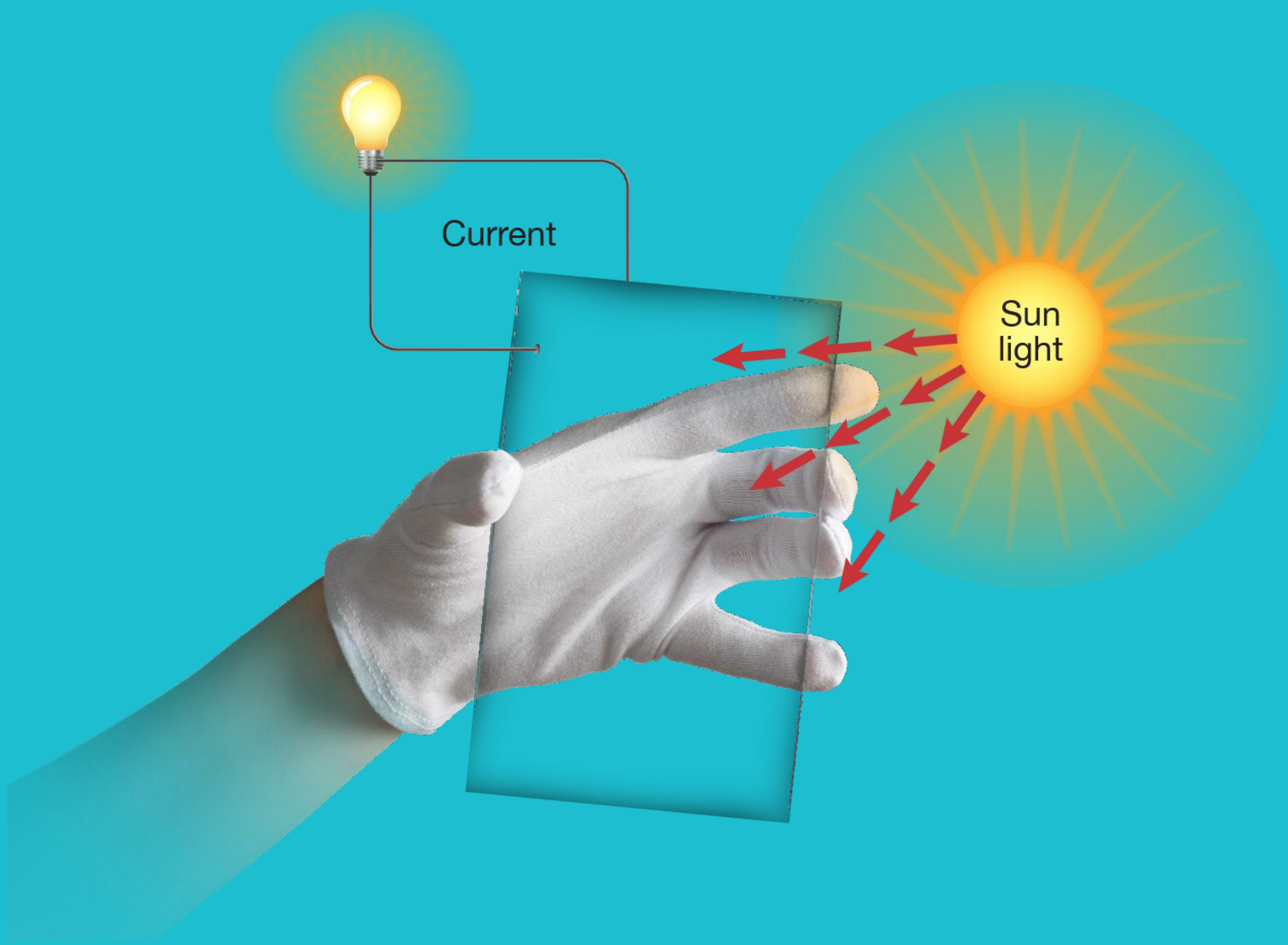
The RRI of Perovskite-Based Photovoltaic Cells



Weizmann Institute of Science

irresistible

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The RRI of Perovskite-Based Photovoltaic Cells

"Under what conditions, if any, would we (the students) agree to have perovskite-based photovoltaic cells installed on the windows of our school?"

Main Goal of the Module. The main goal of the module is to foster positive attitudes towards RRI by both teachers and students, by focusing on the use of perovskite-based photovoltaic cells within the context of using alternative energy. Perovskite-based photovoltaic cells are the research topic of a Weizmann Institute scientist. These photovoltaic cells have a relatively high efficiency but also have liabilities, such as the use small amounts of lead, a poisonous substance.

Target Group: 10th to 12th grade chemistry students

Duration of the Module: One 3-hour lesson on RRI (in the classroom), followed by a 6-hour visit (in the Garden of Science - science museum and in the Weizmann Institute of Science) and a 3- to 4-hour session on building the exhibits (in the classroom).

Learning Outcomes: The students will be able to apply RRI dimensions in order to decide "Under what conditions, if any, would we (the students) agree to have perovskite based photovoltaic cells installed on the windows of our school?" The students will present their decision by constructing an exhibition.

Development team: The module was developed at the Weizmann Institute of Science by PI Ron Blonder and the other Community of Learner (CoL) team: Ronit Barad, Ziva Bar-Dov , Fadia Khatib, Shelley Rap, Sherman Rosenfeld, Sohair Sakhnini, Alon Shaham, and Esty Zemler .

Table of Contents

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Outline of the Module

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In the following table the structure of the module is outlined. Duration of each activity is also provided.

Activity	Duration (hours)	6E Aspect
Pre-visit RRI unit in the classroom **"The Story of Lead"**	3	**ENGAGE** Students learn about the history of lead use, as a basis for understanding the 6 dimensions of RRI.
Visit to the Weizmann Institute's The Garden of Science (science museum) on the topic of **alternative energy**	1	**EXPLORE** The visit invites students to explore interactive exhibits on different aspects of alternative energy.
Special news broadcast on perovskite-based photovoltaic cells	1/4	**ENGAGE** The broadcast frames the module's guiding question and learning goals.
Experiment and lecture on **photovoltaic cells**; group summary for the exhibits.	2	**EXPLAIN and ELABORATE** These activities invite students to delve into the module's scientific content.
Group discussion on **RRI**	1/4	**EXPLAIN and ELABORATE** The discussion helps students remember the content of the pre-visit unit on RRI.
Three short news broadcasts which present negative aspects of the proposed innovation	1/4	**EXPLAIN and ELABORATE** These short broadcasts present liabilities relating to the photovoltaic cells. Students are challenged to integrate these aspects.
Group summary of the RRI panel for the exhibits	1/2	**EXCHANGE** The students start to work on the first panel of their exhibits.
Group work on the **design of the exhibits**; presentation of the "Price of Chocolate" exhibit	1/2	**EXCHANGE** The chocolate exhibit serves as a source of different ways to represent information and dilemmas in the student exhibits.
Design of the exhibits. In their classroom, students work on building the exhibits.	4	**EXCHANGE** Students work in groups to design their exhibits. The exhibits include: general background, scientific content, and RRI aspects.
o. Presentation of exhibits to other students in the school	2-1	**EVALUATE** The quality of the exhibits and the audience reactions to them allow teachers and students to evaluate student learning.

2

Introductory Lesson: RRI & the Story of Lead

Introductory Lesson: RRI & the Story of Lead

Responsible Research and Innovation (RRI) stands at the centre of several EU projects and represents a contemporary view of the connection between science and society. Previous 'techno-disasters' together with many facets of the current financial crisis have resulted in a loss of public trust in business and governments across the world. The goal of RRI is to create a shared understanding of the appropriate behaviours of the European Commission, governments, business and NGOs which are central to building trust and confidence of the public and other stakeholders in safe and effective systems, process and products of innovation (Sutcliffe, 2011).

RRI is built of six dimensions:

1. Engagement
2. Gender Equality
3. Science Education
4. Open Access
5. Ethics
6. Governance

The integration of these dimensions is recommended in order to improve RRI.

In this part we describe an introductory lesson that was developed in Israel for teaching RRI for high school chemistry students by analyzing the historical story of lead.

Description of the Lesson

The 4.5-hour lesson, "The Story of Lead", is composed of 6 classroom activities described below.

Summary of "The Story of Lead"

Class activity	Type of activity	Hours
1. Characteristics of Lead	Classroom lesson	0.5 h
2. A Short History of Lead Use	Classroom lesson	1.5 h
3. The Story of Clair Peterson: A Scientist Who Fought Against Leaded Gasoline	Video	1 h
4. Students Identify RRI Dimensions	group discussion	0.5h
5. Elaborating the 6 RRI Dimensions	Class discussion	0.5h
6. Applying RRI Dimensions	Game	0.5h

Characteristics of Lead

In the opening lesson connects the module to the chemistry content that is usually taught. Teachers teach about the chemical properties element lead (e.g., a bright and silvery metal with a slight shade of blue, a soft metal easy to use for welding and brazing); how it is found in nature; how lead is extract and produced, the radioactive decays the produce lead, and uses of lead (e.g., lead-sulfur plates in accumulators and some batteries, corrosion-resistant coating, diving and fishing weights). The opening lesson can be introduced when teachers teach about the periodic table or when they teach about radioactive decays both are part of the high school chemistry curriculum in Israel.

A Short History of Lead Use

After the introduction of the chemical properties of lead, the teachers tell their students about the Romans, who used lead in their water pipes and vessels, including cooking pots and wine bottles. One of the "value-added" aspects of the latter case is that lead neutralized the wine's acidic taste and added a sweet taste to the wine, as presented in equation 1. Unfortunately, the Romans did not know that lead is poisonous to the human body and can cause severe neurological damage, cognitive damage and sterility. Some historians believe that lead poisoning was a contributing factor to the fall of the Roman Empire.

Equation 1:

$$PbO_{(s)} + 2CH_3COOH_{(aq)} \rightarrow Pb(CH_3COO)_{2(aq)} + H_2O_{(l)}$$

The first documented evidence of lead's toxicity was made in the 1st century. Pedanius Dioscorides (about 40 – 90 AD) was Greek physician who lived in the time of Roman Emperor Nero. He pointed out that lead is toxic and can cause a person to become mentally ill, noting that “Lead makes the mind give way."

Another aspect of the story of lead is then presented – its connection with the paint industry in the early 20th Century. Lead was used as an additive to speed up drying, increase durability and resist moisture that causes corrosion. Once again, these benefits were offset by the severe problem of lead poisoning, which is especially acute with children. Although this problem was known, it was downplayed by the paint industry. Eventually, lead was outlawed in paints.

The Story of Clair Peterson: A Scientist Who Fought Against Leaded Gasoline

To continue the story of lead, the teachers show a video (Cosmos, episode 7) about Clair Peterson (1922-1995), who campaigned against the oil industry's use of leaded gasoline (The exact minutes that are essential for the lesson are provided in the supplement materials). The addition of tetraethyl lead (TEL) helped to reduce engine knock and to design cars with higher compression in the cylinders, resulting in greater power and efficiency. But the health hazards of lead were once again ignored or (as has been

recently documented) suppressed by the oil industry. Peterson was a well-respected geochemist, one of the inventors of the lead-lead dating method, which established the age of the Earth at 4.5 billion years. In the mid-1960's, he became an outspoken opponent of leaded gasoline. His efforts, based on his scientific studies about the health hazards of lead, contributed to the outlawing of lead additives in gasoline in the United States in the mid-1970's; unfortunately, today leaded gas is still widely used in other countries, such as in Africa. Link ti the video:
https://www.youtube.com/watch?v=dyNRQOpLdu8

Students Identify RRI Dimensions

This historical case study becomes the basis for a class discussion of the ethical, social and environment aspects of lead. Students discuss in small groups questions such as "What could have been done to prevent the terrible consequences of lead use? Why did it take hundreds of years before lead poisoning was recognized on a societal level and outlawed? How might society avoid similar dangers, today and in the future?" To engage the students in the discussion the teachers ask them three questions for a group discussion:

a. Were "red lines" crossed?
b. Would are the reasons?
c. What are your conclusions?

The groups present in their conclusions to the class and the teachers use the class discussion as the catalyst to present the 6 dimensions of RRI: engagement, gender equality, science education, open access, ethics, and governance. Students are challenged to address this question: "Under what circumstances could the story of lead been different? What dimensions of RRI could or should have been applied earlier?"

Elaborating the 6 RRI Dimensions

In the class discussion the teachers collect on the board different dimensions raised by the students groups. The teachers' guide the students to use the story of lead to extract the different dimensions of RRI, while adding those dimensions that were not identified by the students (usually science education and gender equality). The teachers present and explain the 6 dimensions. For each dimension the students are asked to suggest questions that could be asked to examine the dimension. Examples of possible questions for each dimension are presented in the table.

Here we provide student examples for questions relating to each RRI dimension

RRI Dimension	**Related Student Questions**
Engagement	Who should be involved? Are the voices of all those involved equal in the decision-making process? What is the decision-making process? Should people who are not knowledgeable of science influence scientific decisions?
Open Access	Is it enough to publish research results in professional journals that are accessible to the scientific community? Should studies also publish possible shortcomings and risks? Should there be an obligation to publish information about patents?
Ethics	Which ethical values are essential to consider? Does adhering to ethical standards improve research or hinder it? Does the product and its development take into account social and environmental values? Is the development sustainable? Does it take into account possible effects on the future?
Science Education	What degree of commitment (if any) should the scientist have to science education? How much effort should scientists and technologists be asked to invest, in order to share their research and development with people who are not experts in these areas?
Gender Equality	What is the proper representation of men and women in R & D work? What should happen if there is no proper representation of men and women?
Governance	Who will supervise the work? What stages of research and development need to involve the supervision? What is the source of authority for this supervision? Do scientists and technologists have an obligation to report their work? What is involved in the process of supervision?

Applying RRI Dimensions

A game was played by different student groups. Its purpose was to challenge the students to apply different RRI dimensions to specific information about the story of lead. In the game, each group was given one of 15 information cards which presented specific information regarding the story of lead. A member of the group rolled a 6-sided die which had a different RRI dimension written on each side, resulting in the random choice of one RRI dimension. In the game, the students are asked to find evidence of the chosen RRI dimension in their information card. For example, one information card shows an advertisement from 1940, in which a miner of lead describes the value of adding lead to paint (see in the following Table). If the group rolled the die and received the RRI dimension of Open Access, they would need to find how this dimension relates to the advertisement. In this case, students might conclude that the advertisement did not present the detrimental characteristics of lead. If the group received the RRI dimension of Governance, they might conclude that during the time of the advertisement there were no standards limiting the addition of lead in paint (Such standards were introduced only in the 1950's). If the group received the RRI dimension of Gender, they might conclude that there is no connection with the information card.

Description of the Cards in the RRI Game

Card No.	Card Content	Link to Graphic/Information Source
1	Advertisement in National Geographic (1923), one of a series of the National Lead Company: "Lead helps to guard your health."	http://theintellectualist.co/the-insidiousness-of-the-lead-industry-lead-helps-to-guard-your-health/
2	Advertisement of Dutch Paints (year?) which claims that the painted walls "don't just look good. They're yummy too!"	http://www.truerealty.net/2011/10/13/lead-based-paint-lbp/
3	Advertisement in which a miner of lead describes the value of adding lead to paint (1940).	http://3.bp.blogspot.com/-YdgdQBVql5w/UGo_cbQBVGI/AAAAAAAAIQA/ayh1-ih5r9Y/s1600/LeadPaint.jpg

4	A list of regulations regarding the use of lead in paints, in different countries, from 1909 to 1978.	http://www.toxipedia.org/display/toxipedia/History+of+Lead+Use (Protzman, *et al.*, 2016), p. 7-18
5	Newsweek cover about an investigative journalism article ("Lead and Your Kids") showing that up to year when lead was regulated in paint (1978) over 3 million children in the USA suffered from lead poisoning.	http://europe.newsweek.com/lead-and-your-kids-205232?rm=eu
6	The changing definition of "lead poisoning in children" (in terms of elevated blood lead levels) from 40 µg/dL in 1971 to 10 µg /dL in 1991.	http://www.toxipedia.org/display/toxipedia/History+of+Lead+Use (Protzman, *et al.*, 2016), p. 7-18
7	Description of a tragic case study of lead poisoning in Nigeria (2008), as the result of gold mining. The gold had to be purified from lead and the process released lead dust into the environment, which caused severe lead poisoning, leading to death of 460 children.	http://www.terragraphicsinternational.org/#!nigeria/c1jis
8	Information about tetra ethyl lead (TEL), General Motors' lead additive to gasoline (1923).	https://en.wikipedia.org/wiki/Thomas_Midgley,_Jr.
9	Information about how General Motors hired a medical consultant, Robert Kehoe, who argued that research did not show that TEL was a public health hazard (1925).	http://www.thenation.com/article/secret-history-lead/
10	Advertisement in National Geographic (1927) presenting TEL's added value of "high compression." In the advertisement, the words "TEL" and "lead" are not mentioned. Instead, the additive is called "Ethyl".	http://www.amazon.com/Ethyl-Gasoline-Compression-Original-Vintage/dp/B007FS9I4E
11	A 1933 advertisement showing a father and son riding in a car, with the son showing his disappointment in saying, "Gee, Pop – They're all passing you." The advertisement concludes: "Next time, stop at the Ethyl pump."	http://advertisingcliche.blogspot.co.il/search/label/1933

12	A list of regulations around the world, prohibiting the use of lead in gasoline from 1970 to 2007.	http://www.lead.org.au/Chronology-Making_Leaded_Petrol_History.pdf
13	Summary of 1985 research conducted by the Environmental Protection Agency (EPA) regarding the reduction of cases in lead poisoning, as a result of regulation.	http://www.nytimes.com/1985/03/05/us/epa-orders-90-percent-cut-in-lead-content-of-gasoline-by-1986.html
14	Data from the Center for Disease Control (CDC) regarding the percentage of children under 6 years with elevated blood levels, from 1997-2012.	http://www.cdc.gov/nceh/lead/data/StateConfirmedByYear1997-2012.htm
15	Illustrations from Dutch Boy Paints booklet for children, describing the advantages of lead in different commercial products. The children are encouraged to give these coupons to their parents.	http://www.cumc.columbia.edu/publications/in-vivo/Vol1_Iss16_oct09_02/pov.html

After the Presentation of the Story of Lead and Before the RRI Activity: Questions for Discussion

The story of lead presented scientific studies and technological developments. Try to review them with the students.
Some questions for discussion:

- What are "red lines" in research and development? (Possibilities include: Activities that undermine scientific integrity, such as falsification of data and the selective use of data; the exploitation of people; the lack of transparency, etc.)
- Were these "red lines" crossed during research and development efforts regarding lead?
- What could be the reason why these red lines were crossed ?
- What is the overall picture from the story of the lead?
- What factors motivated the researchers/industry leaders? (economic, political, social, etc.)
- Who funded the research?
- Did the public get what they expected from the research and development in this story?
- What should have been the limits of research and development? At what points in the story? How should these limits been set? Who should have set them?
- What are the consequences of crossing the red lines?
- What are the implications of the Story of Lead?
- What lessons can we learn from this story?
- What limits and guidelines should society and science share, so that the story of lead is not repeated? (**Hint**: These limits and guidelines can lead into a discussion of the 6 dimensions of Responsible Research and Development.)

Summary RRI & the Story of Lead

"The Story of Lead" can be a good introduction to the topic of RRI in chemistry classrooms. It creates a different way of perceiving the connections between science and society and it activates chemistry teachers and students to be more aware of possible problems that can influence them as responsible scientifically literate citizens.

As one of our teachers said:

"The 6 RRI dimensions are not just good for researchers. They are good for all of us. They build a person's character because they are also good principles for helping you to think deeply and to lead you to better manage your life."

Assignment 2-RRI & the Story of Lead

After the RRI Activity

To the Teacher: Divide the students into 6 groups.
Distribute a slide about one RRI dimension to each group.

To the Students:
Read the slide about the dimension of RRI that you have been given.

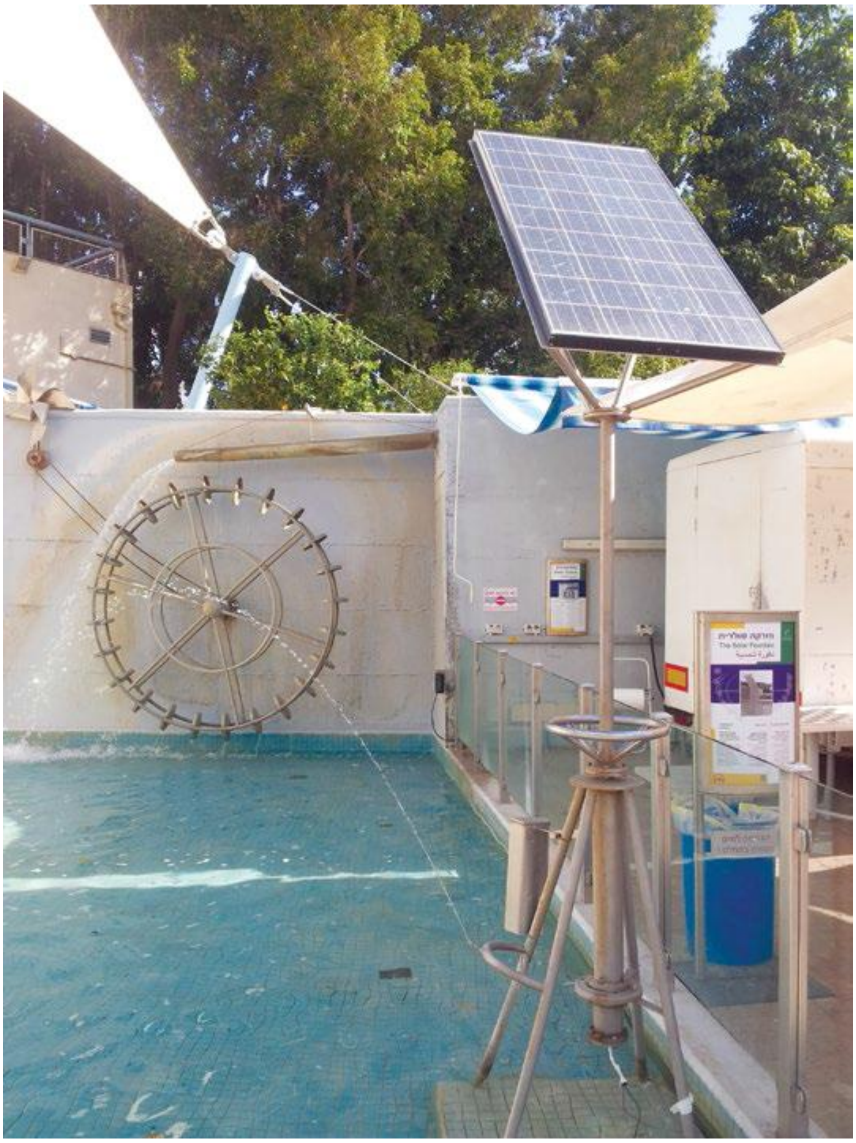
Each group should answer the questions relating its RRI dimension
(See the table above, page 14 "Elaborating the 6 RRI Dimensions".)

3

Visit to the Science Museum: Alternative Energy

Visit to Science Museum

In this part we describe the visit in the Clore Garden of Science to deal with the topic of renewable energy sources. We believe that individuals who adopt this program will be able to find at least some of these exhibits in their local science museums.



The Weizmann Institute of Science's Garden of Science (like most other science museums) has many different exhibits which focus on alternative energy and their uses in daily life. The following notes relate to a student visit which focuses on alternative energy exhibits.

Introduction to the Visit

During recent times, there has been a continuing public debate about alternative energy sources and their uses in daily life. In all physical and chemical processes, the total amount of energy is conserved. The main challenge is to acquire usable energy from physical and chemical processes that does not pollute the environment.

In this visit, we will focus on the benefits and limitations of solar energy, as illustrated by several science exhibits.

Water Wheel and Solar Water Pump

Description of the Exhibits: The water wheel shows how running water turns a water wheel. The solar water pump shows how photovoltaic (solar) cells generate electricity which powers a small water pump. (See photo at the beginning of this section.)

Discussion: When the students stand in these two exhibits, pose a question: How do power plants generate electricity? Answer: In the power plant, energy drives turbine generators to produce electricity. Where does this energy come from? In hydroelectric power plants, the energy source is falling water. In coal-driven power plants, coal is burned to evaporate water into steam, which then drives the turbines.

Is burning coal to produce electricity a good thing? Well, yes and no. Yes, because the resulting electricity gives us light, air-conditions our homes, charges our cell-phones, and the like. No, because burning the coal releases large amounts of carbon dioxide, a greenhouse gas that contributes to global warming and changing weather patterns. In addition, other substances -- mainly sulphur compounds – are released, which cause environmental problems such as acid rain.

What are alternatives? One "clean alternative" is to use hydroelectric power (as illustrated by the water wheel) and photovoltaic power (as illustrated by the solar water pump). The disadvantage of this solution is that sufficient amounts of water to drive turbines are not always available.

Another "clean alternative" is to use solar energy. The Sun provides enormous amounts of energy to free all day and photovoltaic cells (such as those that power the Solar Water Pump) convert solar energy into electricity using semiconductors. In the exhibit, electricity that has been generated by the Sun is transmitted to the pump that creates the water flow. Notice that if you turn the board with the solar cells on it away from sunlight, the power output of the pump decreases. And if you cover the board completely, the pump will not work. This illustrates that one disadvantage of solar cells is that sunlight is not always available (due to cloudiness and night). Other disadvantages are that solar cells are expensive and need a large area to generate a significant amount of electricity.

From Waves to Electricity

Description of the Exhibit. A machine consistently generates waves in a trough of standing water. A "wave-to-electricity" device – positioned on top of the water – converts the mechanical energy generated by the rising and falling of the water into electricity.

Discussion. Another "clean alternative" that can be used is wave energy. There are thousands of miles of beaches around the world where waves moving up and down near the shoreline can be a source of energy, day and night, all year around.

This exhibit uses the stored energy in the wave pool to generate electricity. Buoys connected to a central axis that runs a dynamo produces electricity, which lights up a light bulb.

The use of wave energy to create electricity is innovative and remains a challenge to implement. The innovation represented by the exhibit is not suitable for the production of electricity in a practical way, because in nature waves do not reach a constant frequency and amplitude, unlike what happens in the wave pool.

In reality, different-sized facilities have been adapted to different frequencies and amplitudes of the waves, in order to provide electricity efficiently and continuously.

Solar Water Heater

Description of the Exhibit. The exhibit has been designed to illustrate how a solar water heater works. Water that enters the water heater from the central water system then passes to the storage tank. From the tank it flows through black tubes that wind through a closed transparent panel, which produces the greenhouse effect and heats the water. The hot water then pass back to the storage tank, floats above the cold water, and then can flow through a tap outside. The visitor can compare by temperatures of the water when it enters and leaves the water heater, manually (by feeling the water itself, in both cases) and/or through temperature dials.

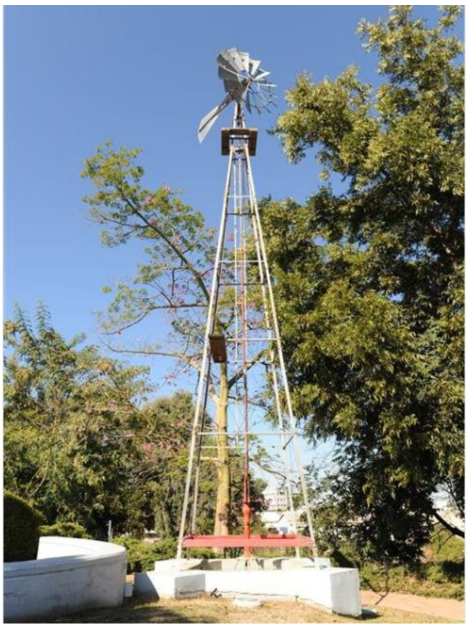
Discussion. Unlike the Solar Water Pump exhibit, the Solar Water Heater converts solar energy into heat and not into electricity. Almost all the homes and buildings in Israel have water heaters, due to a law passed after the 1976 oil embargo caused the price of oil to rise dramatically on the world market. Israel has nearly 300 days of sunshine per year, which can be used for heating water freely, without the need to spend money to heat water with electricity.

Solar water heaters face the south, in order to receive the most radiation throughout the day. They are not designed to "follow the Sun," since their effectiveness is high enough without having to produce a complicated and expensive tracking system. The advantages of the solar water heater are obvious. Equally obvious is its disadvantage, i.e., that it is limited only to heating water. Nonetheless, an average solar water heater saves its owner about 2,000 kWh per year in electricity costs.

Solar Oven

Description of the Exhibit. The exhibit, a large concave mirror, uses solar energy to reach high temperatures.

Discussion. When the concave mirror is turned towards the Sun, the sunlight that strikes the mirror is reflected back to a single point, called the focal point. If a wooden stick is placed in this point, it will start to burn very quickly. The high temperatures reached by the solar oven can also be generated by other solar devices to generate electricity that will produce steam to drive turbines in power plants to produce electricity.



Wind Turbine

Description of the Exhibit. A weather vane is connected to a water pump. As the wind moves the turbine, it causes a vertical motion of a piston which pumps water to a fountain. This is another example of using clean available energy.

Discussion. This exhibit demonstrates the use of wind power to pump water. Although the exhibit works as a closed system, it can also be seen as means for storing energy. Only when there is a strong gust of wind is the water pumped up, but it remains up, which means that the pump stores energy. In this way, the water can be used at any time, even when there is no wind.

Human Yo-Yo

Description of Exhibit. A flywheel -- mounted at the top of the exhibit – stores energy when the user pulls the handle of the rope downward. This energy is then released to pick the user off the ground.

Discussion. This fun experience – of being a human yo-yo! – demonstrates principles of energy conservation and storage. One interesting aspect of the exhibit is that when the user adds energy to the system – by pulling down the handle of the rope even farther downward – the energy is stored each time, so the user can be "picked up" to a height of several meters. Hybrid cars also have a flywheel which collects the wasted in braking in order to save energy during acceleration from rest.

4

Special News Broadcasts

Special News Broadcasts

A series of special news broadcasts was produced for the module in one of the leading Israeli TV channels. The broadcast was produced in Hebrew. So we provide below a series of captioned screen shots of the news broadcasts, so similar broadcasts can be produced and used in other countries.

"The Storm Surrounding Perovskite-Based Photovoltaic Cells" The news announcer presents the background behind this innovation.

"Live News Story – Photovoltaic Cells on School Windows."
A reporter presents the background to this innovation.

"Prof. David Kahan from the Weizmann Institute on Perovskite-Based Solar Cells"A research scientist who works on perovskite-based solar cells explains how they work and how they can improve the energy efficiency beyond that of silicon-based of solar cells.

"A Nationwide Protest – Parents Against Solar Cells in Schools"
A reporter interviews parents who express their opposition to the use of perovskite-based solar cells in schools.

"The Environmental Protection Ministry Reacts to the Initiative"
A statement from this governmental body presents the fact that perovskite contains small quantities of lead, which is poisonous and can be cancerous to all people and especially to children. The statement also defines the Israeli standard for acceptable levels of lead: up to 5 5 µg/dL.

The TV reporter cites source who state that while solar cells can have positive environmental effects, the perovskite solar cells can be dangerous to the environment.

5

Background Articles

Background Articles

1. What are Solar Cells?

Solar cells (also called photovoltaic cells or PV cells) are devices which generate electricity directly from light. This means that solar cells can generate electricity directly from the Sun – which is a renewable energy source. Thus, solar cells are considered a source of renewable energy.

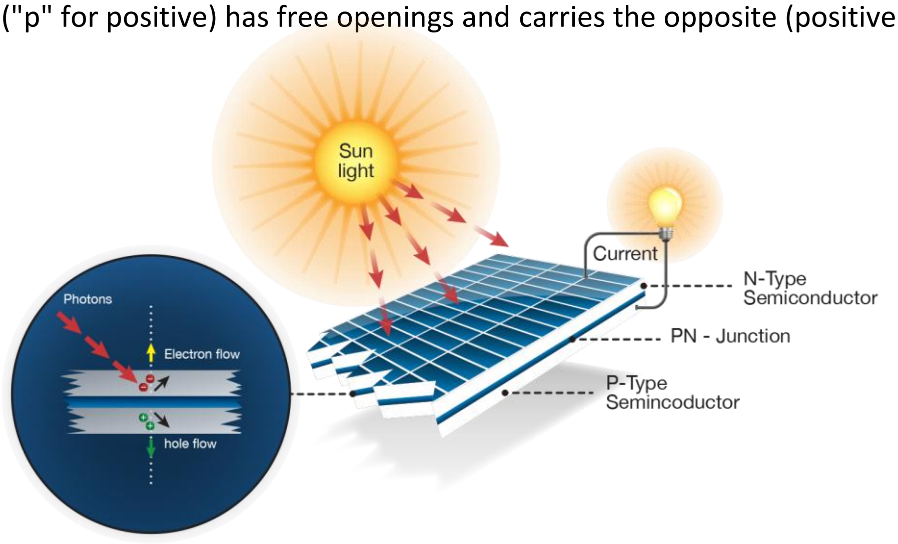
Solar cells are commonly used to power small electronic devices, such as pocket calculators, watches, and batteries. They are also used to power street lights, emergency phone systems, transportation signals, and satellites in space. In addition, large fields of PV panels can produce high-voltage electricity.

In most commercial solar cells, silicon is the light-harvesting active layer.

2. How Do Solar Cells Work?

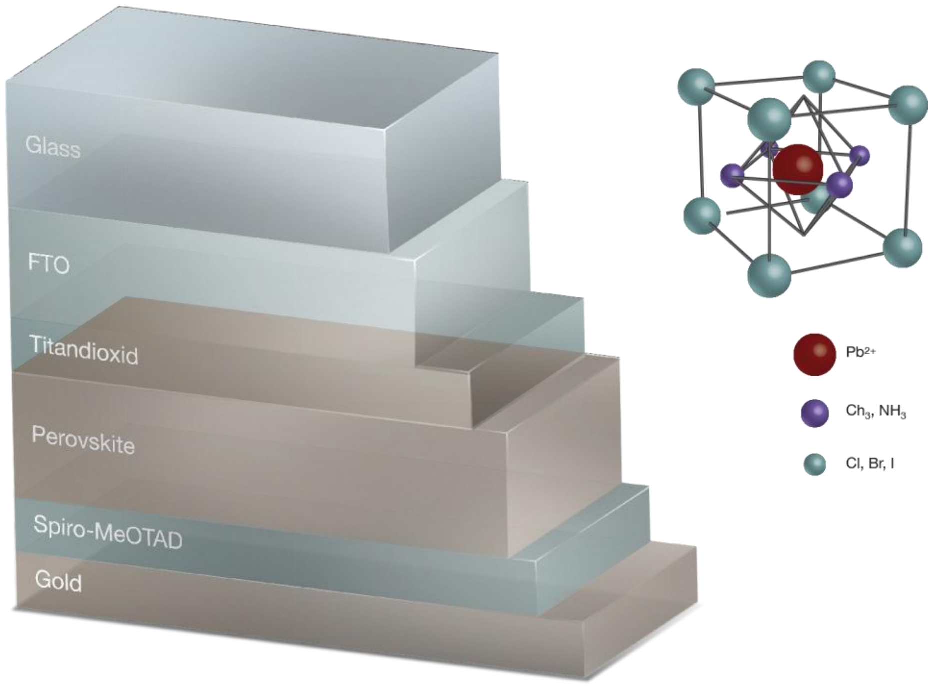
Solar cells generate electricity directly from sunlight by means of the photovoltaic effect. Today 90% of the solar cells produced are from silicon. When photons strike the surface of the silicon, electrons are released and start to flow. In order to enhance this process, "doping" occurs whereby other substances are added to the silicon in small amounts, in order to aid in the separation of charges.

The doping (the process of adding impurities on purpose) is based on two types: n-type and p-type. When doped with the element phosphorous, the resulting silicon is called N-type ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon. The other part of a typical solar cell is doped with the element boron, which has only three electrons in its outer shell instead of four, to become P-type silicon. Instead of having free electrons, P-type ("p" for positive) has free openings and carries the opposite (positive) charge.



3. What are Perovskite Solar Cells? What is their Potential?

- Perovskite solar cells are a type of solar cell which includes **metal halide perovskite** ($CH_3NH_3PbCl_{3-x}I_x$) instead of silicon, as the light-harvesting active layer.
- Perovskite solar cells have tremendous potential: they are the **fastest-advancing solar technology to date** (from 3.8% solar cell efficiency in 2009 to over 22% in 2016).
- They are transparent and can replace a window!
- They also can be produced at much **lower temperatures** than silicon solar cells, with **no need for clean rooms facilities**.
- As a result, these solar cells have the potential to become **cheaper to produce** and **simpler to manufacture** than silicon solar cells.



For the background we suggest several on-line sources.

1. Alternative energy
http://www.ucsusa.org/our-work/energy/our-energy-choices/our-energy-choices-renewable-energy

2. A video explaining the working mechanism of photovoltaic cells
https://www.youtube.com/watch?v=u0hckM8TKY0

3. The research of perovskite-based solar cells, prof. David Cahen, Weizmann Institute of Science
http://wis-wander.weizmann.ac.il/higher-end-lower-cost

4. The chemical properties of Lead
https://en.wikipedia.org/wiki/Lead

5. Toxicology of Lead
http://www.toxipedia.org/display/toxipedia/Lead

6. Cosmos A Spacetime Odyssey - Episode 7
A video about Clair Peterson (1922-1995), who campaigned against the oil industry's use of leaded gasoline
https://www.youtube.com/watch?v=dyNRQOpLdu8
The relevant minutes are
16:35 - 18:00
31:30 - 40:00
41:30 - 45:00

7. Sutcliffe, H. (2011). *A report on Responsible Research and Innovation for the European Commission*.
http://ec.europa.eu/research/science-society/document_library/pdf_06/rri-report-hilary-sutcliffe_en.pdf

Summary Background Articles

What are the Major Scientific Challenges?

• A major challenge is that perovskite solar cells are stable only in a vacuum; they decay rapidly in the atmosphere.

• Also, the experimental perovskite solar cells used in the laboratory are quite small. It will be a challenge to scale up the device for commercial use.

• Perovskite solar cells also contain small quantities of lead, which is a poisonous substance. There is a need to replace the lead with non-poisonous substances, such as like Tin (Sn), Germanium (Ge), etc.

• In addition to scientific challenges, there are challenges relating to RRI, which are addressed later in this exhibit.

RRI

6

Student Experiment on Photovoltaic Cells

Student experiment on Photovoltaic Cells

Preparing solar cell- inquiry experiment

The experiment is based on:

https://www.youtube.com/watch?v=Jw3qCLOXmi0

The adaptation to the Irresistible project was conducted by: Sohair Sakhnini, Nir Kedem, Miri Lauer Baumann, and Ron Blonder, Weizmann Institute of Science

General instructions:

Read the experiment instructions carefully and clearly.

Fulfill the instructions accurately.

This is a group team activity- it is required to work as a team.

You should use an accurate scientific language, during the whole inquiry procedure.

You should previously check the whole materials, equipment and supplies needed for the applying the experiment.

During the experiment, you should use gloves and protective glasses

Materials

1- Two pieces of (2.5 cm X 2.5 cm) Conductive transparent glass
2- Titanium dioxide suspension (P_{25}- the nanoparticles size)
3- Water
4- Organic dye Prepared from blueberries (blueberries juice)
5- Prepared Iodide electrolyte solution (KI+ I_2+ ethylene glycol)

Equipment and Supplies:

1- Light source (A halogen lamp)
2- Heat source (A hot plate)
3- Scotch tape
4- Ethanol in Squirt bottles for cleaning the TiO_2 leftover.
5- Soft graphite pencil (no. 2)
6- Two binder clips
7- Multi-meter, capable of measuring volts and ohms
8- Two Alligator clips
9- Two pipettes
10- A tweezer
11- A squares sheet
12- A microscope slide (to spread the TiO_2 suspension smoothly)
13- Two Petri dishes (for washing the glasses electrodes)

Working Procedure

1. Identify which side of the square glasses, is conductive by using a multi-meter (repeat this step for both of the od glasses):
   I. Place both alligator clips (black and red), connected to the multi-meter on each of the glasses slides - if the multi-meter beeps, then this is the indication of the conductive side of the glass slide.
   II. If the multi-meter doesn't beep, you need to turn up side down the glass square and to repeat step I.
   III. Mark the unconducive side of both glasses slides, with the letter B. Make sure that the conductive side is faced to you.
2. Draw a 1cm x 1cm square, on the square sheet you have.
3. Clean both square glass slides gently with ethanol and Kim Wipes (of course by using gloves!!!).
4. Place the cleaned square glass slides on the square sheet you have, orienting one glass slide with its conductive side up.
5. Apply three pieces of scotch tape to the conductive side of the glass slide. The scotch tape pieces should unmask a 1cm x 1cm area of the conductive glass.

Work as a team- one of the students puts the glass on the squared paper, the other applies the scotch tape on the three edges of the squared glass. (It is recommended to work without gloves while applying the scotch tape).

6. Clean again the unmasked area of the conductive glass with ethanol and Kim Wipes.
7. Ask the teacher to inject a thin amount of TiO_2 on the crosswise of the unmasked conductive glass- **this step should be done by the teacher.**
8. Use the glass microscope slide, in order to spread the TiO_2 suspension smoothly on the conductive slide. Do it until a thin film of TiO_2 covers the conducting slide (the thickness of the film, should be equal to the scotch tape thickness). The use of the glass stir rod should ease up the spread of the TiO_2 suspension so you can get a thin and homogeneous layer of TiO_2.
9. Separate the scotch tape from the conductive glass slide, and put the conductive glass layered with TiO_2 on a hot plate.
10. While heating, the white color of the TiO_2 layer will turn to be brown, and after a short time will turn to be white again- at this level of the experiment (after 15 minutes of heating) the heating should be stopped and you should get the glass off the heating plate **using tweezers** and wait until the glass is cooled to room temperature.
11. Using an eyedropper, drop blackberry juice on the **edges** of the TiO_2 coated glass slide- **don't drop directly on the top of the** $\mathbf{TiO_2}$ **coated glass slide.**
12. Make sure that the entire white TiO_2 square is totally covered by the blackberry juice.
13. Wash the leftovers of the blackberry juice, from the TiO_2 coated glass, using Ethanol - the wash should be held over a petri dish.
14. Put the TiO_2 coated glass slide on the table to dry up. **(<u>Not</u> on a hot plate!)**
15. To prepare the counter electrode, identify which side is conductive for the second glass slide, user the procedure described in step 1.
16. Clean the second conductive glass with ethanol and Kim Wipes.
17. Make sure to dry well the glass slide, and don't leave wipes leftovers on the glass.
18. Take the graphite pencil and apply a heavy film to the entire conductive side of the slide. Place the dye stained glass slide with the titanium dioxide side face up.

Place the graphite glass slide, face down, on top of the dye stained glass slide so that the conductive sides are facing each other - you should keep them in contact and ensure that they do not slide past each other.

19. Use the two binder clips to attach the two glasses slides (Figure 1). Notice to leave both glass slides not past each other completely!

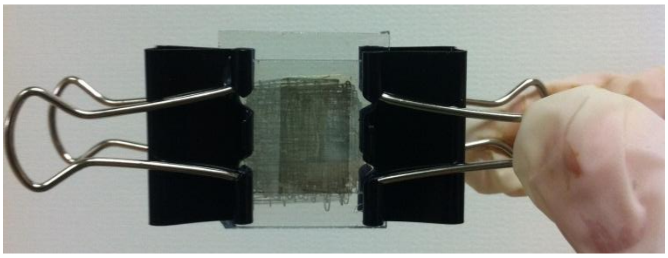
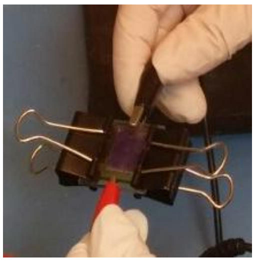


Figure1.

20. Use a pipette to add the electrolyte solution from both sides of the cell, in such a way that you will see how the solution is slowly drawn into the cell until it is completely saturated.
21. Make sure to dry well the cell sides, and don't leave leftovers of the electrolyte on the sides.
22. Your solar cell is ready now!
23. Now, take a multi-meter to measure the current that your cell produces:
    I. Use two alligator clips - to attach your cell, the first alligator will be attached to the first glass slide, and the second alligator clip to the second glass slide.



    II. Attach the two alligator clips binders to the multi-meter, for measuring a DC current output and the voltage.
    III. In a sunny day – go outside the building and measure the current and voltage. In a dark day, use the halogen lamp, bring the solar cell close to

the light source (as it is attached to the multi-meter), and measure the current output (and later the voltage).

IV. Turn the light off, and measure again the current output.

V. Turn on the halogen lamp again, put your solar cell underneath it, while changing the distance between them. Measure the current output in each time.

24. Write your observations through the experiment.
25. Arrange your observations and your results in three steps- before the experiment, during the experiment and at the end of the experiment.

Part two- starting an inquiry process (recommended and not obligatory)

1. Formulate three varied, relevant questions that arose following the observations made. Choose one of these questions that you want to investigate.
2. Formulate this question clearly as an inquiry question, and if possible, as a link between the variables.
3. Formulate clearly a hypothesis for the question you chose to investigate. Give reasons for your hypothesis based on correct, relevant scientific knowledge.
4. Plan an experiment that that will check the validity of your hypothesis. Detail all the stages of the experiment, including the control stage.
5. Carry out the experiment that you proposed after receiving your teachers' approval.
6. Present the observations and the results in an organized manner (table, diagram, graph, etc.).
7. Analyze and explain the results.

Draw conclusions based on all the results of the experiment and provide reasons. Check the connection Check the connection between the inquiry question and the results.Preparing solar cell- inquiry experiment (lab technician)

Materials, Equipment and Supplies:

6- Two pieces of (2.5 cm X 2.5 cm) conductive transparent glass per one solar cell
7- Two grams of titanium dioxide powder (P $_{25}$- the nanoparticles size)
8- 0.5 ml Surfactant (clear and transparent dish detergent)+ two drops of Water

9- Hot plate (Heating source)
10- overhead projector (A halogen lamp)
11- Water bathtub for the electrolyte dissolves.
12- Scotch tape
13- A crater and pestle
14- (3 ml) acetic acid
15- Ethanol in squirt bottles for cleaning the TiO_2 leftover.
16- Soft graphite pencil (no. 2)
17- Organic dye Prepared from blueberries (blueberries juice)
18- Two binder clips
19- Multi-meter, capable of measuring volts and ohms, Two Alligator clips
20- Two pipettes
21- A squares sheet
22- Prepared iodide electrolyte solution (KI+ I_2+ ethylene glycol)

Preparation of TiO_2 suspension

Measure out 2 g of TiO_2 powder. Put them into a crater. Add (3 ml) acetic acid.
Stir them together while grinding with a pestle, until you get a lump free, smooth paste.
Store the TiO_2 paste in a small plastic syringe.

Iodide electrolyte solution preparation:

1- 10 ml ethylene glycol solution
2- 0.83 g KI
3- 0.127 g I_2

Stir all the materials together with a clean glass rod or mixing instrument, and put them in a bathtub, so that the materials will dissolve well in the solvent.

7

Building and Evaluating the Exhibits

Building and Evaluating the Exhibits

In order to support students while they plan design and build their exhibits, we suggest using the exhibit guidelines that were developed by the Portuguese team. Here we provide several recommendations that are specific to this module and a rubric that can be used for assessment.

Background for Student Exhibits -1

On the basis of your knowledge about the topic of solar cells, plan an exhibit on some aspect of the topic: the RRI of perovskute-based solar cells. We suggest that your exhibit contains three parts: (1) scientific backgrounds on solar cells, (3) background on RRI dimensions, and (3) a relevant dilemma.

1. Solar Cells - Their Structure and Mechanism

Goal: To engage and stimulate the visitor (who lacks knowledge and awareness of the topic) with the topic of perovskite-based solar cells and windows (the innovative result of research and innovation) which may replace the school's windows.

Guidelines:

1 . Discuss among yourselves the content of this part. What relevant scientific background on alternative energy, solar cells, and perovskite-based solar cells should you provide?

2. Plan how this exhibit will look in terms of its title, captions, content, images, the arrangement of the various elements, their sizes, colors and so on.

3. Note that on the basis of your sketch, later in school you will be asked to prepare an exhibit which includes this part.

2. Background on RRI Dimensions

You will now design another part of the exhibit, which deals with the perspective of RRI, regarding the question of replacing school windows with perovskite-based solar windows:

Goal: To engage and stimulate the visitor (who lacks knowledge and awareness of the topic) with the significant RRI dimensions, as they relate to the topic of perovskite-based solar windows which may replace the school's windows.

Guidelines:

1 . Discuss among yourselves the content of the slide. What RRI dimensions you would like to address? What you would like to say about these dimensions?

2. Plan how this exhibit will look in terms of its title, captions, content, images, the arrangement of the various elements, their sizes, colors and so on.

3. Note that on the basis of your sketch, later in school you will be asked to prepare an exhibit which includes this part.

3. A Relevant Dilemma

The Goal: To stimulate the visitor (who has no prior knowledge and the topic) to take a position regarding a dilemma you pose about the use of solar windows based on perovskite-based solar cells. For this purpose, your group must clearly define the dilemma about which you want the visitor to take a stand.

Guidelines:

1. Define the dilemma for which you want the viewer to take a stand (For example, under what conditions, if any, would you agree to replace school windows with solar windows? Would you use perovskite-based solar cells or not?)
2. Plan the content of this dilemma and how it will be presented. (For example, you can invite the viewer to take a stand, to vote for a particular point of view, to express his opinion, etc.).
3. Plan how this exhibit will look in terms of its title, captions, content, images, the arrangement of the various elements, their sizes, colors and so on. Plan the "look and feel" of the final exhibit: the colors, fonts, and images of all the above three slides of the exhibit.
4. Use computers and sources from the Internet to inform and design your exhibit.

Assessment Tool for Evaluation of Student Exhibits

Category	Level 1	Level 2	Level 3
1. Introduction of Exhibit Topic	Exhibit topic is not well-defined.	Exhibit topic is well-defined but not attractive.	Exhibit topic is well-defined and attractive.
2. Presentation of Balanced Dilemma	Exhibit presents only one point of view. There is no dilemma.	Exhibit presents two points of view, but not in a balanced way.	Exhibit presents two points of view in a balanced way.
3. Presentation of Thesis (optional)	The thesis is not well-defined.	The thesis is well-defined but not well-supported.	The thesis is well-defined and well-supported.
4. Scientific Background	No basic science concepts are presented.	Only some basic science concepts are presented.	All the basic science concepts are presented.
5. RRI	There is no mention of RRI.	There is a weak connection of RRI to the exhibit.	There is a strong connection of RRI to the exhibit.
6. Organization	The exhibit is not organized at all.	The exhibit is partially organized but not easy to follow.	The exhibit is well-organized and easy to follow.
7. Presentation	Little thought is given to the selection of color, format, and representations of knowledge that help convey the exhibit's message.	Some thought is given to the selection of color, format, and representations of knowledge that help convey the exhibit's message.	Much thought is given to the selection of color, format, and representations of knowledge that help convey the exhibit's message.
8. Group Work	Only a few members work.	All the members work, but not cooperatively.	All the members work with full cooperation.
9. Feedback and Revisions	There is no exhibit feedback by visitors. There are no revisions of the exhibit.	There is exhibit feedback by visitors but it is not used in revisions of the exhibit.	There is exhibit feedback by visitors and it is used in revisions of the exhibit.

RRI

The module "The RRI of Perovskite-Based Photovoltaic Cells" that was developed in Israel deals with the scientific and RRI aspects of innovative photovoltaic cells.

We believe that it can inspire teachers and students to the use of RRI in other research and development innovations.

As one of the Israeli teachers said:

"The 6 RRI dimensions are not just good for researchers. They are good for all of us. They build a person's character because they are also good principles for helping you to think deeply and to lead you to better manage your life."

Weizmann Institute of Science