# NanoScience and Nanotechnology Applications

# Teacher's Guide

Responsible Research and Innovation www.irresistible-project.eu

# Colophon

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

www.irresistitle-project.eu
Coordinator: j.h.apotheker@rug.nl

**Developed by:**

Emily Michailidi, Giannis Sgouros and Dimitris Stavrou (Laboatory for Science Teaching, Department of Primary Education, University of Crete)

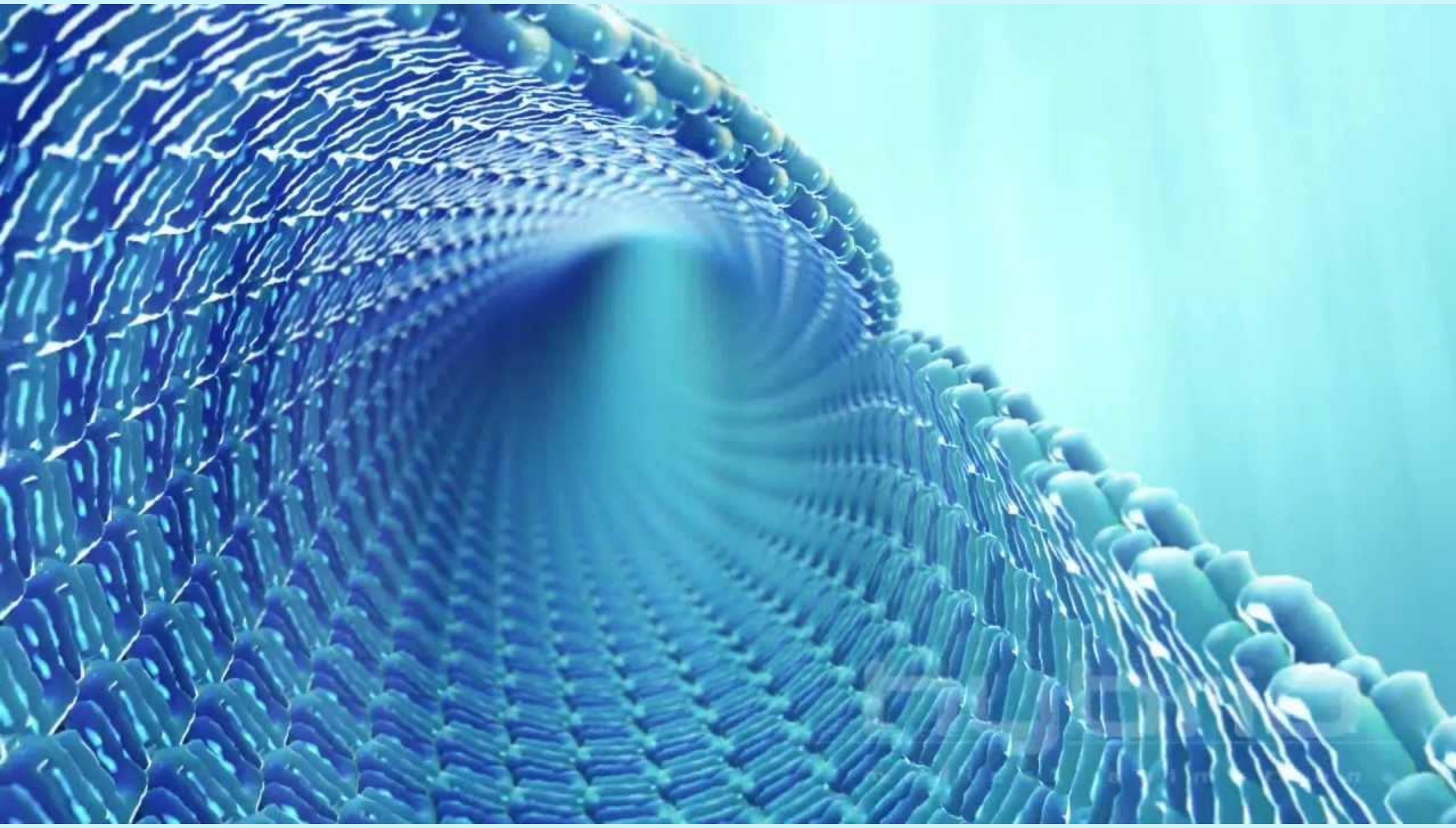
**in cooperation with:**

- Kyriaki Dimitriadi, Achilleas Mandrikas, Antonis Margaritis, Katerina Salta and Athanasios Velentzas (teachers)

- Ioannis Alexopoulos and Christina Troumpetari (Eugenides Foundation)

- George Kiriakidis and Vassilis Binas (Transparent Conductive Materials Group, Foundation for Research and Technology - Hellas)

- Katerina Voreadou (Natural History Museum of Crete, University of Crete)



University of Crete

Eugenides Foundation

# Introduction

## Short description of the Module

**The module developed in Greece focuses on technologies related to improve quality of life. Students come in touch with state of the art (photocatalytic) nanomaterials and their use for a healthy environment (air and water quality control) developed by researchers of Foundation of Research and Technology Hellas in Heraklion Crete (FORTH) who participate in the Community of Learners developing this module. The engagement has a two-fold impact on students: first it boosts their environmental awareness and involvement with prime societal problems such as quality of air and second it provides an opportunity to realize the role of nanomaterials and technology and their impact and risks to human health.**

## Target group

**The module, appropriately adjusted, has been implemented in primary school classes (aged 11-12), in lower secondary classes (aged 14-15) and upper secondary classes (aged 16-17). In the detailed description of the module we point out the activities appropriate for each age.**

## Students Starting Point

**At the outset of this module students should be able:**

**•To order (sub-)microscopic entities by size**
**•To estimate the size of an object using a unit or another object as reference**
**•To know what properties of a material are and to be able to report some of them (activity, colour, hardness, etc.)**
**•To understand the concepts of area and volume**
**•To calculate the surface and volume of familiar shapes (e.g. cube, rectangle).**

# Structure of the Module

**The main structure of the module consists of the following lessons:**

**Lesson 1. Introduction**
**Lesson 2. Visiting the Science Museum**
**Lessons 3 & 4. Nanoscience Applications: Self-Cleaning Materials**
- **How small is Nano?**
- **Size-dependent properties**

**Lesson 5. RRI-Issues**
- **Newspaper articles**
- **Discussion with experts in school and the research center**

**Lesson 6. Visiting the Research Center**
**Lesson 7. Construction of Exhibits**

# Applying the 6E Model

**In the module the 6E Model can be used as follows:**

**Engage:** Students' engagement takes place: a) through videos that present current nanotechnology applications and applications of self-cleaning materials and b) through a visit to the science and research center.
**Explore & Explain:** Students explore in their regular class various aspects of nanoscience as for example "How small is Nano?" and "Size-Dependent Properties" through their involvement in a series of nano related activities based on nanomaterials developed by researchers of local research groups. With their teacher's support they collect, analyze data and draw conclusions dealing with experimental activities and filling-up the correspondent worksheets (see students guide).
**Elaborate:** Students have the opportunity to elaborate their findings and discuss RRI issues: a) by visiting the research institute and coming in touch with experts, b) through newspaper articles about cutting edge research on nanotechnology and c) through a lecture held by an expert in the school classes (focused in our case on Gender Issues and Ethics in Research).
**Exchange:** During the visit to the science center a discussion follows about principals of the exhibits development in terms of content, communication methods of the content to the users, advantages/disadvantages involved. Also science museum experts may visit teachers and students in their classrooms providing advice and materials. Student exhibits are presented by the students themselves at the science centers on a specific day.
**Evaluate:** The evaluation of students' learning can take place through the final questionnaire and the exhibits development and presentation. In addition students' homework during the lessons can be used for the evaluation.

# RRI Issues

**In the module RRI issues are addressed as follows:**

**Engagement:** The module focuses on the role of researchers and civil society in the RRI process. This is realized: a) by the active participation of experts from the science center and the research institute in different phases of the module implementation and b) by presenting students' exhibitions in a wider audience, sharing this way a part of current cutting-edge scientific knowledge with the local society. Industry's and policymakers' role is addressed indirectly, through students' discussions with science experts and their teachers.

**Gender Equality:** The module attempts to address gender equality through a targeted discussion based on extracts from media and a lecture held by an expert on gender-issues.

**Science Education:** Via the module's activities students are brought in contact with various aspects of nanoscience as: size and scale, size-dependent properties as well as Science-Technology- Society issues which simultaneously are used to raise their awareness on RRI issues.

**Open Access:** The module addresses the transparency and accessibility of research and innovation by the participation of researchers from a research institute who shared the latest advances in NanoScience and NanoTechnology (NST) with the students.

**Ethics:** The ethics parameter is approached by an intensive discussion of students with their teachers and science experts, on ethical aspects of NST, such as safety, toxicity, or difficulty of disposal of nanomaterials.

**Governance:** During the discussion about ethical aspects of using new products the need of regulations by stakeholders arises.

# Web 2.0 tools

**A part of the module's activities utilizes the possibilities that web 2.0 tools offer. Particularly, on-line videos and simulations are used to facilitate students' understanding. Moreover, Skype can be used to set up teleconferences with experts in research institutes or science centers, particularly if visiting the grounds is not possible. A Learning Management System (Edmodo, Moodle etc) can also be used for student-student and student-teacher communication and for students to deliver their homework.**

# Icons & Abbreviations

Information for the teacher

Note for the teacher

Differentiated teaching

Written activity

Assignment

Assignment on computer

**PE:** Primary Education (age 11-12)
**LSE:** Lower Secondary Education (age 14- 15)
**USE:** Upper Secondary Education (age 16-17)
**DQ:** Driving Question
**NST:** Nano-Science and Technology

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# Engagement

# Lesson 1: Introduction

**Duration:** 90-120 minutes

**Teaching goals:** Students should be motivated to learn about NST via an introduction to future and current applications of nanotechnology in everyday materials.

## Materials needed:

•Video projector
•Videos:
- http://ec.europa.eu/research/industrial_technologies/dvds-videos-films_en.html (Film: "Nanotechnology" – E.U. DVD in multiple languages)
- http://www.youtube.com/watch?v=mEH6tDLKcVU ("Power of Nanotechnology")

## Nanoscale Science and Technology

Although still a commonly accepted definition doesn't exist, nanoscience is the term given to a wide multidisciplinary field, which studies phenomena and materials of about 1 to 100nm at least in one dimension and display in this size range properties that differ significantly from those of larger scales (e.g. the macro- or micro- scale) or the scale of subatomic particles.
Similarly, Nanotechnology is defined as the wide range of technologies that measure, control and manipulate matter at the level of individual molecules and clusters of molecules with at least one dimension in the nanoscale, aiming to the design, production and application of structures, machines and systems with fundamentally new properties and functions that arise from their nanostructure (Stevens et al., 2009; Hingant & Albe, 2010).

From the above definitions follows that:
1. Nanotechnology is closely intertwined with applications of properties of numerous but specific materials.
2. Nanotechnology examines and integrates in the developed applications, materials that exhibit at the nanoscale different properties than at larger scales.
So according to this observation nanoscience is not concerned with scale phenomena, where the macroscopic laws simply transform into smaller scales through miniaturization, without showing any significant nonlinear change of properties.

On this last point another important observation arises: That in nanoscience and nanotechnology it's not just the composition of the material that determines its properties but mainly its dimensions.

## Lesson description:

1. The teacher makes a short introduction to the subject.

2. The teacher shows the video “Power of Nanotechnology” {8 min} (or any other video with impressive current nano-applications e.g. “A Day made of glass” {11 min} https://www.youtube.com/watch?v=jzLYh3j6xn8 ).
3. Afterwards he/she asks students: “What impressed you most?”, “Do you believe these applications exist or that they will become true in the next few years?”. After the discussion he/she informs the students that some of these applications-products are already in market.
4. Then the teacher discusses with students how these products could affect everyday life and what other applications they could have.
5. The teacher informs the students that the scientific domain that has contributed to the realization of those products is nanotechnology, and based on the videos gives some information, focusing on the size range and the special properties the nanoscale entails.
6. Then the “Nanotechnology” video is projected.
7. At the end, the teacher poses questions like:
    - What impressed you most among what we saw/ discussed today?
    - About what topic would you like to know more? Why?
    - What would you like to learn?

# Lesson 2:

# Visiting the Science Museum

**Duration:** 90 minutes

**Teaching goals:** The main goal is students to be motivated regarding the development of a scientific exhibit and to come in touch with the basic guidelines of exhibits development.

## Lesson description:

Since school students will have a high active role on the development of exhibits the aim of the visit to the science museum is to enable students understand different communication approaches used in science-related exhibits.

1. As soon as they arrive at the science museum, students will be greeted by a science museum educator and taken to follow an educational pathway where they will be introduced to the selected exhibits linked to the field of Nanotechnology in combination with RRI aspects.

Each science museum may adapt or offer different activities in accordance with their exhibits or scientific content such as make a presentation or a workshop. In addition to the suggested activities, teachers can choose their own way to conduct visits by creating their own "Pathway", to better suit the class requirements, the students' preferences and the teaching content of each individual class. However, even if the museum does not have exhibits related to nanotechnology applications or RRI issues, exhibits from its permanent collections could be used in order to focus exclusively on the communications approaches used by those exhibits.[text]

2. The class is divided into teams, with each team having to interact with specific exhibits. The context will be set as follows: To each team is offered a worksheet with focus questions on the content of the exhibits in order to raise their interest on Nanotechnology (if provided / otherwise to science issues presented in the museum) and to tackle emergent RRI issues. Moreover, the worksheet includes questions which lead the students to think on how the exhibit attempts to engage the user and to communicate its content. An example is the following:
    - Take a quick look at the exhibit item. What message do you get immediately?
    - When you read accompanying texts, which parts are difficult to understand? Why?
    - What will you try to avoid when building your exhibit?
    - What visual devices help you understand the message better?
    - How are they used to make the exhibit more pleasing to look at?
    - How are they used to focus your attention?”

3. Exploration and interaction: Each team interact with each exhibit five to ten minutes. The museum science educator acts as facilitator and assists each team in the interaction with the exhibits (If necessary).

4. Review and conclusion: After the exploration, the students share their impressions about the exhibits with the museum science educator.
5. Afterwards, the educator sets a series of questions on the content, communication methods of the content to the user, advantages/disadvantages involved, the interactivity degree and how it could be improved.
6. At the end of the visit, students will have to acquire a critical look on the communication methods of the content of an exhibit that will help them at the stage of the design process and enhance their creativity and their imagination.

In case that a local science museum/centre is not available or it is in long distance, the suggested visit would be realized virtual, using web 2.0 applications or communication platforms (e.g. skype), with the museum staff.

The interaction between school and science museum/center will be continuous with the museum staff to visit the school classes in order to share knowledge, to present guidelines and interactive scenarios for building up an exhibit and overall, motivate students to develop exhibits (see lesson 7).

In case that a local science museum/center is not available or it is in long distance, the visits of the museum staff to the school classes could be substituted by virtual meetings, using web 2.0 applications or communication platforms such as skype for instance.

# 2

# Exploration & Explanation

# Lesson 3:

# NanoScience Applications: Self Cleaning Materials

## Part A – How small is Nano?

**Duration:** 90-120 minutes (depends on chosen experiments)

**Teaching goals:** By the end of the lesson students should be able to:

- define the nanoscale area
- express dimensions of macroscale objects in nanometers
- compare typical nanoscale objects with other small (both visible and invisible) items
- conclude that the surface/volume ratio of an object is increased when the object shrinks
- explain phenomena associated with the surface/volume ratio
- observe actively
- carry out simple experiments
- take measurements

## Size and scale

Size and scale, have been identified as key issues for teaching nanoscience (and science in general). A detailed understanding of size and scale not only helps students to understand the range of sizes nanoscience deals with, but also facilitate the understanding of size-dependent properties. Without a clear understanding of size and scale, it is difficult for students to understand why certain materials behave differently at the nanoscale (Stevens et al., 2009).

### Lesson description:

Lessons 3 and 4 consist of activities aiming to provide students with a theoretical background enabling them to understand the key operating principles which will be thoroughly explained by the scientists themselves during the students visit (in person or virtually) at similar research centres (lesson 6).

Specifically, this lesson consists of multiple short activities that combined can give students a sense of size & scale in the nanoworld (activities 1,2&3) and of the S/V ratio (activities 4, 5, 6 & 7) that will be used to interpret size-dependent properties in lesson 4.

The suitable activities for each age group (Primary Education / PE: 11 -12; Lower Secondary Education/ LSE: 14-15 and Upper Secondary Education / USE: 16-17) are shown in the following table:

| | PE | LSE | USE |
|---|---|---|---|
| Act_1 | √ | √ | √ |
| Act_2 | √ | √ | √(see Note) |
| Act_3 | √ | √ | √ |
| Act_4 | √ | √ | √ |
| Act_5 | √a | √b | √c |
| Act_6 | √ | √ | √ |

- At the beginning of the lesson, teacher projects a video abstract of an informative show where in our case scientists of FORTH Institute describe their innovation on photocatalytic materials that degrade air and water pollutants (e.g. https://www.youtube.com/watch?v=O9JDuDD5iX8 (2' 58''/Greek version) or https://www.youtube.com/watch?v=oaleZS63m10 (11' 20'' / Greek version).
- Alternatively, TEDx videos on nanotechnology and its current and future applications can be shown (e.g. www.youtube.com/watch?v=KXwW6F181i0, www.youtube.com/watch?v=_1jbigmsLBw ) or videos in other languages relative to nano-applications that change our everyday lives.

- Then a discussion is conducted about:
  - What impressed students
  - How could these products be useful
  - What everyday problems would they solve

The main idea of the module is to use current nanoscience applications developed by local science researchers and provide students with a base to understand these applications. So, in case of applying the module in other countries other nanoscience applications developed in a local research institute can be used.

- Afterwards the teacher informs students that they will have the opportunity to meet these scientists in person and ask them questions. But to be prepared for this meeting, let's learn more about the science behind this innovation!

- Worksheet_1 **(see student worksheet)** is distributed and students conduct activity 1.

## Act_1. Measurements with nanoruler.
## *"What's the length of my pen in nanometres?"*

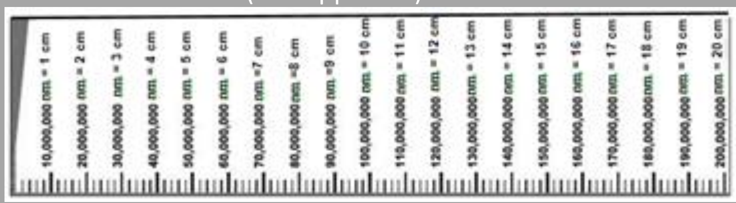
**Objectives:**

The aim of this activity is to familiarize students with nanometres as a measurement unit.

This activity will also lead them to the conclusion that nanoscale is inappropriate for measuring dimensions of objects in macroscale.

**Materials needed:**

- Normal ruler
- Ruler in nanoscale (see Appendix)




**Activity description:**

1. The teacher calls students to estimate the length of their pen in nanometres. (D.Q: How long do you think your pen is in nanometres?)
2. Then he/she distributes normal rulers to the students and calls them to measure one dimension of a book, a pen etc. in centimetres and to emend (if they want to) their original estimation.
3. Then, he/she distributes them the special nanoruler and students are called upon to check their answers by measuring the same objects with it.

Instead of measuring with the nanoruler older students of upper secondary education can be called to directly convert the measurement units in nanometers. At this point students can familiarize with measurement error (as even using rulers they can get various numbers). So they could be called to calculate and compare an average result between groups.

- By the end of the activity the teacher asks students if they would prefer, in their everyday lives, to use nanometers instead of centi- or milli- meters, to conclude that every unit is useful in a specific scale of objects.

## Act_2.Cut paper strips into pieces.

## *"How many times would you have to cut to approach nano?"*

**Objectives:**

The aim of this activity is to acquaint students with nanoscale and to reinforce their conception that objects in nanoscale are much smaller than visible ones. The desired outcome of this process is a gain in students' knowledge on the size of nanoscale objects.

**Materials needed:**

- paper strips 1m long
- scissors
- ruler

**Activity description:**

1. Students are supplied with a paper strip 1m long and a pair of scissors.
2. The teacher asks them to estimate how many times they should cut the strip in 1/10 to approach the nanoscale.
3. They are called to sequentially cut along the paper strip in pieces of 1/10 in length (that means to cut the 1 – meter – paper strip to 10 pieces, and each piece to 10 other pieces and so on) and to estimate the number of times they will need to

- Between the third and fourth cutting effort students reach an impasse because they can no further cut the remaining piece.
- At that point the teacher informs them that the total number of cuts is 9, fact that gives them a hint on how small a nanometer is!
- But which entities are nanosized?? (Proceed to Act.3)

# Act_3. Classifying entities according to their size

**Objectives:**

The aim is to familiarize students with different scales and indicative nanosize objects .

**Materials needed:**

- Cards, portraying objects/entities with different size ranging from macroscale to atoms.
- multimedia application “Scale of the Universe”: http://htwins.net/scale2/
- video “Powers of Ten” https://www.youtube.com/watch?v=0fKBhvDjuy0
- Note: Chosen entities on the cards must also appear in the application.



**Activity description:**

1. Initially, as a motive, students watch the video “Powers of Ten”, and they discuss about scales.
2. Next, the teacher distributes the cards in each team and calls students to order (based on their prior knowledge) the entities portrayed on the cards according to their size, on a “size line”
3. The teacher calls them to justify their order and to share with the whole classroom their way of thinking.
4. Afterwards, he/ she projects the multimedia application “Scale of the Universe” on the board and calls students to explore entities belonging in different scales ranging from macroscale to nanoscale.
5. Students’ final task is to check their card’s classification, to make any necessary reclassification and to write down the correspondent order of magnitude of each pictured entity.
6. By the end of the activity the teacher calls students to reflect on their mistakes.
   - Did anything puzzle you?
   - Why is that?

The teacher must point out that even though we can't see them with a naked eye, there are entities all around and inside us that belong to the nano- and the micro-scale. And all these entities beyond 10-4 are not indiscriminately same sized.

(For Lower & Upper Secondary Education students)
Using the Scale of universe application divide the given entities as pertaining in the macroworld, the microworld or the nanoworld.

Through those activities students should have created a perception of how small the nano-scale is.
Afterwards, the interest is focused on the S/V ratio and its effect on various reactions. The following activities (4, 5 & 6) present various aspects of the effect S/V ratio has on the rate and intensity of reactions, while activity 7 gives a mathematical interpretation of these phenomena.

## Size-dependent properties

Size-dependent properties consist one of the nodal ideas of nanoscience, as most innovative applications of nanomaterials are due to them. Changing the length of one dimension of an object, brings multiple changes to its surface and volume. Equally disproportionately, the properties that depend on them will change. One of the consequences of miniaturization of an object is that the surface area/volume (S/V) ratio increases. These changes indicate an increase in the relative number of surface atoms. Chemical reactions involve the interaction between surface atoms of a material and atoms of its environment. Therefore changes in the size of the exposed surface influence the rate of chemical reactions and thus the reactivity of the material. As the proportion of surface atoms rises sharply when cutting a quantity in nanoscale entities, the interactions that depend on surface drastically alter the behavior of materials at the nanoscale. The effect of increasing the surface area by reducing the size can be observed even in macroscale. Exactly at this point we rely on to structure the following activities, as an analogy of what takes place in the nanoworld (The Royal Society & The Royal Academy of Engineering, 2004; Stevens et al., 2009).

As activities 4, 5 & 6 are quite similar, the teacher, according to the time available, may choose to carry out one or two of them in class and the last one to transform it in a thought experiment as homework.

- So far we have talked about materials that show unusual properties in the nanoscale.
    - What exactly do we mean? Give examples.
    - What do you think these changes are due to? How would you explain it?
- Students are given worksheet_2 (see students worksheets)

## Act_4. Chemical reaction of potato with hydrogen peroxide (H2O2).

**Objectives:**

The aim of this activity is to observe the shift in chemical's reaction rate, as potato is submerged in a hydrogen peroxide solution.

**Materials needed:**

- Pieces of potato in different sizes
- Hydrogen Peroxide (H2O2) solution 3% or Coke for younger students
- Two plastic cups

Chemical reaction of potato with hydrogen peroxide (H2O2).

**Activity description:**

1. The teacher gives each team 2 cups with the same quantity of H2O2 in them and 2 equal pieces of potato.
2. Students are called to cut one potato piece in smaller ones and to predict what would happen if they immerse them (the big and the smaller ones) simultaneously, in the 2 cups containing hydrogen peroxide solutions. Will they act differently or the same way?
3. Afterwards they are called to carry out the aforementioned procedure and to share their observations with the classroom.

Due to increased total surface area, bubbles generation in the cup with the small potato pieces will be more intense.

4. The teacher stimulates students to explain the different reaction in the 2 cups.

- Finally, after students share their opinions he/ she explains that this chemical reaction occurs at the interface between the potato and the $H_2O_2$ solution and hence the smaller the potato pieces, the surface increases as well as the reaction rate.

For a more qualitative explanation of how size impacts a material's properties, elementary students can participate in the following activity:

1. Students are called to hold hands, and keeping this formation, to pass through the class door.
2. When they reach an impasse, the teacher asks them: If you let go of hands, can you now get through the door? What was the difference?

The aim of this activity is students to conclude that even with same constituents of matter, properties can differ if it is in small or in big parts.

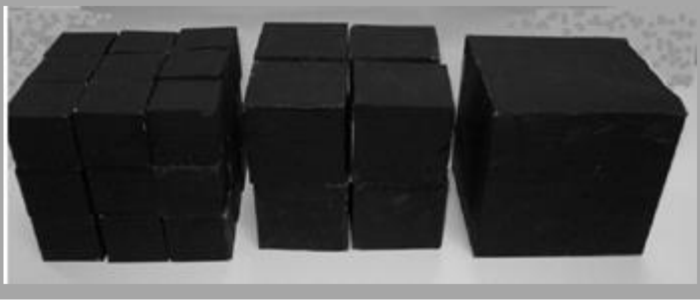
- But let's give a more mathematical explanation. Students proceed to the analogy depicted in activity .

# Act_5. Cutting paper cube in small pieces

**Objectives:**
The aim of this activity, is to observe the increase in total surface area of an object as we cut it in smaller pieces.

**Materials needed:**

- Paper cubes (1 cube with 12cm edge, 8 cubes with 6cm edge , 27 cubes of 4cm edge). Alternatively you can use pieces of cheese, cut in the respective dimensions.
- Ruler



*27 cubes with 4cm edge (left), 8 cubes with 6cm edge (center) and 1 cube with 12cm*

**Preparation for the teacher:**

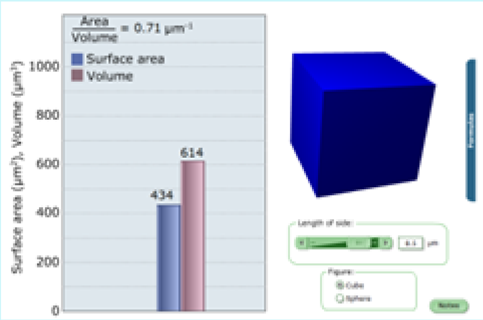
Construction of three paper cubes with different edge but equal total volume. One paper cube of 12cm edge each, eight paper cubes of 6cm edge each and 27 paper cubes of 4cm edge each.

As the mathematical knowledge of different age groups differs, this activity is offered in 3 variations, for Primary (PE), Lower secondary (LSE) and upper secondary education (USE) students

Activity description:

1. The teacher shows the three cubes with a total edge of 12cm each to the students. The first one is integral, the second consists of eight cubes of 6cm edge each, and respectively the third consists of twenty seven smaller cubes of 4cm edge each.
2. (PE): The teacher calls students to investigate that the 3 cubes occupy the same space.
3. (LSE) & (USE): Students are called to measure the three cubes' total volume.
4. As a next step, students' task, is to estimate if the total surface area of the cubes is equal or different in each construction.
   Afterwards, they are called upon to check their answers, by participating in different activities, according to their grade level.
5. (PE): Students unfold the paper cubes and stick colored square paper sheets to all surfaces disclosed. The quantity of square sheets required to complete each cube, highlights and the total surface area. (if PE students are competent enough they could also work on worksheet_3a).
   (LSE): Students unfold the paper cubes, and measure their dimensions. Using geometrical knowledge, they calculate the total surface area of each paper cube. Then they calculate the ratio of Surface Area / Volume (S/V). The final task is to order these fractions in ascending order and to discern the relationship between the size of each cube and the corresponding ratio (Workshhet_3a).
   (USE): In order to study S/V ratio students perform the a series of mathematical calculations (Worksheet_3b).

Lower & Upper Secondary Education students can also interact with this application: http://esminfo.prenhall.com/science/BiologyArchive/lectureanimations/closerlook/cellsurface.html .



To increase students' understanding of the rate of the intensity dependency of a reaction from the S/V ratio, we proceed to Activity 6 (worksheet_4). The following activity is similar to Act_4 and is used enhance students' knowledge in new situations.

# Act_6. Dissolution of effervescent tablets in water

**Objectives:**

The aim is to observe the change in dissolution rate of effervescent tablet when we cut it into small pieces and to stimulate students attribute the intensity of surface-dependent properties to the small size of the pieces that the material consists of.

In terms of inquiry-based learning the aim is students to exercise their inquiry skills (hypothesis formulation, controlling variables, data collection, draw a conclusion).

**Suggested materials:**

- effervescent tablets
- Plastic can with lid lid/ glass/ balloons
- stopwatch

**Activity description (Worksheet 4a):**

1. The teacher asks the students what they would do if they wanted the tablet to dissolve more quickly and they discuss all the opinions in the classroom.
2. Students are called to suggest an experiment to answer the above driving question.
3. Then they formulate an hypothesis, identify the variables involved, collect and note down their data and draw their conclusions.

In case students aren't familiarized with planning investigations, the teacher can use Worksheet 4b. In this alternative students are given the materials and they are called to follow the steps described in the activity:

1. Students are called to break one tablet in smaller pieces and to predict what would happen if they infused simultaneously in the 2 different cases with water, the 2 tablets having break the one into small pieces. Would they act differently or the same way?
2. Afterwards they are called to carry out the aforementioned procedure and to share their observations with the classroom.

Due to the increased contact surface, the formation of bubbles generated in the case containing the grated tablet, are made the lid to pop-up with greater force and much faster. This is an immediate observation of property change (dissolution rate) as the size of the object becomes smaller

3. Finally, the teacher urges students to explain the different reaction in the 2 cases, using their knowledge from the previous activities.

**Thought experiment**

If we tried to set on fire a thread spool and a same quantity of single thread which one of the two forms would light up faster? Justify your answer.

Alternatively the teacher could conduct the experiment in the classroom, but only as a demonstration. Due to increased total surface area of thread in the fragmented form (single thread) combustion is faster and more easily observable. This is another immediate observation of property change (combustion rate) as the size of the object becomes smaller. [text]

# Lesson 4:

# NanoScience Applications: Self Cleaning Materials

## Part B – Size-dependent properties

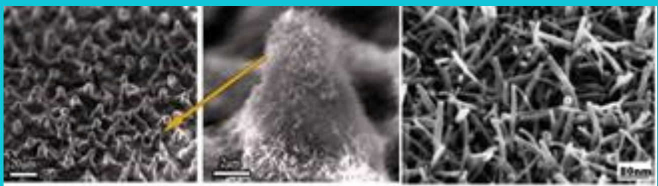
**Duration:** 90 minutes

**Teaching goals:** By the end of the lesson students should be able to:

- explain phenomena associated with the surface/volume ratio
- report the properties of super-hydrophobic materials (self-cleaning, water-repellence)
- interpret these properties as due to the contact surface structure (which also defines the shape the water drops take when falling on it)
- explain the concept of biomimicry and to link it to the development of innovative materials
- observe actively
- carry out simple experiments
- take measurements

# Super-hydrophobic materials

Super-hydrophobicity is a property exhibited by certain nanomaterials both natural (such as the lotus leaf) and artificial (such as waterproof fabrics).The hydrophobicity of lotus leaves is due to their structure. The leaf surface has a structure of two superposed layers (Bhushan, Jung & Koch, 2009). The first layer is covered with small protrusions 5-10mm each, spaced 10-15mm. Each protrusion is covered by bumps of a hydrophobic waxy material, having a height of only 100nm. When water drops fall on the leaf, they stand lightly on the edges of the hydrophobic protuberances, which prevent the drops to penetrate into the interspace, resulting in only 2-3% of the surface area of the drops coming into contact with the leaf.



**Lotus leaf structure in multiple magnification.**
**www.sciencedirect.com**

A measure of the water repellent property is the contact angle formed between the water drop and the surface of the leaf. In case of an hydrophilic surface the drops are wider so the contact angle decreases (<90◦). In case of an hydrophobic surface the interface shrinks and the contact angle increases (> 90). The waxy lotus bumps create a contact angle of 157◦. This reduces cohesion forces and the leaf is coated with a hydrophobic surface. This way, water can't moisten the surface and flows more easily.

The above lead to another property associated with lotus: self-cleaning. When raindrops fall on the leaves entrain all dirt they find on their way. This process keeps the leaves dry, clean and free of microorganisms.

Self-cleaning and water-repellency of super-hydrophobic surfaces are properties exploitable by many nanotechnology applications. Buildings dyes, tiles and various coatings already exist in market. These products are examples of biomimicry. Understanding the mechanism of how the lotus, and other plants create super hydrophobic surfaces using two staggered layers, scientists and engineers built artificial surfaces with similar nanostructure that mimic the properties of natural ones (Ensikat et al., 2011; NSF CAREER Award and RET Program).

## Lesson description:

In lesson 4 we focus on the peculiar properties of nanomaterials, that are due to the increased S/V ratio, and particularly on super-hydrophobic (natural and artificial) materials, on the change in gold nanoparticles solution's color and on ferrofluids.

The suitable activities for each age group (Primary Education: 11 -12; Lower Secondary: 14-15 and Upper Secondary: 16-17) are shown in the following table:

| | PE | LSE | USE |
|---|---|---|---|
| Act_7 | √ | √ | √ |
| Act_8 | √ | √ | √ |
| Act_9 | Only demonstration of ready products | √ | √ |
| Act_10 | | √ | √ |
| Act_11 | Only demonstration of ready products | √ | √ |

- The lesson starts with the teacher providing a research problem: " Are properties of a particular substance independent from the size of its particles? What kind of properties would you like to investigate?
- Then he/she projects the "Lotus effect demonstration" video (https://www.youtube.com/watch?v=LJtQ6dvcbOg) and asks students to say what impressed them among what they saw.
- He introduces the concept of hydrophilicity-hydrophobicity and asks them to give possible explanations.
- Students proceed to activity 7 and the distribution of Worksheet_5 (see students' worksheets)

# Act_7. Hydrophobic materials

**Objectives:**

The aim of this activity, is the observation of water interaction with several surfaces and its interpretation as due to the contact surface structure (and consequently due to S/V ratio). Students should also familiarize with natural and artificial nanomaterials and their properties, as well as with the concept of biomimicry.

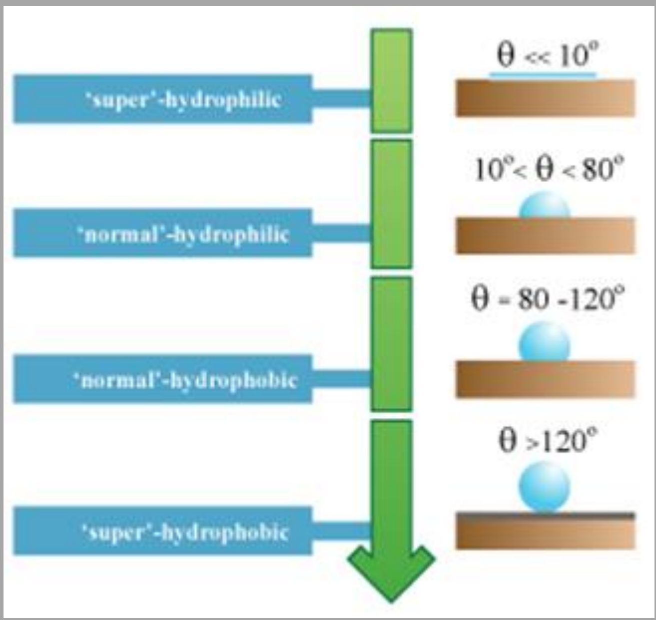
Materials needed:

- pipettes
- different types of surface (plastic, paper, nano-tex, aluminium foil, wax paper…)
- plant leaves (water lilies, tulips…)
- an android tablet with “Photo Measures Lite” application or camera and projector

Activity description:

1. The teacher distributes different surfaces at each group, 1 pipette and a glass of water.
2. He/ She calls students to pour water drops of the same size (using the pippete) on the various surfaces and to observe their shape carefully.
3. PE: Younger students are called to draw the side view of each droplet and to characterize the material as super-hydrophilic, hydrophilic, hydrophobic or super-hydrophobic according to the table below.

4. LSE & USE: Older students are called to take a photo of the side view of each droplet, to use the Photo Measures app to draw and calculate the contact angle (formed at the point of contact of the droplet with the respective surface) and then characterize the material as super-hydrophilic, hydrophilic, hydrophobic or super-hydrophobic according to the table below. Alternatively, students can take a picture, project it to the board, draw the contact angle and calculate it.




- The teacher asks students about the similarities and the differences they observe between the nanotex and the water-lily leaf (-> both super-hydrophobic) guiding the discussion around the concept of biomimicry.
- Apart from hydrophobicity another property of water-repellant surfaces is self-cleaning. Let's check it out proceeding to activity 8

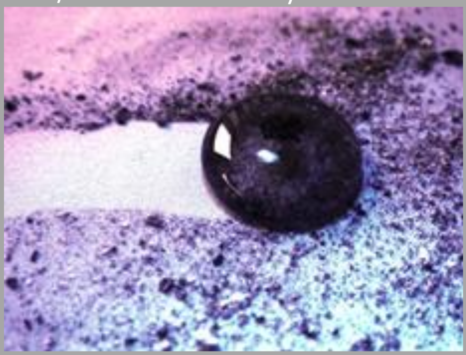
# Act_8. Self-cleaning materials

**Objectives:**

The aim of this activity, is the observation of water interaction with several surfaces and its interpretation as due to the contact surface structure (and consequently due to S/V ratio). It also explains the interaction of the water droplet and the surface of hydrophobic / hydrophilic materials Students should also familiarize with natural and artificial nanomaterials and their properties as self-clearance, as well as with the concept of biomimicry

**Materials needed:**

- fine dust (finely ground garden clay), fine ash, cocoa
- tap water
- different types of surface (plastic, paper, nano-tex fabric, aluminum foil, wax paper…)
- plant leaves (water lilies, tulips…)
- video projector
- videos: “Lotus effect” https://www.youtube.com/watch?v=M9wKko4ur7A
- “NanoTech” https://www.youtube.com/watch?v=EeJz7iPPy1Y



**Activity description:**

1. Using the same surfaces as in the activity before, students are called to sprinkle them with dust, add some water drops on them and create an inclination using a book underneath.
2. The teacher induces them to write down their observations. Did the droplet leave the same kind of traces on each surface? Did they observe anything about the cleanability of each surface?

To interpret those effects we use a model for water absorption and scrolling feature on different surfaces – a hydrophilic, a medium and a hudrophobic. The teacher presents a model as shown below made of:

- 3 pieces of styrofoam (30 x 50 x 5 cm)
- ~200 wooden straws
- 1 plastic bag

Wooden straw

Models of surfaces of different roughness

## Preparation tip for the teacher

Nail to the nose downward and evenly (at equal intervals) wooden straws in three pieces of styrofoam to create three surfaces of different roughness. Fill the bag with water and slamming tying the end (if possible airtight).

- The teacher calls students to place the plastic bag on all three inclined surfaces and let it interact. The observable difference of the interaction can simulate water droplets' behavior on hydrophobic / hydrophilic surfaces.
- This simplistic model gets more concrete via the "Lotus Effect" video that presents an animated model of the self-cleaning properties of lotus plant.
- Finally through the "NanoTech" video the explanation of the mechanism deepens, getting enriched with more pictorial models and it also describes the procedure of biomimicry an presents current nanomaterials inspired from nature.

Sketch how you imagine the structure of a lotus leaf, of a paper sheet and of a plastic surface.

Secondary education students LSE & USE, can proceed to the preparation of colloidal gold solutions, following the instructions below. Primary education students (PE) may watch the procedure or just examine and interact with the final products.

# Gold nanoparticles’ optical properties

Characteristics and properties are normally ways to describe a substance. For example gold is glossy, and yellow (optical properties), conductive (electrical properties), and malleable and ductile and melts at high temperatures (natural properties). Scientists and engineers use this information to predict how a bit of gold will behave and for what uses it’s appropriate.

Until recently, it was believed that these properties were fixed for a given substance, regardless the quantity or size of its particles. However with the help of new instruments researchers found that at molecule aggregations between 1 and 100nm, properties are not foreseeable. However not all materials demonstrate different properties at the nanoscale, as there are other factors involved like size, arrangement of atoms, shape and electrical charge.

Gold, however, is a material that when taken in nanoscale amounts, modifies drastically many of its properties. For example, increases its activity to an extent that it can be used as a catalyst, but also is converted from a good conductor into a semiconductor. The color of gold is one of the most striking examples of optical properties change. The color of gold nanoparticles, can become red, blue or purple depending on its size and shape.

The color of gold, like all objects, is a result of incident radiation’s interaction with matter: a part of it is reflected, a part passes through and a part is absorbed. In case of gold, violet radiation is absorbed and the combination of the remaining reflected radiation gives us its known golden color (Stevens et al., 2009; nanocomposix.com).

The enchantment of Au nanoparticless since ancient times, as reflected in their intense color, originates from the basic photophysical response that does not exist to nonmetallic particles. When a metal particle is exposed to light, the oscillating electromagnetic field of the light induces a collective coherent oscillation of the free electrons (conduction band electrons) of the metal. This electron oscillation around the particle surface causes a charge separation with respect to the ionic lattice, forming a dipole oscillation along the direction of the electric field of the light. The amplitude of the oscillation reaches maximum at a specific frequency, called surface plasmon resonance (SPR). The SPR induces a strong absorption of the incident light.

The SPR band is much stronger for plasmonic nanoparticles (noble metal, especially Au and Ag) than other metals. The SPR band intensity and wavelength depends on the factors affecting the electron charge density on the particle surface such as the metal type, particle size, shape, structure, composition and the dielectric constant of the surrounding medium. Agglomeration of metal nanoparticles and therefore changing their dimensions will change the frequency of plasmon resonance and in accordance changes the light adsorption characteristics of the nanostructure. Increase in the dimensions of metal nanoparticles will lower the plasmon resonance and therefore longer wavelenghts will appear.For instance, Au in Colloidal form (less than 2 nm) is light pink while when Au nanoparticles are agglomerated they will become red. Therefore changing the diameter of nanoparticles will change their light adsorption properties and therefore their color (Huang & El-Sayed, 2010).

# Act_9. Gold solutions

**Objectives:**

The aim in this activity is to observe the different color of gold solutions, depending on the colloids' size contained therein. This is an observation of color change of gold at the nanoscale.

**Materials needed:**

- Jars with auric chloride solution: tetrachlorauric (III) acid trihy-drate ($HAuCl_4$)
- Jars with citrate solution: trinatriumcitrate dihydrate ($C_6H_5Na_3O_7$ x 2 $H_2O$)

**Activity description:**

1. The teacher presents two containers with solutions to students and let them browse (without opening them).

2. After giving them a little time, he/ she asks them to try to guess what might be within the two containers. As gold usually isn't among their answers the teacher poses the following questions:
   a. Could these jars contain gold/ solutions of gold? (-> No!)
   b. Where do you conclude that from? (-> they mention the characteristic properties of gold, mostly its color)

- The teacher reminds them the previous activities and the fact that when approaching the nanoscale the properties of some materials change radically. One of those properties is the color of gold, and those two jars contain gold solutions of different size gold nanoparticles.
- The blue solution contains gold particles of about 100nm, and the purple solution gold particles of about 50 nm

Secondary education students can proceed to the preparation of colloidal gold solutions, following the instructions (see Appendix) and to the next activity on Tyndall effect.

Observation of color change in gold colloidal solutions can be achieved by studying their absorption spectrum. Spectroscopic analysis of gold solutions combined with atomic theory, energy levels, emission & absorption spectra of atoms can faciliate students understanding in optical properties change in nanoscale[text]

## Tyndall effect

Colloidal Solutions are dispersions wherein the solute is in the form of aggregates called micelles, approximately 1-1000nm in size and uniformly distributed in a dispersant. Colloidal solutions cover the "gap" between homogeneous and heterogeneous mixtures. Fog, smoke (dispersion of fine liquid drops or solid particles in the air - aerosols), blood (cell dispersion particles in blood serum) and milk (consisting of tiny casein protein complexes and liquid fat droplets in water) are known colloidal systems.

The colloidal solutions in contrast to ionic or molecular solutions scatter visible light in oblique directions in the particle boundaries, since the dispersed particles have dimensions comparable to the wavelength of incident radiation.

**Light transmittance (left) and light scattering (right, Tyndall effect) in colloidal solution. www.surfguppy.com**

This phenomenon was discovered by Tyndall in the 19th century and is typical of colloidal solutions, since refractive index of the dispersed particles is different from that of the dispersion medium. A simple way to test if a mixture is a homogeneous solution or a colloid is to illuminate the mixture with light beam or laser-rays. Light is only dissipated by the colloidal solution as the image demonstrates (http://www.svpvril.com/Tyndall.html)

# Act_10. Tyndall Effect

**Objectives:**

The aim in this activity is students to classify mixtures as colloidal or not, by observing light dispersion (laser light of 635nm) as it passes through different solutions (Tyndall effect).

**Materials needed:**

- distilled water
- distilled water with droplets of milk
- milk
- citrate solution
- NaCl solution
- $HAuCl_4$ solution
- gold solutions
- 6 glass beakers

**Activity description:**

1. Students are called to prepare the above solutions and place them in seven different glass beakers.
2. Afterwards they radiate with red laser light each solution and they observe carefully the interaction.
3. Finally they are called to classify the solutions as colloidal or not according to their interaction with light.

- After experimenting with colloidal solutions students through Activity 11 will come in contact with a different kind of liquid, ferrofluid.

i

## Ferrofluids

Ferrofluids (FF) are suspensions of small magnetic particles with a mean diameter of about 10 nm in proper carrier liquids. The composition of a typical ferrofluid is about 5% magnetic solids, 10% surfactant and 85% carrier, by volume. The surfactants are generally organic solutions like oleic acid, citric acid or soy lecithin. The surfactants prevent magnetite particles from agglomeration. The carrier liquid is generally kerosene.

Ferrofluid in a strong magnetic field of an

icon

## Act_11. Ferrofluids

**Objectives:**

The aim in this activity, is to observe different behavior of matter at the macroscopic and microscopic scale. In absence of magnetic field, iron nanoparticles move freely in the solution and it behaves as a normal liquid. In presence of a strong magnet, iron nanoparticles are temporarily magnetized and the solution acquires a solid magnet's behavior.

**Materials needed:**

- Video projector
- "Ferro Fluid Tests" https://www.youtube.com/watch?v=kL8R8SfuXp8 (0:40'' – 3:12'')
- Magnets
- iron filings
- ferrofluid (https://www.supermagnete.de/eng/physics-magnets/ferrofluid-10-ml-magnetic-fluid-for-experiments-in-little-glass-bottle-with-pipette_FER-01 60cc bottle costs around 18€)

**Activity description:**

1. Students are given different magnets, ferrofluid in sealed container and iron filings to interact and they fill in worksheet_7

2. The teacher asks them to predict what would happen if they approached the magnet at the iron filings and at the jar with the ferrofluid.
3. After carrying out the procedure they are called to write down their observations and to notice the similarities and the differences at the shapes of the ferrofluid and the iron filings

- Afterwards, the teacher discusses with the students ferrofluids' uses and unique properties and how those are due to its nanostructure, adjusting the depth of his/ her explanation to the students' age group.
- As a closure the teacher shows students the video "Ferro Fluid Tests" in which they can see more more experiments with ferrofluids

3

# Elaboration

# Lesson 5:

# RRI issues

**Duration:** 90 minutes

**Teaching goals:** By the end of the lesson students should have:

- developed concerns about the production and use of nanomaterials
- developed a critical attitude towards the use of derivatives of current research
- accepted the need for ethical standards in science
- raised their interest about current scientific research

## Materials needed:

- newspaper articles on controversial uses of nanotechnology: e.g. medicine, Cosmetics, food industry, environment

## Learning outcomes:

The main purpose is to sensitize students in ethical issues arising from the growing use of new technological applications. It would be valuable if, through this process, students could realize the need for their education in natural sciences so that they become technologically informed citizens, with critical attitude towards the use of new applications in their everyday life.

## Lesson description:

- At the beginning of the lesson the teacher provides each team with 2-3 short newspaper articles referred to nanotechnology applications (e.g. in medicine, environmental protection, energy saving etc) and the possible risks of their use.
- Each team studies the articles and its members divided in two sub-groups are called to argue against and in favor of nanotechnology applications, running a debate in the classroom.
- Then, an open dialogue is conducted, during which students reflect on the ethical issues raised and assess the potential benefits along with the risks that may arise from the use of nanotechnology applications in medicine, environmental protection, energy saving etc. Based on students arguments the teacher also discusses with the students other aspects of RRI (e.g. engagement, governance etc.).
- At the second half of the lesson, an expert visits the classroom and gives a lecture focused on RRI issues and particularly on:
    - ethics (bringing up examples of misinformation of the public in cases where widely promoted innovations had not been fully tested by scientists for their consequences – e.g. DDT)
    - gender equality (underlying womens' role in the advancement of science indicating their inadequate recognition)
- The lecture is followed with discussion where students are encouraged to express their views, questions and concerns.

By the end of the lesson, and as a preamble of their visit at the Research Center, students are assigned to prepare questions they would like to ask a scientist.

# Lesson 6:

# Visiting the Research Centre

**Duration:** 90 minutes

**Teaching goals:** By the end of the lesson students should have:

- developed concerns about the production and use of nanomaterials
- developed a critical attitude towards the use of derivatives of current research
- accepted the need for ethical standards in science
- raised their interest about current scientific research

## Lesson description:

*Students having acquired an adequate background for nanotechnology through Lessons 3 and 4 and for RRI matters (Lesson 5) they now have the opportunity to come into direct contact with cutting edge nanotechnology applications (apart from the videos presented at lesson 3) and to discuss with the researchers themselves about the fundamental principles of nanotechnology and RRI issues.*

- Before the lesson students have prepared themselves for the visit, having already a list of questions they would like to address to a scientist.
- During the visit at the Research Center students are guided in the laboratory facilities to come in touch with a scientist's working environment. They are also shown current nanoscience applications (as self-cleaning materials, photocatalytic paint that purifies air etc) that are developed in the lab as long as the instruments that are used for this purpose. Scientists also develop the main principles of nanoscience.
- At the end of the visit students have the opportunity to discuss with scientists, express their concerns and address them questions about their profession, the ethic dilemmas they are confronted with and about other RRI aspects. For example:
    - As far as it concerns your work in the laboratory, are you obligated to send a report of the results of your experiments at someone superior (financier, the state etc)?
    - Should your research results be published in the press?
    - When you are conducting a research, do you know in advance what may be the consequences and generally the negative impact of your research? If so what do you do about it?
    - If you happen to discover something important for the world would you inform citizens about it? Would you also make some visits to schools to inform children?

4

# Exchange

# Lesson 7: Construction of exhibits

**Duration:** 90 minutes for the general guidelines + the time students need to complete their exhibits

**Teaching goals:** By the end of the lesson students should be able to:

- cooperate effectively to build a scientific exhibit
- present their knowledge through scientific exhibits
- select and synthesize information creatively to include them in their exhibits
- include in their exhibits key aspects of nano-science and RRI taking into account the basic principles of exhibits design

## Lesson description:

Students exchange their acquired knowledge with wide audience, by developing exhibits. They suggest ideas for the construction of their own exhibits and cooperate with peers in order to accomplish this demanding task. Teachers and experts from non-formal education support students in this process. Visits in science exhibition halls and science museums will familiarize students with the basic principles of exhibitions' development (see lesson 2).

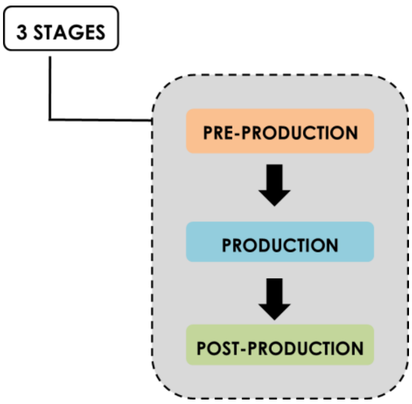
Students' exhibits are presented in a special event to the wide audience. School and science museum / exhibitions halls representatives will organize and communicate this event at local community. Students will have the opportunity to communicate acquired knowledge to peers, friends and citizens of the local community. Through this constructive process, they will actively participate in a public awareness process on the benefits and potential risks arising from applications of nanotechnology.

## Exploring Interactivity

There are several existing definitions for the concept of interactive exhibits, for instance, according to Bitgood (1991), "Interactives might include something as simple as pressing a button which illuminates a light or something as complex as a sophisticated interactive computer system. The important point is that there is a visitor-controlled change in the exhibit". In the museum context usually interactivity is strongly connected with the use of ICT. This is however not necessary. An interactive exhibit might be consisted of any material or equipment is needed, in order for the exhibit to actively engage the visitor in a process that requires not necessary physical interaction but mainly mental. Moreover, an interactive exhibit should encourage the interaction and collaboration amongst users and even maintain feedback of the previous visitor for the next visitor.

**A three-stage production process**

The design process of an exhibit can be organized into three different stages: pre-production, production and post-production.




**A. Pre-Production:**

This stage includes (a) the initial research (students cannot design an exhibit unless they know something about the subject matter) and (b) the design of the actual exhibit. Research is a critical part of the school museum process and should involve:

clarifying research questions, locating information, summarizing information, analysing information and synthesizing information (table 7.1).

Table 7.1: **Five basic research steps in building an exhibit** [1]

| | | |
|---|---|---|
| Clarify research questions | Focus areas of interest | Students must thoroughly understand their questions before they can successfully conduct research - if questions are too broad, students may not know how to begin research. |
| Locate information | Use a variety of resources | Students should use multiple and diverse sources of information to answer their research questions - people, books, magazines and newspapers, videotapes, DVDs and CDs, Internet sites, etc. |
| Summarize information | Take notes | Students need to summarize what they have learned - they will use their notes to answer the focus questions and develop their exhibits. To be able to effectively summarize, students must understand information at a fairly deep level and make decisions about what information to keep, to delete or to substitute. |
| Analyze information | Examine notes to draw conclusions and answer research questions | Students are now ready to answer their research questions - developing a short written response to their research questions requires that they analyze their notes, prepare research conclusions and evaluate how well they have answered their questions. |
| Synthesize information | Share information with teammates to answer focus question and write a big idea and story line | Students are now ready to share findings with exhibit team members. This process forces students to step back from their independent research and integrate their collective knowledge. At this stage students must adequately answer the focus question, in doing so, they will need to listen carefully to one another, synthesize information and evaluate the adequacy of their answers. When students are clear about their big idea, they are ready to answer the question "What do we want visitors to learn, feel and act in our exhibit?". |

Once the research has been completed, you are ready to design your exhibit using the following guideline (table 7.2):

Table 7.2: **Guiding Questions for Exhibit Design**[2]

[1] **Irresistible Exhibition, A Development guide**

[2] **Irresistible Exhibition, A Development guide**

| | | |
|---|---|---|
| What will we use to tell our story? | What objects will we select and/or build and what presentation methods will we use to display them? | Objects are central to exhibits as they are the visual devices that carry the story line. They may include: artifacts (real or created), models, interactive devices, video presentations, pictures, photographs, graphics, timelines, diagrams, charts and maps. |
| How will we get visitors to experience our story? | How will we make our exhibit relevant to visitors? How can we engage their senses? | Students must try to have in mind five principles: (1) relate to the visitor's personal experience; (2) reveal the big idea to the visitor ; (3) use creative art forms to help tell the story; (4) encourage the visitor's curiosity, interest, and questions; (5) present a whole story, rather than a part of a story.<br>Displays that engage the senses are more likely to attract and hold the attention of visitors: students should consider ways to add visual, auditory, kinesthetic, and tactile interest to their exhibits. |
| What will our complete exhibit look like? | What materials can we use to create our exhibit? How will we plan our space? | Creative displays can be made from ordinary supplies such as heavy cardboard, old shipping boxes, butcher paper, tension string and paint.<br>Depending on where the exhibit will be housed, students may need a scale drawing for the entire floor plan. Developing this plan may involve the entire class, or the task could be assigned to a smaller group. The plan should specify the amount of space allotted for each display and the anticipated path of the visitor. |
| Will our exhibit work? | Will visitors like our exhibit? Will it be a cohesive whole? | After students have designed their exhibits, they can conduct formative evaluation to improve their designs using their drawings. They can ask students from other exhibit teams, other students in the school, parents, or other adults to respond to their exhibit ideas. Serrell (1996, p. 141) developed evaluation questions that might be useful during the formative evaluation process; (1) do they like it?, (2) do they think it is fun?, (3) do they understand it?, (4) do they find it meaningful?, (5) does their understanding coincide with (or at least not contradict) the stated communication objectives for the element?, (6) does it give the user a sense of discovery, wonder or "wow"? Based on what students learn from the formative evaluation, they may want to brainstorm alternative, better ways to design their exhibits.<br>Prototyping helps students test their assumptions with visitors before they go too far in the exhibit development and design process - before they are inclined to stick with their idea and design, even if it doesn't work for visitors (McLean, data???) Prototyping is actually an iterative conceptual design process. Students design the mock-up, talk to visitors and redesign based on visitor input. |

**B. Production:**

After completing the work of research and exhibit design, now starts the construction of the exhibits. Attention! It’s not “time off” from school; it is time when teamwork, problem-solving, and organization skills are developed and formed. It is also fun for students; probably the best part of the process.

Create small teams with specific roles and responsibilities; roles can be alternated. Make a clear construction plan (list of tasks, who will complete them and when should be done) and a list of all the materials, supplies and equipment necessary to construct your exhibits. Update regularly your plan and make the necessary adjustments on time. You can use the relevant worksheets (see Student's Worksheets**)**.

**C. Post-Production:**

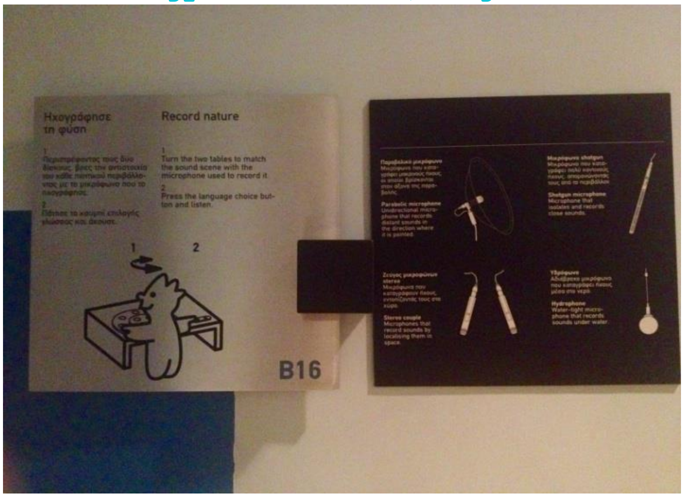
A public opening of the exhibition is a significant event for students' works and a tangible point for evaluation from the general public and other school students' teams. The opening event can include a celebration with the participation of parents, students' teams, teachers, museum staff, and all who contributed to the design of the exhibits. Students attend the opening and act as greeters, explainers, presenters or evaluators and interact with visitors in a variety of ways. Different strategies can be followed. For example, the public opening of the IRRESISTIBLE exhibition in Greece was realized with the participation of students and teachers involved and their parents in Athens and Crete simultaneously. More specific, each exhibit team from Athens (Eugenides Foundation) given a brief presentation about their exhibit to the exhibit teams in Crete (Natural History museum) and vice-versa. The presentations were made through skype. Then, the participants interacted with the exhibits under the interpretation and guidance of the students.

After the public opening, the exhibition can be kept for long as you can by organizing other events such as night activities. If the exhibition is installed at the museum, this gives the opportunity to other schools and education community members to visit the students' exhibits. Furthermore, media coverage may attract more visitors to see the exhibition. To this end, the IRRESISTIBLE exhibition of Greece was presented in the European Museums Night where Eugenides Foundation participates officially. This event was an exciting culminating event for students and excellent promotion of the project. To this end, a press release was prepared and sent to the mass media in order to encourage as many people as possible to attend and recognize the efforts of students. In the framework of the European Museums Night, students from Greece attend the event as exhibit designers. They also served as docents or explainers. They were stationed at each exhibit, encouraging visitors interaction with the exhibits, assisting them (if necessary) and posing or answering questions.

**Instructions or interpretations accompany an exhibit**

Provide information in small sections and with simple understandable proposals and not altogether in a single text. The use of labels with explanatory texts, diagrams, etc., should be limited to a minimum level (but no less than it should be!). In accordance with the type of text, the text length should not exceed 1000 characters. The instructions are always positioned in a place with good visibility and close to the handling points of exhibit. Provision for disabled people must be taken into account (see as example Table 7.3: Exhibit B16).

**Table 7.3: Exhibit B16: "Record Nature" (Interactive Science &Technology Exhibition, Eugenides Foundation)**




5

# Evaluation

# Lesson 8:

# Evaluation of students' knowledge

**Duration:** 90 minutes

**Objectives:** Through this final activity we want students to:

- actively reflect on their gained knowledge on RRI and Nanotechnology
- check their knowledge

Beyond the Irresistible student questionnaire, students' learning is assessed in every lesson through:

- students' answers in worksheets, specially developed for modules' implementation
- activities for homework

Additionally, the final science exhibits students developed can be used to assess their knowledge on RRI issues and on nanotechnology (see Appendix, table 7.4).

Finally, certain tasks could be assigned to students as the following:

**1. Match the prefix to the size and write down an object of the appropriate size**

| **Prefix** | **size** | **Suggested object** |
|---|---|---|
| Giga | 0,000000001 | |
| Micro | 1.000 | |
| Nano | 0,000001 | |
| Kilo | 1.000.000.000 | |

**2. Write down your height in nanometres**

……………………………………………………………………………………………………………………………

**3. Arrange the objects listed in ascending order:**

a) an acre
b) a bacterium
c) a drum
d) an electron
e) the Galaxy
f) a hydrogen ion
g) the Moon
h) an oxygen molecule
i) a virus
j) a man

| | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |
| 10 | |

**4. Decide whether the following statements are true or false:**

| | **true** | **false** |
|---|---|---|
| To be called a nanomaterial, all 3 dimensions of the material have to range between 1 and 100 nm | | |
| The properties of nanomaterials differ considerably from those of the same substances in the micro- and macro-scale | | |
| A hydrophobic material is the one on which a drop of water spills out | | |
| Colloidal gold particles undergo aggregation if we add egg white to the solution | | |

| | | |
|---|---|---|
| In the absence of a magnetic field, ferrofluids behave as liquids, while in the presence of such a field, they demonstrate the properties of solids | | |
| The properties of a substance (element, chemical compound) are constant regardless of the degree of its fragmentation | | |

5. **Complete the sentences:**

**a)** The smaller the object, the ................................ the ratio of its surface area to the volume
**b)** The smaller the surface area of the reactants, the .................................. the reaction.
**c)** In the case of self-cleaning surfaces, the ....................... effect is used.
**d)** The change of the colour of gold depending on the degree of its fragmentation is an example of the change in the property of ....................................

6. **Suggest (and describe) an experiment aiming to investigate the reactivity of a substance depending on its surface area (formulate a hypothesis, specify dependent, independent and controlled variables, describe the course of the experiment and the method of data collection)**

.......................................................................................................................................................
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7. **Please determine whether you agree or disagree with the following statements**

| | Agree | Disagree |
|---|---|---|
| **Scientists should publish their research findings only for other scientists.** | | |
| **It is fine if a male researcher prefers to hire male students over female students, even though both have the same qualifications.** | | |
| **Scientists should present their research to the general public in popular lectures.** | | |
| **To decide what topics to research, scientists should consult with community representatives, such as people who work for nature conservation, human rights, and consumer rights.** | | |
| **People who create products do not need to think about the possible risks of these products.** | | |
| **Scientists should report their findings to the government, even if they are not required to do so.** | | |
| **Government, businesses and scientific communities, are not motivated by the same interests so they cannot work together.** | | |
| **Scientists should spend part of their research budget to present their research online, in a free and open way.** | | |

| | | |
|---|---|---|
| **Having high ethical standards can help ensure high quality results in science and technology.** | | |
| **If it is clear that doing research has negative implications or risks, scientists have the duty to stop conducting this research.** | | |
| **Women and men should have equal rights and responsibilities in scientific research.** | | |
| **One of the roles of government is to prevent harmful or unethical practices in research and innovation.** | | |
| **Scientists have an obligation to make their research findings available to everyone.** | | |

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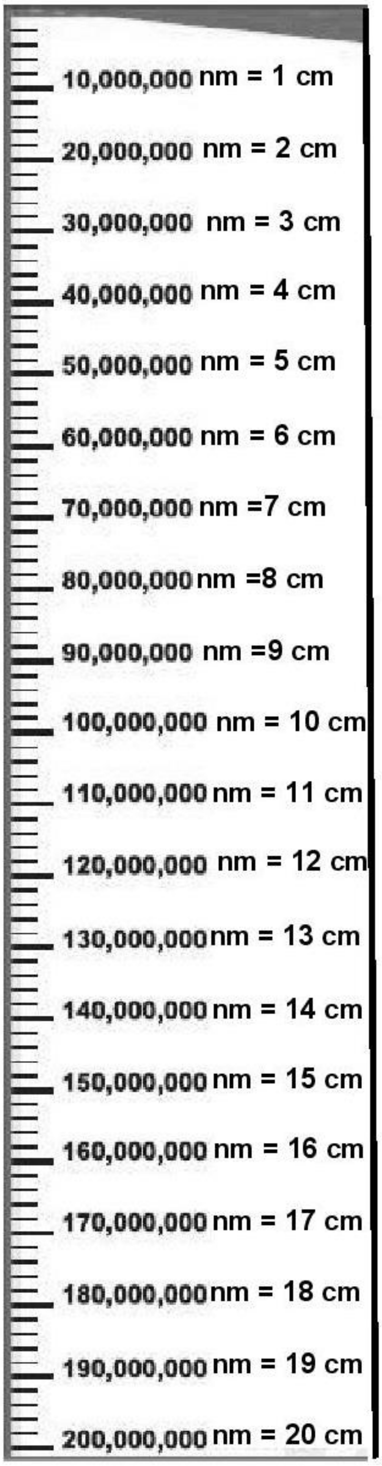
# 7

# Appendix

# Nano ruler


10,000,000 nm = 1 cm
20,000,000 nm = 2 cm
30,000,000 nm = 3 cm
40,000,000 nm = 4 cm
50,000,000 nm = 5 cm
60,000,000 nm = 6 cm
70,000,000 nm =7 cm
80,000,000 nm =8 cm
90,000,000 nm =9 cm
100,000,000 nm = 10 cm
110,000,000 nm = 11 cm
120,000,000 nm = 12 cm
130,000,000 nm = 13 cm
140,000,000 nm = 14 cm
150,000,000 nm = 15 cm
160,000,000 nm = 16 cm
170,000,000 nm = 17 cm
180,000,000 nm = 18 cm
190,000,000 nm = 19 cm
200,000,000 nm = 20 cm

# NanoGold Sample preparation

## PREPARATION OF STOCK SOLUTIONS

***Initial products:***

- ✓ 1.00 g solid chloroauric acid (HAuCl4)
- ✓ 0.5g sodium citrate dihydrate (C6H5Na3O7 . 2H2O)
- ✓ Distilled water

*Note: the solid chloroauric acid should be kept in a refrigerator.*
*The products, particularly chloroauric acid, are irritable to skin. Wear protective gloves and glasses when handling the liquids.*

1. Chloroauric acid stock solution, concentration 10,0 mM: Dissolve 1.00 g of solid chloro-auric acid ($HAuCl_4$) into 250 ml of distilled water. Place the solution in a brown bottle (or cover a clear bottle with e.g. tinfoil) and keep from sun. Solution stays usable for several years.
2. Sodium citrate stock solution, concentration 1% (38,8 mM): Dissolve 0.50 g of sodium citrate $Na_3C_6H_5O_7 . 2\ H_2O$) into 50 ml of distilled water.
3. Table salt NaCl solution, concentration 1 M: Dissolve 0.5 g of table salt (NaCl) into 10 ml of distilled water.

## PREPARATION OF NANOGOLD SOLUTION

***Materials and equipment:***

- ✓ 1 ml 10,0mM chloroauric acid solution
- ✓ 1 ml 1% sodium citrate solution
- ✓ 40 ml distilled water
- ✓ Heater and mixer, preferably a combined magnetic stirring plate with heating
- ✓ Thermometer up to 100 °C
- ✓ Heat proof Erlenmeyer flask, 100 ml
- ✓ Graduated cylinder 100 ml
- ✓ Pipettes

***WARNING :***
*Auric chloride is caustic and is harmful to your health if swallowed (hazard classes R 22 and R 34). Wear safety glasses, gloves and a lab coat. Consider working in a Fume hood.*

i. Measure 40 ml of distilled water and place in the Erlenmeyer flask
ii. Add 1 ml of chloroauric acid solution.
iii. Bring the liquid to boil on the heater plate, mixing slowly.
iv. Add 1 ml of sodium citrate solution. Allow the mixture to boil gently (you may need to adjust the heater to smaller power) for 10 minutes, mixing it more vigorously.
v. Remove flask from the heater plate and allow to cool.
vi. For comparison, repeat this procedure with 0.5 ml Au solution to 40 ml distilled water. Compare the time needed for the change of color to develop. If you increase the citrate concentration in a further experiment, the colloids will obtain a deep violet color, which is a result of a different size of the emerging colloids.

# Ferrofluid Sample preparation

(http://vlab.ntse-nanotech.eu/NanoVirtualLab/dataentitys/show/163)

***Materials needed:***

- ✓ Digital Scale
- ✓ Hot plate with magnetic stirrer
- ✓ Steel Wool
- ✓ Ferric Chloride ($FeCl_3$)
- ✓ Oleic Acid
- ✓ Distilled water
- ✓ Ammonia Solution
- ✓ Kerosene
- ✓ Graduated Cylinder
- ✓ Heat Resistant Glass Bottles (you can use beakers)
- ✓ Filter Paper
- ✓ Beaker
- ✓ Funnel
- ✓ 5 ml pipette
- ✓ Spatula
- ✓ Pipette bulb

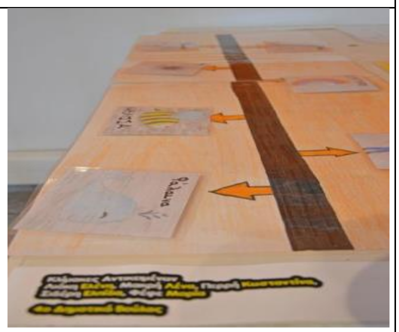
***WARNING:*** *This experiment should be done in the fume hood due to the dangerous vaporization of ammonia solution.*

i. Weigh 20,272 grams of ferric chloride in the beaker using the digital scale.
ii. Add 50 ml of distilled water to the beaker and dissolve $FeCl_3$ in order to prepare 1,5 M $FeCl_3$ solution. The brown solution is formed.
iii. Take 5 ml of ferric chloride solution by using a pipette with bulb and pour it into another beaker.
iv. Cut a piece of steel wool and put it in the 5 ml solution. Stir the solution until all the steel wool is chemically dissolved and no more can be dissolved. As steel wool reacts with the solution, ferric ions -Fe (III) are reduced to ferrous ions- Fe (II) and the brown colour of the solution turns greenish.
v. Filter the greenish solution of ferrous chloride by using filter paper and funnel.
vi. Take another 10 ml of ferric chloride solution and pour into ferrous chloride solution-the light green solution.

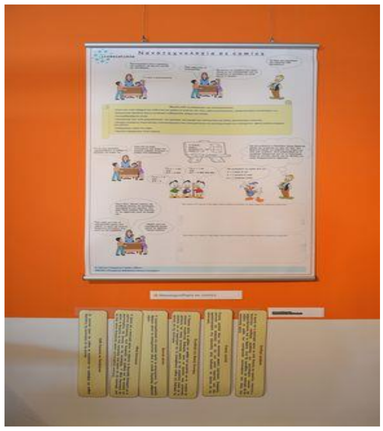
vii. Measure 75 ml of ammonia solution by using a graduated cylinder and pour it into the ferric/ferrous chloride solution. You can see magnetite forming in black colour.
viii. Heat the solution until it starts to boil while stirring with magnetic stirrer
ix. Take 2,5 ml of oleic acid and pour into the boiling solution.
x. Continue boiling the solution for about 1 hour in order to evaporate all the ammonia.
xi. When all the ammonia is evaporated oleic acid coated magnetite particles can be seen at the bottom of the bottle.
xii. Remove the mixture from heat and let it cool down to room temperature.
xiii. Decant the water and leave magnetite in the beaker.
xiv. Add 50 ml of kerosene. Kerosene will dissolve all the oleic acid coated magnetite. Now, you have your very own Ferrofluid.

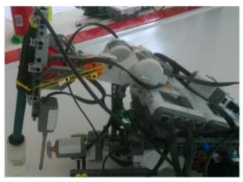
# Example of exhibit development by students the IRRESISTIBLE exhibits in Greece (phase A)

**Table 7.4 – Exhibition Matrix**

| Level | Type | Title | Description | RRI aspects | Exhibit |
|---|---|---|---|---|---|
| Primary Education | *Board Game* | "Nano-Snake" | Children (until four players) will have fun as they roll the dice and move up (or down) the numbered grids by answering questions on Nanotechnology concept until to reach the end of game. | Science education |  |
| Primary Education | *Board Game* | "Nano-City" | Children roll the dice and follow a certain pathway. On the way they answer questions on Nanotechnology concepts and accordingly they try to reach the end of game. | Science education |  |
| Primary Education | *Interactive Poster* | "Scales Objects" | Visitors will attempt to set the suitable object-card in the right place in the scale of objects which vary (from nano to macro). At the end of the process, they can compare their answer with the correct. | Science education |  |
| Primary Education | *Interactive Poster* | "Nanotechnology" | Visitors will attempt to set the suitable object-card in the right place in the scale of objects which vary (from nano to macro). At the end of the process, they can compare their answer with the correct. | Science education |  |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |
| Primary Education | *Experiment* | "Nanospray" | Visitors are invited to thrown water with the dropper on the surface of two different boots. The one boot is waterproof which has been sprayed with a special spray using nanoparticles. The other one is normal (unsprayed). Visitors compare the different outcomes and by this way they introduce themselves to the process of converting the properties of materials using nanotechnology. | Science education - Engagement |  |
| Primary Education | *Informative Poster* | "Nanotechnology" | Information on Nanotechnology concepts and applications. | Science education |   |
| Primary Education | *Interactive Game* | "Scale-Souvlaki" | This exhibit consisted of two parts: The first part is a poster where visitors will attempt to put the object-card in the right place in the scale of objects which vary (from nano to macro).<br>The second part is an artefact (in form of souvlaki) which demonstrates the correct order of the previous or similar objects in view of scale. Visitors use the second part as point of reference in order to compare their answers to those already given at the | Science education |  |

| | | | | | |
|---|---|---|---|---|---|
| | | | first part. | | |
| Lower Secondary Education | *Interactive Poster* | "Nanotechnology in comics" | Visitors are introduced on the concepts of Nanotechnology and Nanoparticles, especially in size-dependent properties, in format of cartoons and various examples. Also RRI aspects are presented in separate removable cards. Afterwards, visitors are invited to follow a discussion regarding the size of nanoparticles and their effects on the health and environment in relation with RRI issues. Following the discussion, they have to select the two appropriate RRI aspects-cards and thereafter, they place them in the adequate place. The next visitor can change the cards in case he/she does not agree with the selected cards. | Engagement - Gender Equality - Science Education - Ethics - Open Access - Governance |  |
| Lower Secondary Education | *4 Digital (Interactive) Posters* | "Nanotechnology in the service of Medicine" | Visitors will interact with a PPP slides which guide them to four different interactive posters concerning Nanotechnology in the service of Medicine. In addition, a scratch application is available concerning RRI issues. At the end of this application, visitors are asked to give their opinion which is recorded for the next visitor in order to see it. | Engagement - Gender Equality - Science Education - Ethics - Open Access - Governance |   |

| | | | | | |
|---|---|---|---|---|---|
| | | | | |  |
| Lower Secondary Education | *Digital quiz* | “NanoQuiz” | Visitors are introduced to nanotechnology via a playful android application, answering questions and learning information about:<br>- Nanoscience<br>- Its relation with society<br>- Nanotechnology and art<br>- Peculiar properties of nanomaterials<br>- How small is nano etc…<br>Visitors also had the chance to study and learn more in a separate sector of the app, where all information was gathered. | Engagement<br>-<br>Gender Equality<br>-<br>Science Education<br>-<br>Ethics<br>-<br>Open Access<br>-<br>Governance |  |
| Lower Secondary Education | *Interactive poster and model* | “Nanomedicine” | Visitors get information about nanomedicine, its advantages and the potential risks involved. The poster also describes the mechanism nanorobots use to trace down and exterminate cancer cells. A moving model of the nanorobot is functioning nearby. Finally visitors are called to question themselves and vote under what circumstances they would use nanomedicine. | Ethics<br>-<br>Science Education<br>-<br>Engagement | <br><br> |

| | | | | | |
|---|---|---|---|---|---|
| Lower Secondary Education | *Informative poster & experiment* | “Hydrophpbic materials- When science labs imitate nature” | Visitors experiment with natural materials (leaves) and checks their hydrophobic properties by observing the way they interact with water drops. Then they try the same on a hydofhobic and a hydrophilic textile and they are called to characterize them as such by placing the correspondent card underneath them. Finally, visitors interact with a model of the 2 fabrics’ structure made by Styrofoam and pins. The poster gives extra information on hydrophobic properties and biomimicry. | |  |
| Upper Secondary Education | *Introduction Video – Experiment – Digital Quiz* | “A paper holding an umbrella” | This activity consisted of three stages. At the $1^{st}$ stage, a video introduces the visitors to the applications of nanotechnology such as waterproof materials using nanoparticles. At the $2^{nd}$ stage, the visitors are asked to observe this type of materials by executing an activity: They throw water with the dropper on the surface of a paper (which is sprayed with waterproof “nano”spray). At the final stage, visitor is invited to learn how the hydrophilic materials (nanomaterials) work by answering a digital quiz on a tablet. | Engagement - Science Education |    |
| Upper Secondary Education | *Informative Poster* | “NANO-Tetrahedron Origami” | A poster provides information on how nanoparticles shelf- | Science education - | |

| | | | | | |
|---|---|---|---|---|---|
| | – *Tetrahedron Origami sheet* – *Video guide for construction of Tetrahedron Origami crafts* | | assembling in Tetrahedron structures, creating in this way a variety of different objects such as catalyst used in industry or drug carries used in medicine.<br>After that, visitors are asked to construct a small tetrahedron origami by following the instructions provided through a video clip.<br>RRI aspects are illustrated in the different sides of tetrahedron. | Engagement | <br><br> |
| Upper Secondary Education | *Digital Game* | "From the Nanotechnology to the Prodigy" | This game consisted of a PPP presentation in combination with a scratch application. Visitors -through the presentation- opt to learn on subjects of breast cancer or HIV virus by selecting gender and disease. After, they play a digital game where they control a nano-robot which attacked to the cancer cells or HIV virus, trying to destroy them. When the game is finished, the exhibit tries to put forward a query | Science education - Engagement - Ethics - Gender equality |  |

| | | | | | |
|---|---|---|---|---|---|
| | | | to the visitors on what will happen in case the robot attacks by mistake to a healthy cell. | | |
| Upper Secondary Education | *Demonstration experiments & information poster* | "Experiments corner – Nanoapplications" | Students in collaboration with the research center present visitors current nanotechnology applications and explain the underlying nanoscience. They also perform impressive experiments using ferrofluids they produced themselves, self-cleaning materials and nanogold colloids. Visitors could get more information about current nanotechnology research from the poster. | Science education - Engagement |   |