

3) Both Mario and Francesco bought the same car model, but Mario chose a black one and Francesco a white one. During a sunny summer day, who will need more air conditioned?
a) Mario
b) Francesco
c) the same

4) The sun is an energy source. Please write below some examples of natural systems capable of converting solar energy to other forms.

5) Renewable energy sources are:

a) energy sources that do not run out in time comparable to the average human life
b) energy sources that regenerate themselves during their use
c) energy sources that run out in time comparable to the average human life
d) energy sources that do not produce wastes. Explain your answer.

6) List the renewable energy sources available in Sicily. Among these, in your opinion, which is the source to be preferred? Explain your answer.

7) What kind of energy is that you use at home to charge your mobile phone? From which source could it be produced?

8) What kind of energy transformation occurs during the use of tour mobile phone?

9) In photosynthesis, the transformation of solar energy in chemical energy occurs. In organic photovoltaic panels, using natural vegetable substances as active elements, transformation of solar energy in electrical energy occurs. In your opinion, are there possible

analogies between photosynthesis and the operating mechanism of an organic photovoltaic panel?

a) No. They are two processes that use different energy sources
b) Yes. They have in common the production of solar energy from chemical energy.
c) Yes. In both cases solar energy makes the electrons more mobile for the redox process
d) No. In the organic photovoltaic panel the process is not spontaneous.

Explain your answer.

10) A piece of coal burns slowly in air, but if it is reduced in a very fine powder, the combustion proceeds so quickly that the reaction can be explosive. Can you explain the different behaviour of the same substance (coal) with respect to its speed of combustion?

11) Both heat from burning oil and solar energy can be used for heating a medium for energy production purposes. From an environmental view point and considering the by-products generated, do you think that the two processes are equivalent? Explain your answer.

12) Recent international conventions have further reduced the quantity of CO_2 emission in atmosphere in many countries. Can you identify some processes in which this gas is produced and why it is desirable to reduce its emission in the atmosphere?

A4.3.1

Thermal and electric effects of light

Light and its effects

Class:_________________ Date:_____________________

Student: ____________________________________

Other group members:____

As you know, an object exposed to light can be subject to several effects. Please write below a few examples.

Imagine to have an electric lamp and a plastic bottle full of water. Please write below some physical property of water, which you can measure, that may change as a consequence of variations in any feature of the light source.

How could you measure the changes you mentioned in the previous question? Think about an experiment that you could do and the materials/instruments you would need. Discuss with the other group members and write your ideas below.

The teacher will now ask one person of each group to report about their ideas. Write all the groups ideas below.

A4.3.2

Thermal and electric effects of light

Thermal effects of light

Class:__________________ Date:______________________
Student: ______________________________________
Other group members:____

We all know that an electric lamp warms the object on which its light is focused. In fact, if we put a hand close to the lamp, we can feel the heat, even if we do not actually touch it. Similarly, an object that has been near a light bulb for some time varied its temperature and, after exposure to light, it is warmer than before.
Now we want to understand a little more about this phenomenon.
In your opinion, what are the factors that determine how much an object placed near a lamp, that has been turned on, heats up? Discuss with your group mates and write your ideas below.

The teacher will now ask one person of each group to report about their ideas. Write all the groups ideas below.

Each group will now be assigned the task to study the effect of one of the factors previously identified on the heating of an illuminated object. Choose the factor you want to study and coordinate your work with the other groups and the teacher. Write below the factor your group will study.

Think about the materials and instruments you think you will need for your study and ask for them to the teacher. Then, write below a list of these materials and instruments.

Sketch your experimental apparatus and give a description of the measuring procedures you have planned.

Perform with the other group members the experiments and report below the results. Discuss with the other group members the conclusions you think you can obtain from your data. Then, describe what effects you think the factor you have studied has on the heating of an illuminated object.

The teacher will now ask one person of each group to report about their results and conclusions. Write all the group results and conclusions below.

Do you think that in Nature there are systems or phenomena that “work” similarly to what you studied in the laboratory?

Think about a real object that can be represented by the plastic bottle in your experiment and write its name below. Explain your answer.

Think about a real object that can be represented by the lighted lamp in your experiment and write its name below. Explain your answer.

Think about analogies and differences between the natural systems you identified and the objects you used to perform your experiment. Explain and discuss them.

A4.3.3

Thermal and electric effects of light

Heating is not the only effect of light on matter

Class:__________________ Date:______________________

Student: ______________________________________

Other group members:____

In addition to thermal effects, do you know other effects produced by light focused on an object? Write below any example taken from your real-life experience, or from situations/phenomena you have personally learned about by watching Tv, Internet, etc.

Describe a possible experiment that can be used to demonstrate non-thermal effects of light.

A4.3.4

Thermal and electric effects of light

Electric effects of light

Class:__________________ Date:______________________

Student: ______________________________________

Other group members:____

You surely know that solar panels are devices that convert light in electricity. Please write below a few examples of how solar panel are used in practical applications.

The teacher is showing you a solar panel connected to a small LED lamp. Sketch the experimental apparatus and describe below what the teacher is doing. Also write down any observations you might have about the experiment.

In the experiment, the LED is lighting up. Where do you think is coming the energy necessary to light it from?

The teacher will now connect two instruments to the solar panel. They can measure electric current and electric voltage, two properties providing information about the conversion of light in electricity. Sketch the experimental apparatus and describe below what the teacher is doing. Also write down any observations you might have about the experiment.

Based on the above observations, what are the factors that can influence the process of conversion of light in electricity? i.e., what are the factors that can influence the electric current and voltage measured in a solar panel exposed to light?
Discuss with the other group members and write below your ideas.

The teacher will now ask one person of each group to report about their results and conclusions. Write all the group results and conclusions below.

Each group will now be assigned the task to study the effect of one of the factors previously found on the current and voltage produced by the lighted solar panel. Choose the factor you want to study and coordinate your work with the other groups and the teacher. Write below the factor your group will study.

Sketch your experimental apparatus and give a description of the measuring procedures you are planning.

OPT: Perform with your group mates the experiments and report below the results you obtain. Discuss with your group mates the conclusions that can be drawn. Then, report the effects you think the factor you have studied has on the current and voltage produced by the lighted solar panel.

OPT: The teacher will now ask one person of each group to report about their results and conclusions. Write all the group results and conclusions below.

Do you think that in Nature there are systems or phenomena that "work" similarly to what you studied in the laboratory and transform light in other forms of energy?

Think about a real object that can be represented by the solar panel in your experiment and write its name below. Explain your answer.

Think about a real object that can be represented by the light source in your experiment and write its name below. Explain your answer.

Think about analogies and differences between the natural systems you found and the objects you used to perform your experiment. Explain your answers.

OPT = OPTIONAL QUESTIONS

A4.6.1

Instruction for preparing and assembling a DSSC cell taken from:

https://www.youtube.com/watch?v=Qbsl1NP5uZI

PART 1 - Preparing the TiO_2 Suspension

Step 1: start with 6 grams of titanium dioxide powder in a mortar and pestle. Under ventilated fume hood, slowly add vinegar in 1ml increments to the solution, grinding well each time. The process should take around 30 minutes and what will result in a very white milky paint-like solution.

Step 2: Add a drop of clear dishwashing liquid to the solution but did not grind otherwise it will get foamy and bubbly. The dishwashing liquid will act as a surfactant which reduces the surface tension at the solution and thus helps it coat the glass plates more evenly.

Sep 3: Use the funnel to pour the solution into the small dropper bottle. Leave the solution alone to equilibrate for at least 15 minutes.

PART 2 – Coating Slide with TiO_2 Suspension

Step 1: Clean two conductive glass slides by rinsing them with a wash bottle filled with ethanol; gently dry them with a soft tissue.

Step 2: Use a multimeter set to resistance –ohms to check which side of the glass side is conductive. The slide should conduct between 10 and 30 ohms on the conductive side and nothing on the non-conductive side. There should be a slight visible difference between the conductive and non-conductive slides as well. The conductive side will appear bluish and cloudy while the non-conductive side will appear clear and yellowish.

Step 3: Use the transparent tape to tape one glass slide down on the table on all four edges. The tape should cover roughly 1 mm of the slide on three of the edges and about 4 mm of the slide on the remaining edge. This tape has a controlled thickness and will form a 40-45 micron deep channel into which the titanium dioxide suspension can flow.

Step 4: Use ethanol on a tissue to wipe off any finger prints or oils on the slide.

Step 5: Put a drop or two of the titanium dioxide solution on the slide and quickly spread the solution as evenly as possible over the slide using a clean glass stirring rod.

Step 6: Wait for the slide to dry for a few minutes before carefully removing the tape.

PART 3 - Annealing the Coated Slides

Step 1: Annealing the titanium dioxide film on the glass side in a fume hood or well-ventilated area. Use one of the following methods:

1) make a simple tube furnace from the hot air gun. Start by removing the outer plastic casing at the base of the nozzle to prevent it from melting. Then wrap aluminum foil around the nozzle to form an enclosed oven. The slides will lie flat inside this oven for the annealing process. Be sure to leave a small opening in the oil so that you can watch the slides for color change as they anneal. Turn the hot air gun on high or to 450 degrees Celsius. Let heat for 30 minutes.

2) Place a ring stand over an alcohol burner. 1. Anneal the slides one by one by resting them on the ring stand on the tip of the flame for 10 minutes.

Step 2: Watch the slides as they anneal. The titanium dioxide coated section should turn purplish-brown and then back to white as the heat burns off the surfactant.

Step 3: Store the slides for later use.

PART 4 - Staining the TiO_2 with Anthocyanin Dye

Step 1: Use a clean mortar and pestle to crush 3-4 berries. Transfer the crushed berries to a petri dish.

Step 2: Add about a table spoon of distilled water to the crushed berries and stir with a clean glass rod.

Step 3: Place the slide faced down into the berry mixture so that the titanium dioxide coated section is submerged in berry juice.

Step 4: Let the slide soak in the juice for 10 minutes. The film should be stained bright purple. If you can see any white titanium dioxide remaining on either side of the glass after 10 minutes, put the slide back into the dye for another 5 minutes. Now is a good time to start on part 4: carbon coating the counter electrode.

Step 5: Lift the slide out of the juice using a pair of plastic tweezers. Rinse the slide first in distilled water to remove any fibrous debris from the berries and then in ethanol to remove excess water from the porous titanium dioxide coated section. Let the slide dry with a tissue.

Step 6: You have now made a titanium dioxide dye-sensitized electrode. If the slide is not going to be used right away, store it submerged in distilled white vinegar in a closed dark-colored bottle.

PART 5 - Carbon coating the counter electrode

Step 1: While the titanium dioxide electrode is being stained in the berry juice, make the counter electrode from another piece of conductive glass.

Step 2: Light a tea candle with a match.

Step 3: Determine which side of the clean glass plate is conductive with a multimeter set to resistance-ohms. Hold the side by one edge with metal tongs. Pass the conductive side through the middle of the flame until the entire site is coated evenly with soot, except where the metal tongs were.

Step 4: Place the carbon coated slide face up on the counter. Be careful the slide will be hot. Allow it to cool. Then use a tissue and cotton swab to clean any residual soot off the edge of the slide covered by the metal tongs to clear the carbon off of a 4 mm strip. This edge will be where the alligator clip attaches.

Step 5: You have now made a carbon coated counter electrode. The carbon coating on the slide is very fragile and is easily rubbed off. Be careful not to touch it.

PART 6 - Assembling the Solar cell device

Step 1: This stained titanium dioxide glass slide has been stored in vinegar. Carefully remove it. Rinse the slide with water and then with ethanol. Then gently blot it with a tissue.

Step 2: These two slides, the titanium coated slide and the carbon coated slide, will be sandwiched together to make a solar cell. Both slides have 4 mm strip on one edge that is clear any coating. The slides must be assembled so that the coated areas of the slides are touching each other completely. This means the slides will be offset and the 4 mm empty strips will be exposed on each side. This two exposed edges will serve as the contact points for the negative and positive electrodes.

Step 3: Place the dry titanium dioxide coated slide on a flat surface so that the titanium dioxide coated section is faced up. Place the carbon coated slide faced down on top of the titanium dioxide slide so that the coating completely covers the titanium dioxide coating, leaving a 4 mm strip exposed on each slide.

Step 4: Pick up the two slides in this orientation being careful not to let them move. Clip the edges, the ones that do not have the 4 mm strip exposed together on both sides with two binder clips.

Step 5: Place one or two drops of the iodine electrolyte solution at one of the edges of the slides.

Step 6: Alternately, open and close each side of the solar cell by releasing and returning the blinder clips. The liquid is drawn into the space between the electrodes by capillary action. This wets stained titanium dioxide film. Make sure that all of the stained area is contacted by the electrolyte.

Step 7: Wipe off the excess electrolyte solution from the exposed areas of the glass using a cotton swab and tissues dampened with ethanol. The cell will not work well if there is any electrolyte solution left on the exposed areas where the alligator clips attached.

Step 8: Fasten alligator clips to the two exposed sides or poles of the solar cell to make electrical contact to the finished device.

PART 7 - Measuring the Electrical Output

Step 1: The completed solar cell can be taken outside and measured under sun light. The cell will last longer if it is protected from the elements by a polycarbonate plastic cover like a plastic petri dish. Sun and air will dry out the iodine electrolyte solution inside the cell which will speed up the deterioration of the dye molecules in the berry juice.

Step 2: For more instructions on how to measure the voltage in amperage of the cell see experiment 1 measuring voltage and current.

A4.6.2

Procedure for assembling a DSSC cell

ADD ANTHOCYANS TO THE GLASS WITH TiO_2

1) Crush raspberries in a mortar and transfer the crushed berries to a Petri dish
2) Add about 10 ml of distilled water and stir with a clean glass stirring rod
3) Place the TiO_2 coated slide face down into the berry mixture so that the titanium dioxide coated section is completely submerged
4) Let the slide soak in the juice for 10 minutes and, in any case, until no remaining white areas are visible
5) Lift the slide out of the juice, rinse it in distilled water to remove any fibrous debris from the berries and then in ethanol to remove excess water. Gently dry with a tissue paper.

CARBON COATING THE COUNTER ELECTRODE

1) Light the candle
2) Determine which side of a clean glass slide is conductive with a multimeter set to resistance-ohms.
3) Hold the slide with metal tongs and pass it on the candle so that the conductive side goes through the flame: a uniform soot layer will be formed.
4) Place the carbon coated slide face up on the counter, allow it to cool and remove any residual soot off the edge of the slide with a cotton swab to clean the area where the alligator clip attaches for the electric contact.

ASSEMBLING THE SOLAR CELL

1) Put the carbon coated slide on top of the titanium coated slide, previously placed on the work desk, so that the coated areas of the slides are touching each other completely and the empty strips will be exposed in each side
2) Clip the edges completely overlapped with two binder clips, avoiding that the glass electrodes slide one on the other
3) Place one or two drops of the iodine electrolyte solution at one of the edges of the slides
4) Alternately, open and close each side of the solar cell by releasing and returning the blinder clips, the solution will spread into the space between the electrodes wetting the titanium dioxide film
5) Wipe off the excess electrolyte solution from the exposed areas of the glass using a cotton swab and tissues
6) Fasten two alligator clips on the two sides of the cell

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The work reported in this Module is the result of two years of planning and testing in several secondary schools in Palermo.

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