



# MATERIALS 4 A SUSTAINABLE FUTURE

## Stimulate

An education pack for students (age 14 -17) promoting the importance of advanced materials in our everyday lives. Links with Science, Art and Design and Sustainability Studies.

Funded by:



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The Open  
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National  
Technical  
University  
of Athens



## About this project

‘Stimulate’ is an exciting Europe-wide project that aims to reveal the importance of advanced materials in our everyday life. Advanced materials are our allies for a sustainable future and this is the main message that we aim to communicate in 23 European languages through our website, a documentary and film clips, an interactive computer game and this educational resource. Learn about the role that advanced materials play in the fields of health, the environment, technology, innovation, energy and much more.

The aim of this education pack is to generate interest, understanding and enthusiasm among secondary school students for the whole field of advanced materials and their many applications in our lives. We also hope the passion of the scientists and designers featured will inspire young people to choose a study pathway or career in science and technology for themselves.

## How to use this resource

This education pack was written as part of the ‘Stimulate’ project and can be used alongside the other resources available. The activities are based around the enhanced clips taken from the documentary ‘The Secret Life of Materials’ and the information on the Materials Future website ([www.materialsfuture.eu](http://www.materialsfuture.eu)).

The pack is divided into three parts. It starts with activities exploring the need for advanced materials, then moves on to discovering different types of advanced materials and finally looks at how students can get involved themselves. The sections and activities in this pack have been written in such a way that they can be worked through from beginning to end or you can pick and choose activities. Worksheets and teacher notes have been provided where necessary. This pack refers to the story ‘Max and Lily’s Adventures’ and the game ‘Materials Hunter’. Both of these can be accessed on the website.

This pack is appropriate for teaching students aged 14-17. As this pack has to be suitable for use in different EU countries, there are no specific curriculum links. However the activities link with topics in the subjects Science and Technology, Art and Design and Sustainability Studies.

By completing the activities in this pack students will:

- understand what advanced materials are and know several types;
- understand the importance and potential of advanced materials for a sustainable future;
- have explored what it would be like to work or study in the field of science.

## Part I: The need for advanced materials

These activities will help students understand the current state and limitations of our use of the planet's resources. Students will also be introduced to the world of advanced materials.

By the end of these activities, students will be able to:

- explore the limitations and possibilities of our planet's resources;
- understand what sustainability means;
- explain what an advanced material is.

### Resources:

- Worksheet 1
- Access to the Internet

### Activity I | Debating sustainability (20 min)

**(Introducing the topic)** *Sustainability* is concerned with meeting the needs of the present without compromising the ability of future generations to meet their own needs. We have been using renewable plant-derived materials like wood, cotton and rubber for a long time. However in the last century we have been using them at such a rate that the plants or animals (e.g. overfishing!) cannot replenish themselves in time. We have also become increasingly dependent on resources such as coal, gas and petroleum oil and have been depleting them at a rapid rate. Oil is not only used as fuel, but also as a source of raw material to create products such as plastics, dyes, medicines and textiles. The challenge for scientists is to find ways to create products using sustainable energy and resources efficiently. Great topic for discussion!

**(Activity)** Ask students for their initial opinion on the three statements. Then ask them to research the issues in groups and discuss them. You could take a vote and perhaps even make a plan of action if students feel passionate about an issue discussed.

- 1 The benefits of renewable energy resources outweigh the drawbacks;
- 2 Plastic bags should be banned;
- 3 We need to change our way of life to preserve the planet for future generations.

Encourage students to consider questions such as: why is plastic so widely used? Why is it a problem? What methods of production and disposal are used in producing materials? Effects on the environment and animals? Jobs and land use? Current materials and energy sources used, and what are the alternatives?

## Activity 2 | Developing technologies (40 min)

**(Introducing the topic)** More than seventy percent of all technical innovations, in a broad range of fields and applications, depend today directly or indirectly on the development of advanced materials. People tend not to notice the many advanced materials used in everyday life, because they are incorporated into everyday products. People are generally unaware that most of the technological products that they use rely on the continuous improvement of the properties of functional materials.

**(Activity)** In this activity ask students to explore how technologies and science have improved the materials used in everyday items. Ask each student to choose one everyday item to research (e.g. oven, refrigerator, table, computer, toys, etc.). They should research how the item looked when it was first invented and what materials were used to make it; and then they should investigate how the item has been developed and improved over time. How have the technologies improved that are needed to make the item? How have the materials improved? Have your students write a short report or present their findings.

## Activity 3 | Introducing advanced materials (20 min)

**(Introducing the topic)** There is still a lot of scope for the resources we use to be even more sustainable and efficient, so scientists are continuing to research and develop new and innovative materials. The ‘Stimulate’ project focuses on promoting the importance of **advanced materials** in our everyday life. As Max and Lily say: “...all these advanced materials that have re-shaped our world and made it faster, stronger, cheaper and more efficient. And also healthier and more sustainable.”

Ask students if they can come up with a definition for advanced materials or if they can name any. Write any suggestions on the board. Then tell them advanced materials are: “*super materials; materials with an extremely high performance regarding one property.*” They can be new materials or modifications of existing ones. Certain prefixes indicate that it concerns an advanced material: **ultra-**, **super-** and **nano-**. **Ultra** hard materials, **super**conducting or **super**-hydrophobic (strongly repels water), or **nanoparticles** or **nanotubes**. Materials that imitate nature (biomimicry) or that can remember a particular shape (shape memory alloy) are also considered advanced materials.

**(Activity)** Students will look at the different materials and their applications in detail in part 2 of this pack. As an introduction, hand out **worksheet 1** and ask students to find the correct description in the encyclopaedia on the Materials Future website:

[www.materialsfuture.eu/en/learn/encyclopaedia](http://www.materialsfuture.eu/en/learn/encyclopaedia).

## Part 2: Exploring the role of advanced materials

The activities in this part of the pack will introduce students to the role of advanced materials in cutting edge technologies and enable them to explore the possibilities and applications of each of these materials.

By the end of these activities students will:

- have explored six different types of advanced materials and their applications;
- understand the importance of advanced materials for a sustainable future;
- have imagined how these materials can help shape a sustainable future.

### Resources:

- Worksheets 2 - 5
- Film - enhanced shorts 1 – 6 ([www.materialsfuture.eu/en/film](http://www.materialsfuture.eu/en/film))
- Access to the Internet

## I | Solar Energy

### Activity I | Exploring solar power (40 min)

**(Introducing the topic)** Lily provides a definition of solar cells: “... a solar cell is a device that absorbs light from the sun, converts it to electric energy which can be used either directly (by lighting a lamp for example) or stored in batteries.”

**You can read more of the Max and Lily story ‘City of lights’ on the website.**

**(Explanation)** In this activity students are going to explore how solar cells work - and they can also try to make their own. One technology used to turn sunlight into electricity is called *solar photovoltaics*. The word photovoltaic comes from the Greek *photo* which means light and *volt* which refers to the Italian electricity pioneer Alessandro Volta. These are the black solar panels that students will probably have seen before - or perhaps your school even uses them. You could show them a photo on the board. The solar cells work by absorbing the *photons* (tiny packets of energy) that radiate out from the sun and are absorbed by the *semiconductors* on the solar panel; a solar panel is made up of different cells. The *photons* hit the cells and create an electric current which is then transmitted by wires connected to them. The more cells you have and the more efficient these are, the more electricity you can generate.

**(Activity)** To help students understand how solar panels work, have them experiment for themselves. There are many examples of experiments online and **worksheet 2** outlines three simple experiments students can do to explore solar power.

## Activity 2 | Organic solar cells (30 – 60 min)

**(Activity)** Hand out **worksheet 3** and ask students to read through the questions. They will watch the film excerpt on solar energy (<http://www.materialsfuture.eu/en/film/>) and try to answer the questions. They will probably need to watch the clip more than once. The answers to the questions are included on teacher notes 1.

**(Activity)** There are several detailed instructions online for making your own Grätzel cell using household materials such as raspberries or blueberries. 'The Solar Spark' has several good ones for example:

[www.thesolarspark.org.uk/experiments/for-teachers/classroom-experiments](http://www.thesolarspark.org.uk/experiments/for-teachers/classroom-experiments).

The website provides instructions, teacher notes, an equipment list and health and safety tips. The experiment takes around 45-60 minutes. They also outline an experiment to explore the workings of the dye used in the Grätzel cells.

## 2 | Bionic Bodies

### Activity 1 | Bionics (20 min)

**(Activity)** Start this topic by first asking your students if they know what *bionic* means. Gather their ideas and then tell them *bionic* means “to have normal biological capability or performance enhanced or mimicked by electronic or electromechanical devices.” Bionics is a field of science where scientists work to help people with disabilities by creating sophisticated *bionic* human body parts. Now have your students watch the film excerpt (second clip on: <http://www.materialsfuture.eu/en/film/>). In this clip scientists discuss how they are improving the function of bionic hands through *osseointegration*, which means forming a connection between the living bone and the artificial implant. After students have watched the excerpt, you could discuss the following questions:

1. What will the possibilities of *osseointegration* mean for amputees and people receiving bionic body parts? (They get their sensory capabilities back, being able to feel that something is a ball or hard/soft)
2. What ethical issues might arise as bionics enhances? (For example: who will get implants, adding functions that the normal body can't do)

### Activity 2 | Experiencing Sensory input (15 min)

**(Activity)** What would it be like to not get any sensory input from your fingers or hand? Have students experienced this themselves. Set them a task that uses their fine motor skills such as tying shoelaces or picking up tiny objects. Have them complete the task as normal first. Then have them apply fever blister or sunburn relief cream to their fingertips, which will cause a numbing effect. Have them repeat the task. Do they notice a difference?

### Activity 3 | Bionic bodies timeline (40 min)

**(Activity)** Surgeons have been replacing body parts with prosthetics, successfully and less successfully, for thousands of years (think of wooden legs). Great advances in bionics have been made in the last century. Have students research these online and create a timeline. Suggest they look at bionic eyes, ears, legs and arms/hands, but also organs like the liver and heart. You can give them a starting date or let them choose for themselves.

### Activity 4 | Design your own bionic body part (30 min)

**(Activity)** Now ask students to work in small groups (3-4) to design their own bionic body part. Have groups choose an organ or body part and research all the functions of their chosen part online. What will their bionic replacement need to be able to do? You could assign each group a part, then as a class you could assemble an entire bionic human body.

### 3 | Mimicking nature

#### Activity 1 | Seeing colour (30 min)

**(Introducing the topic)** Our eyes are amazing organs with which we can see things far away and up close, perceive depth and distinguish colour. But how do we see different colours? Have students research the following questions:

1. Explain how we perceive colour. Encourage students to make a sketch.
2. What does 'visible spectrum' mean? Which seven colours can we distinguish in this spectrum?
3. What makes people colour blind?
4. Find or design your own simple experiment that illustrates or plays with how we perceive colour. There are many examples online. Have students try each other's experiments.

#### Activity 2 | Structural colour (30 - 40 min)

**(Introducing the topic)** As Lily explains certain plants, animals and materials reflect light in such a way that we see them coloured when in fact they aren't. One example of this is peacock feathers. The surface of the material consists of tiny lines which are positioned in such a way so that they reflect only certain light frequencies back; only e.g. blue or red.

**You can read more of Max and Lily's story 'Structural Colouration' online.**

**(Activity)** Ask students to watch the film excerpt on mimicking nature (third clip on [www.materialsfuture.eu/en/film](http://www.materialsfuture.eu/en/film)). Divide your class into small groups and hand out copies of **worksheet 4**. Provide students with access to the Internet so they can research the terms connected to the theory of structural colour. Encourage them to phrase their explanations in their own words. Answers have been provided for you on teacher notes 2.

**(Activity)** In their research, students will find that the colourful feathers and wings of many birds and butterflies are created by the optical effect of structural colouring. It would be great if students could see these colours for themselves – and they can! Structural colouring is used in the holograms on the Euro banknotes. Ask students to bring in a banknote themselves to study. What do they see in the holograms of the different banknotes?

## 4 | 3D Printing

### Activity 1 | What is 3D Printing? (15 min)

**(Homework)** Before you start this lesson, ask students to find an article about 3D printing online. Encourage them to look for an article about what 3D printing is, but also about its applications. Ask them to come up with questions beforehand.

**Part of Max and Lily' story is about advanced materials and 3D printing and can be read online.**

**(Activity)** In class discuss what the students have found out about 3D printing – how does it work? What kinds of applications can it be used for? What is the potential? What limitations are there? Collect their ideas and write them on the board. Now watch the film excerpt on 3D printing (fifth clip on [www.materialsfuture.eu/en/film](http://www.materialsfuture.eu/en/film)). In this clip a violin maker is researching 3D printing a violin – can he print a violin that sounds as good as a handcrafted wooden one?

Are there still questions that cannot be answered with the information they have already collected? Let them conduct further research online. For you as teacher: the definition of 3D printing can be found in the encyclopaedia on [www.materialsfuture.eu](http://www.materialsfuture.eu). The most common materials used for printing are plastics, ceramics, metals, resins and more. There are different types and technologies of 3D printing. 3D printing has revolutionised prototyping, has been used in medicine and biology, in space, in art and to produce everyday goods.

### Activity 2 | Make your own 3D print (time will vary)

**(Activity)** In this activity students will make their own 3D design. If you have a 3D printer in your school or access to one in your local area, let students actually print their design. If not, students can sketch their design on graph paper or create a 3D design on a computer. Students can also use photographs of an object to create a file to be 3D printed. You can find free software online to create files for 3D printing. Your school could look at buying a 3D printer, they have become more affordable. Websites like [www.myminifactory.com](http://www.myminifactory.com) have tutorials and examples on 3D printing. Make sure students keep in mind that their object needs to be simple enough to be printed and they also need to consider the materials that are possible.

Encourage students to think about the really exciting possibilities for 3D printing that advanced materials offer and encourage them to come up with innovative objects. What could they print using living cells?

## 5 | Nanomaterials

### Activity 1 | Nano to giga (10 min)

**(Activity)** What does the prefix 'nano' mean? Hand out **worksheet 5** and ask students to fill in the blanks in the table. By how much does each length decrease as you go down the units? Answer: 1000 times.

### Activity 2 | Nanoparticles (30 min)

**(Introducing the topic)** Nanomaterials are defined as materials with at least one dimension (height, width, length, thickness, diameter) in the size range from approximately 1-100 nanometres. Nanoparticles are far too small to even be seen with an optical microscope. They no longer behave as bulk materials (so the properties of silver nanoparticles are different than silver). Their tiny size means they have a greater relative surface area than other materials and this can alter or improve properties such as strength and electrical characteristics or reactivity. Examples of nanomaterials are: volcanic ash, graphene, quantum dots, metal and metal oxide nanoparticles, carbon nanotubes, fullerenes, etc.

**(Activity)** In this activity students will research how and where nanomaterials are already being used. Students should find applications in textiles, electronics, sunscreen, coatings, tools, medicine etc. Some examples are: antibacterial coating on socks, harder tools and UV protection. The use of nanomaterials is also slightly controversial – ask students to find out why as well.

### Activity 3 | Graphene (20 min)

**(Introducing the topic)** Graphene is an example of a nanomaterial, namely a nanosheet which means it's the thinnest material in the world, with a thickness of only one atom (about 0.34nm). It is a material based on carbon atoms; it's actually an extremely thin flake of ordinary carbon. High-quality graphene is strong, light, nearly transparent and an excellent conductor of heat and electricity. Its unique properties could help make massive advances in the fields of electronics and other technologies. For example, an imaginary 1m<sup>2</sup> graphene-made cradle would weigh less than a milligram but could safely hold a new-born baby.

**Students can read more about graphene in Max and Lily's story online.**

Graphene is:

- 10 times better at conducting heat than copper;
- 100 times stronger than steel but also very flexible;
- 1,000 kilometres per second is the speed of electrons travelling in it, making it an excellent electric conductor;
- 10,000 times thinner than a human hair;
- 100,000 times lighter than regular printing paper;
- 98% transparent to light, yet so dense that nothing can pass through it.

**(Activity)** The properties and potential of graphene are still being researched by scientists, for example in the field of aerospace and transportation. Divide students into pairs and have them research online what graphene could mean for the future of transportation and aerospace (e.g. super light materials). Encourage them to think about what airplanes and other modes of transport could look like and what functionality could be possible. What would it mean for the cost and environmental impact?

**Note:** If you wanted to extend this activity you could have students study and map the entire history of transportation from the first bicycles, cars, trains and airplanes to our current modes of transportation. What scientific advances were made/needed for each step?

## 6 | Adaptive Materials

### Activity 1 | Adaptive materials (15 min)

**(Activity)** Ask students to watch the film excerpt on adaptive materials (fourth clip on: [www.materialsfuture.eu/en/film](http://www.materialsfuture.eu/en/film)). Write the following questions on the board beforehand.

1. What are the job titles of the three people in the film clip?
2. What do they focus on in their work? What are they trying to achieve?
3. What is the vision of science this clip presents?

After watching the excerpt (students might need to watch it twice) guide your class in a discussion on the three listed questions. The three speakers in the excerpt are all concerned with how science and technology has a purpose and answers needs; that is helps us live better and more sustainable lives. What do students think about this? What need do the trainers designed by Shamees Aden address?

### Activity 2 | Future visions (30 min)

**(Activity)** In the film clip, Martin Hanczyc talks about a vision for the future where the possibilities of living materials could mean that you would have structures that could self-repair, self-grow and self-reproduce. This opens up thinking about what kind of technology could be applied and proposed in the future. For this activity encourage your students, in pairs or small groups, to imagine an application for adaptive materials (like Shamees' adaptive trainers). They can be futuristic and think about the possibilities of materials that can self-repair, self-grow and self-reproduce.

Each group should present their idea to the rest of the class. They should think about/include the need they are responding to, what the material would do and how it would work. They can use the internet to research ideas and make sketches.

## Part 3: Becoming scientists

The activities in this third part of the pack will encourage students to think as scientists themselves and inspire them to choose a study pathway or career in this field.

By the end of these activities students will:

- Have explored being a research themselves
- Have been introduced to the working world of scientists through excursions or guest speakers

### Resources:

- Worksheet 6
- Material Hunters game ([www.materialsfuture.eu/en/game](http://www.materialsfuture.eu/en/game))
- Access to the Internet

### Activity 1 | Be a researcher (time will vary)

**(Activity)** This project aims to promote the importance of advanced materials in our everyday lives. It also aims to make young people excited about careers in the fields of science, technology and design. It is important for students to learn science through designing and conducting their own research. This will also prepare them for the real world of work. Therefore an activity has been included here where students will choose a problem to study themselves and think about solutions.

Divide students into pairs and explain that each pair will be studying a problem/need and coming up with their own design solutions. They can look at a problem in school, at home or in their local area. They should keep the advanced materials they have learned about in this pack in mind – so their solutions can be futuristic and speculative. An example: the school fence needs to be repainted as the colour has faded and peeled off. How could they fix this problem using advanced materials?

Students should follow the steps of the design cycle, but as they might be using their imagination to think of future possibilities they will stay within the design stage. These have been explained in more detail on **worksheet 6**.

## Activity 2 | Materials Hunter

**(Activity)** Give your students time to play the game Materials Hunter, which can be played online at [www.materialsfuture.eu/en/game](http://www.materialsfuture.eu/en/game) or downloaded for smartphones and tablets.

In the game students will use advanced materials to help create a sustainable future and a better life. Students will learn everything about the science that is re-shaping our world. Materials Hunter is a free casual puzzle game in which players will travel through periods in history with the two friends Max and Lily, helping a small community evolve by crafting new technologies from putting together materials. Watch the society improve or fall to ruin as students proceed – the citizen's environment depends on their choices.

The game manual can be accessed at [www.materialsfuture.eu/en/game](http://www.materialsfuture.eu/en/game).

## Activity 3 | Tips for encouraging scientists

The more students are exposed to the world of science, the more excited they will become about pursuing their own career in this field. Below are several tips to generate excitement for science:

- Organise a field trip to your local science or design museum
- Arrange a tour of a local science lab
- Invite a scientist or student of science to come speak to your class; you can find a map with locations where advanced materials research takes place around Europe here: [www.materialsfuture.eu/en/community/](http://www.materialsfuture.eu/en/community/)
- Keep an eye out for events celebrating science such as 'week of science' or science festivals. Often organisers will produce school packs, workshops and activities
- Organise a science fair (focussed on advanced materials!)
- Expose students to role models – students could research a famous scientist (throughout history) and hold a presentation

## Worksheet 1 | Introducing advanced materials

|                               |  |
|-------------------------------|--|
| <b>Fuel cells</b>             |  |
| <b>Stents</b>                 |  |
| <b>Nanomaterials</b>          |  |
| <b>Shape memory alloys</b>    |  |
| <b>Superhydrophobic</b>       |  |
| <b>Graphene</b>               |  |
| <b>Electrochromics</b>        |  |
| <b>Nanotubes</b>              |  |
| <b>Targeted drug delivery</b> |  |
| <b>Photovoltaics</b>          |  |
| <b>Semiconductors</b>         |  |

## Worksheet 2 | Exploring solar power

### 1. What is the best colour for a solar panel?

**Needed per group:** ice cubes, coloured cardboard incl. white and black

In this experiment students will look at the way colour affects the rate at which solar heat is absorbed. This experiment can only be done on a sunny day!

- 1 Divide your class into groups and provide each group with sheets of different coloured cardboard and ice cubes. Make sure the ice cubes are roughly the same size. Black and white card are essential but the other colours can vary.
- 2 Ask students to cut the cardboard into squares of around 10 cm. Place the squares in full sunlight and place an ice cube in the middle. Now time how quickly they melt. Which is the quickest and which the slowest?
- 3 The ice cube on the black card should be the quickest to melt as it absorbs the sun's heat most efficiently, while the white one should be the slowest as it reflects much of the energy. This is why solar panels are typically painted matt black. Which colour would be second best for the panels?

### 2. Alternative experiment with solar power and colour

**Needed per group:** White and black cardboard, 4 plastic cups

Cut two circles out of the white cardboard and two circles out of the black cardboard. Place one of each at the bottom of four equal sized plastic cups. Fill  $\frac{1}{4}$  of each cup and record the temperature. Now close one of the cups with a black circle and one with a white circle (secure them with tape or rubber bands) and place all four cups in direct sunlight. Predict in which cup the temperature will be highest. Measure after 5 minutes and after 10 minutes.

### 3. Make a solar oven

**Needed per group:** cardboard pizza box, aluminium foil, plastic wrap, black paper, newspapers, scissors and tape

Form a flap on the lid by cutting the two long edges and one of the short edges, fold the flap back on the uncut edge and crease it. Cover the inside of the flap with aluminium foil and tape it securely. Open the box and cover the bottom with black paper. Add insulation by tucking newspaper rolls around the inside edge of the box and taping them in place. Stretch plastic foil on the inside of the lid (across the hole made by the flap being cut). Put the food you want to heat up (something like a marshmallow) in the box, close it but open the flap and turn the aluminium foil towards the sunlight. Prop the flap open with a stick and wait about 30 minutes.

## Worksheet 3 | Solar energy film excerpt

1. Who is the scientist in the film?
2. What does he work on?
3. What inspired him?
4. What has he developed?
5. How does it work? What do the cells look like? Draw a cell labelling the parts.
6. What are the advantages compared to silicon cells that are now widely used?
  - 1.
  - 2.
  - 3.
  - 4.
7. What materials can be used in an organic solar cell?

## Worksheet 4 | Structural colour

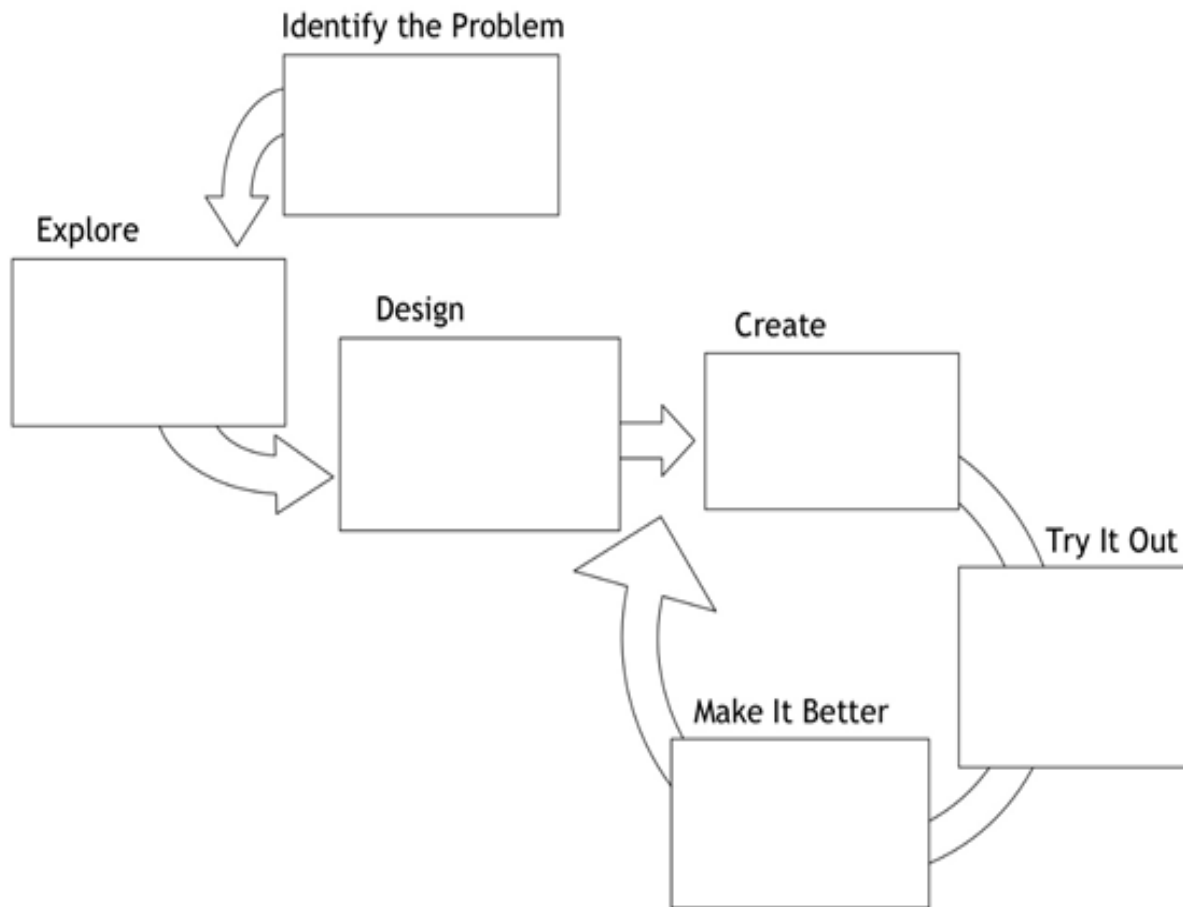
1. Who were the first scientists to observe structural colouration?
2. The feather of which animal did they study? And what was their conclusion?
3. Structural colours are created by an optical effect rather than pigmentation. These optical effects are: wave interference, refraction and diffraction. Research and explain in your own words what these mean.
  - a. Wave interference
  - b. Refraction
  - c. Diffraction
4. What is the name of the berry mentioned in the film excerpt? What is so special about it?
5. Materials that owe their colour to structural colouring are also often *iridescent*. What is iridescence and which animals, plants or materials exhibit this property?
6. What are the possible applications of structural colouring? List three.

## Worksheet 5 | Nano to giga

| Unit name  | Unit symbol   | Meaning                  |
|------------|---------------|--------------------------|
| Gigametre  | Gm            | One billion metres       |
| _____metre | _____         | One million metres       |
| Kilometre  | km            | One _____ metres         |
| Metre      | _____         | One metre                |
| _____metre | mm            | One _____ of a metre     |
| Micrometre | $\mu\text{m}$ | One millionth of a metre |
| _____metre | nm            | One _____ of a metre     |

## Worksheet 6 | The design cycle

Use this diagram to structure your design process.



### Tips

- Research what others have done.
- Look at what materials are available.
- Use your creativity and knowledge to come up with different solutions, then choose one to work out.
- Describe the challenge – include constraints and limits.
- If you can actually make your design, also test it. And make improvements.

## Teacher notes I | Film excerpt solar energy

### 1. Who is the scientist in the film?

Michael Grätzel- students could research him online to find out more about his career, work and the prizes he has won.

### 2. What does he work on?

Creating systems that mimic photosynthesis in order to produce fuel and electricity from sunlight.

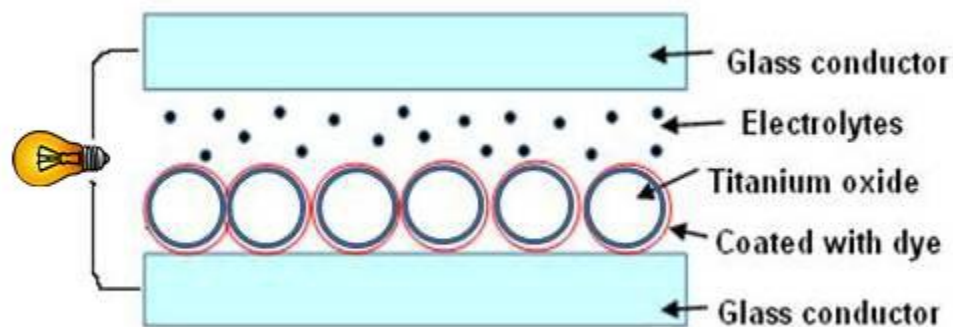
### 3. What inspired him?

The 1970 oil crisis made him realize that there isn't all that much oil left and this made him passionate about finding alternative systems that use light to produce fuel.

### 4. What has he developed?

He has developed *dye-sensitised solar cells* that mimic the natural system of photosynthesis of plants. Molecular dye absorbs sunlight which is then turned into electric energy.

### 5. How does it work? What do the cells look like? Draw a cell labelling the parts.



### 6. What are the advantages compared to silicon cells that are now widely used?

1. Grätzel solar cells collect sunlight on both sides, which is important especially in the desert where light is reflected back
2. Grätzel solar cells collect diffused radiation
3. They can be used indoors
4. Ideal for building integration due to their aesthetic; the coloured glass looks like art

Other advantages of the dye-sensitized solar cells are that with mass production they will be cheaper than the competition and they have a big environmental advantage because they don't use any energy-intensive, high-vacuum methods or toxic elements<sup>1</sup>.

<sup>1</sup>Source: An article by Jacob Aron in The Guardian on 4 July 2010, 'My Bright Idea: Michael Grätzel'; <http://www.theguardian.com/technology/2010/jul/04/michael-gratzel-bright-idea-energy>

## Teacher notes 2 | Structural colour

### 1. Who were the first scientists to observe structural colouration?

Isaac Newton and Robert Hooke. Thomas Young was the first to explain wave interference.

### 2. The feather of which animal did they study? And what was their conclusion?

They found that we perceive peacock feathers as blue and green due to their structure, while in reality they are pigmented brown with melanin. Melanin is a complex polymer which is responsible for skin and hair colour. The surface morphology of the feathers reflects light in such a way that we see them coloured.

### 3. Structural colours are created by an optical effect rather than pigmentation. Research and explain in your own words what this optical effect is and how it works.

“In this case light behaves as a wave” Lily said and threw a tiny pebble in the fountain. The pebble caused a circular wave to spread. Next she threw three pebbles together. They all created waves that interacted with one another. At some points, the waves added together amplifying each other while at some other points, the waves cancelled each other out.” Wave interference happens when the electromagnetic fields that constitute individual waves interact. The microscopic structure of the material works like a prism, splitting the light into rich, component colours. Depending on the frequency reflected back off the surface of the object, the refracted light becomes visible in shimmering iridescent display.

### 4. What is the name of the berry mentioned in the film excerpt? What is so special about it?

The berry is called *Polliacondensata* and it has the most brilliant blue known in any living tissue. It is found in forested Africa regions. The plant from which the berries were taken in the film is 100 years old and the colour has not faded. This is the amazing property of structural colouring.

### 5. Materials that owe their colour to structural colouring are also often *iridescent*. What is iridescence and which animals, plants or materials exhibit this property?

Iridescence is the result of constructive and destructive interference between multiple reflections from two or more surfaces e.g. in semi-transparent thin films, where it is also combined with refraction. As light is reflected from such surfaces a phase shift appears between the light rays that are reflected from the top surface and those reflected by the lower surfaces. Therefore, for a certain wavelength and angle, the amplitude of the light waves may add or subtract. At different angles colours thus appear different. This can be the case with the feathers of certain birds, the wings of butterflies, the scales of fish, soap bubbles, films of oil, beetle shells and mother-of-pearl.

### 6. What are the possible applications of structural colouring? List three.

Structural colouration has potential for many different applications such as fashion materials (textiles), adaptive camouflage, low-reflectance glass, efficient optical switches and anti-reflective surfaces. This technology is already being used to create the security holograms on our credit cards and banknotes; such holograms are very difficult to forge because their surface morphology has been patterned in the nanoscale.