

Geoengineering: Climate Control?

This module on Climate Geoengineering was developed by science teachers within the EU-project IRRESISTIBLE (FP-7 project number 612367): www.irresistible-project.eu.

Geoengineering can be described as the deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change, especially global warming caused by greenhouse gases emissions. Several methods have been considered for this purpose. They can be grouped into two categories: those relating to the removal of CO₂ from the atmosphere and the ones that change Earth's capacity to absorb solar radiation. So far, the disadvantages of Geoengineering approaches have tended to outweigh the advantages in most minds that have turned to the issue. However, in recent years such proposals have received more support from a number of prominent scientists and economists, with calls for more research into their feasibility, costs, side effects and frameworks for implementation.

With this module, students, research about Geoengineering — which is presented to them as “maybe another conspiracy theory? — more precisely about its strategies in mitigation of Global Warming. It is intended that students understand the Biological/Physical/Chemical principles behind each strategy and, also, its advantages and disadvantages. In a second phase, students reflect about the criteria that research and innovation about this topic should respect in order to be considered responsible, and develop an exhibition as a way to educate the community about this topic.

This module comprises 6 steps, named *Engage*, *Explore*, *Explain*, *Elaborate*, *Exchange* and *Evaluate*, which are terms derived from the *5E-model for Inquiry-Based Science Education*, complemented by a 6th and a 7th E (Exchange and Empower). By using this method, students are actively involved in the subject and are stimulated to search for information themselves.

The process of exhibits' construction and presentation allows students to move beyond analysis and discussion, creating an opportunity for them to participate in (and even to instigate) community action on socio-scientific controversial matters. Exhibitions about Responsible Research and Innovation (RRI) can raise questions, elicit personal reflection and stimulate conversations between students and visitors, transforming both of them into learners.

Responsible Research and Innovation (RRI) is a term coined by the EU, where the goal is to bridge the gap between the scientific community and society. Science and industry need to question whether certain innovations are always wanted by society: although they have the power to transform our lives, they also create new risks and new ethical dilemmas. RRI seeks to bring these issues into the open, anticipate the consequences and directions of research and innovation, and involve society in discussing how science and technology can help create the kind of world and future we want.

This module is aimed at students from 12 to 18 years old. Climate Change, its causes and consequences should be a topic already addressed by students and such concepts must be clear so that students can understand not only the potential of Geoengineering but also the risks associated with this scientific field and, as such, the importance of Responsible Research and Innovation.

Learning activities based on the 7E-model

Engage

Task 0 | This initial task is only to be used if students are new to the theme of Climate Change or if teacher feels it's necessary for them to remind or refresh their ideas concerning this topic. It is important that students are aware of what Climate Change is in order to fully understand and benefit from the Climate Geoengineering module. Teacher can give **text 0** in advance to students and have them answering the questions of the task, or can have them trying to answer without giving them prior access to the text.

Task 1 | In this task students are invited to analyze three cartoons related to Climate Geoengineering and come to their own interpretation of them. This task has the purpose of promoting a first glimpse on Climate Geoengineering to students, more precisely on some of its strategies, but also letting them anticipate some of the criticisms that have been made to this Climate Change mitigation approach. Also, through the pictures, teacher can start to **approach some issues of RRI**, namely the contribution of science and scientists and the role of the industry and their responsibility towards the change of climate.

Task 2 | In this task students have to explore some resources on Climate Geoengineering and, in pairs, build a concept map /or a draw that represents their own understanding of the theme. Then they have to present it to their classmates and justify their choices. The chosen resources present the theme of Climate Geoengineering as being related to *conspiracy theories*. This has the purpose to raise interest and engage students in the subject. It is also crucial, for their true engagement in the module and in the subsequent tasks, that they understand the purpose of their whole work: they, as active citizens, have the **power to warn others** and **instigate them to change behaviors and ways of thinking**, throughout an exhibition about RRI in Climate Geoengineering. Through the concept map/picture drawings activity and the confrontation of the several maps/pictures, questions or issues will emerge that need to be clarified in relation to student's doubts and misconceptions. This activity has also the purpose of making clear to students what they already know and what they don't know yet about the topic, but need and want to find out.

Explore

Task 3 | It is intended that students now dig deeper into the theme, understanding that there are various strategies of Climate Geoengineering that are currently being researched and/or officially being mentioned in important reports. There are two versions of this task. For older students, there is **Version 1**, in which they have to identify the main aspects that distinguish the various strategies and also to understand the main biological, geological, physical and chemical principles behind each strategy. Some strategies can be more emphasized by you according to your own subject, lesson plans and curriculum. Class will be divided into 2 groups regarding the two main strategies of Climate Geoengineering: Solar Radiation Management (SRM) e Carbon Dioxide Removal (CDR); then, these 2 groups will be divided into subgroups, each responsible for, at least, one Climate Geoengineering technology (like, for example, Surface Albedo Modification). They will need to perform an oriented research (through given resources) that enables them to answer some questions: What are the biological/chemical/physical principles on which each technology rely on? What are

Example of Citizenship Competences' formative assessment – PT 1



the advantages and disadvantages of each technology? For younger students, the **Version 2** of the activity includes a set of more oriented questions for their research.

Task 4 | This task is an experimental activity through which students can investigate the effect of surface color in Albedo, since painting rooftops white is one of the Climate Geoengineering strategies of Solar Radiation Management. It's an activity adapted from the "Amazing Albedo" activity developed by the American Museum of Natural History. It's an opportunity for students to develop experimental/research skills. It is given a protocol, but also teacher has the possibility of having students designing their own investigation. In this second option students receive a set of orientation questions. The data retrieved from the experimental activity can be used by students to revise the knowledge they have built so far.

Explain

Task 5 | Each of the 2 large groups will need to write a collaborative document (poster, presentation or a virtual board): each subgroup will be responsible for sharing with classmates (of the same large group) their findings. Next, each of the 2 groups must share with the other group their knowledge: students are invited to present and discuss the collaborative documents. Also, each group has to create (previously) an assessment instrument (an online questionnaire) that allows them to assess their classmates' knowledge after their presentation. Also, at the end of this phase, each student has to build a concept map that incorporates what they have researched and, also, what their classmates have presented – therefore, integrating all knowledge. Students must be aware of these two tasks (questionnaire and concept-map) before the sharing-session takes place: this has the purpose of capturing their attention and also instigating their participation during the session.

Elaborate

Task 6 | This task has the purpose of explicitly introducing RRI to students, since it's a somewhat new and not very easy topic for students to understand. After reading an initial text, they need to come to their own definition of RRI and also to what they think each of the 6 RRI dimensions means to them. Next they will need to make the correct correspondence between the RRI dimensions and their definitions. This explicit approach to RRI is intentional; from there, in the subsequent tasks, students will make a better connection between RRI (in abstract) and the theme of their module – Climate Geoengineering.

Task 7 | This task has the purpose of having students researching news on Climate Geoengineering strategies that have been implemented around the world. It is intended that students find in the news some aspects that are related to RRI (where all citizens in agree with the measure, who was involved in the decision, who should have been involved and why, etc.). If such information is not present in the text, students should, nevertheless, try to answer to the questions taking into account their own opinion. Then they need to present the news and their thoughts on it to their classmates.

Task 8 | In this task students will have a discussion session on Climate Geoengineering – that will be promoted by the teacher taking into account some of the guiding questions provided below. In order for students to be

prepared for the discussion, they will need to read the given texts that relate RRI (and some of its dimensions) and Climate Geoengineering – they should take notes from them for the discussion session.

Questions for stimulating the discussion in task 8

- Is it appropriate for researchers or companies to own the intellectual property rights to climate-altering technologies? Why?
- Should nature (and natural resources) be regarded as a set of resources for human beings to use, or as an object of respect or reverence?
- Some might object to geoengineering proposals because they may result in the “loss of the natural”. For others, it might appear to be no different from any other kind of human interaction with the non-human world.
- Climate change is likely to affect water supplies, food supplies, human health, and subject some regions to flooding and others to drought. Geoengineering might help avert some of these outcomes. However, as a large-scale intervention in the Earth’s physical, biological or chemical systems and cycles, it carries its own risk of adverse effects. How should benefits and burdens of geoengineering technologies be distributed?
- Does it matter if the risks could not have been known at the time the decision was taken?
- Can geoengineering technology be developed for commercial profit?
- The risks most commonly associated with geoengineering are risks of unintentionally disrupting complex ecological systems. Another risk is that geoengineering technologies might be intentionally misused, for example, in terrorist or military attacks (we can imagine that a malevolent agent might use such technologies to, for example, induce drought or flood in an enemy territory).
- A country that would benefit from a global temperature rise might seek to induce such a rise through geoengineering methods even if this would harm most other countries.
- Geoengineering techniques for combating climate change can be regarded as treating symptoms (such as temperature rise or elevated carbon dioxide levels) rather than causes (i.e, carbon emissions from human activities).
- Who should pay for the research and its implementation? Who should absorb the risks associated with research on geoengineering interventions and their implementation?
- Should Geoengineering research should be conducted with the public good in mind? Why?
- Who should participate in the process of decision-making concerning geoengineering? Why?
- Who would end up controlling geoengineering systems? Governments? Private companies holding patents on proprietary technology?
- What if one country wants it a couple of degrees warmer, and another country a couple of degrees cooler? Would it be possible to tailor the climate of each region of the planet independently without affecting the others? If we proceed with geoengineering, will we provoke future climate wars?
- Alongside those who will be made better off, some of those most vulnerable to the effects of climate change might end up being harmed.

Elaborate, Exchange & Empower

Task 9 | In this task students are asked to elaborate a Manifest entitled "Responsible Climate Geoengineering: is it possible? If so, how?" which represents a set of guidelines on RRI on Climate Geoengineering to be presented to the community in the final exhibition that the class has to prepare. This final exhibition is very important, since it serves as a platform for students to share with others what they've learned and also share their own opinions and concerns about the topic. Class should be divided in groups, each with preferably 6 students since there are 6 dimensions of RRI. Each student is responsible for one dimension. After deciding on what the Manifest should look like, each group member will then establish a relation between Geoengineering and his/her RRI dimension, contributing to the final object. Each object built by each group must have the 6 RRI dimensions. Students must be aware of the

importance of having groups choosing different objects as a warrant of a richer exhibition. Whatever the exhibit object chosen, they need to have in mind that it must: a) contemplate all of RRI 6 dimensions; b) interact with the visitor, stimulate interaction between visitors, and make them reflect about the theme. The Empowerment dimension relies on the notion (that has to be **explicitly discussed with students**) that students are **active citizens**, capable of acting collectively with the purpose of warning others about RRI issues in Climate Geoengineering and change their way of thinking. This action, funded on scientific research (therefore, not on common sense), may take the form of an exhibition produced by students.

Evaluate

Self and peer evaluation is present at different moments of the module:

Explain | At the end of this phase, students have to build a concept map integrating what they have learned throughout the performed research and also throughout the sharing-session. After that, they can compare this map with the initial one (from the Engage phase); in doing so, they will be able to be aware of their learning as well as the initial incorrect ideas. Both teacher and students will evaluate the presentations performed by the groups. Also at the end of the Explain phase, students need to prepare a questionnaire to test the effectiveness of their presentations in allowing their classmates to better understand the issue that was presented.

Elaborate, Exchange & Empower | Students should evaluate the exhibit objects built by their group (self-assessment), the ones built by other groups (hetero-assessment), as well as the final exhibition. Students will produce a questionnaire (online or printed version) that enables them to assess the impact of their work on visitors' understanding of the topic and on their awareness regarding RRI in Climate Geoengineering.

There are **rubrics** for the assessment of the concept map, presentation, exhibit object and exhibition to be use by both teacher and students. Students must have **prior access** to the assessment criteria in order to have the opportunity to perform at their best.

Rubrics

Below you will find the rubrics to be used by you and your students at different moments of the module.

Concept map

	3	2	1	
1. Understanding of concepts and terminology	Shows an excellent understanding of the concepts and sub-concepts. The concepts and sub-concepts are used accurately.	Shows a good understanding of most concepts and sub-concepts, but makes up to two inaccuracies	Shows a weak understanding of most concepts and sub-concepts, or makes up more than two inaccuracies	___/3
2. Relationships between concepts	The map identifies all the important concepts and reveals complex thinking about the significant relationships between them.	The map identifies several important concepts and awareness about the most significant relationships between them	The map identifies few important concepts revealing little reflection about them or presenting some inaccurate relationships	___/3
3. Arrangement of Concepts	Very well organized map with a logical format. Main concept is easily identifiable; Non-linear structure (sub-concepts properly branching from the main idea) providing a very complete vision and interconnection of ideas.	Most of the map is easy to read; the main concept is easily identifiable; non-linear structure (most sub-concepts branching properly from the main idea) providing a complete and interconnected view of the main ideas.	Poorly organized map (confusing); the main concept is not clearly identified; the sub-concepts are not consistently branching off from the main idea; the map does not provide a complete view or interconnected ideas	___/3
4. Images and videos	Images and videos used are perfectly suited to the context and facilitate the understanding of the topic.	Most of the images and videos used fit the context and facilitate the understanding of the topic.	The images and videos are used inappropriately and excessively and do not facilitate the understanding of the topic.	___/3
5. Design	Great visual aspect; effective use of color and space to organize ideas or sub-themes and / or emphasis.	Good visual aspect; most of the time, color and space are used effectively to organize ideas or sub-themes and / or emphasis.	Disorderly aspect; weak visual aspect; weak use of color and space.	___/3
			Total	___/15

Presentation

	4	3	2	1	
1. Scientific Correction	Presentation revealing excellent domain of concepts and information	Presentation without any incorrections at the level of concepts or information	Presentation with some inaccuracies at the levels of concepts or information	Presentation with several errors at the level of concepts or information	___/4
2. Justification of argumentation	All group members reveal a deep knowledge of the content of their work and justification of argumentation	Most group members reveal a good knowledge of the content of their work and justification of argumentation	Several group members have a poor knowledge of the content of their work OR are unable to justify the arguments	The group members are not sufficiently prepared to defend aspects of their work; They do not have the knowledge or skills needed	___/4
3. Correction of the speech	Speech very well articulated and without grammatical inaccuracies or pronunciation and correct use of scientific language	Speech reasonably well articulated and without grammatical inaccuracies or pronunciation and scientific language	Grammatical lapses and difficulties of pronunciation and scientific language	Difficulty of speech and grammatical incorrectness, pronunciation and scientific language	___/4
4. Articulation between the group members	Excellent relationship between the various elements of the group; Logic and extremely well organized presentation	Good articulation among most group members. However, some of the elements did not prepare the presentation with the other members	Weak coordination between the various elements of the group. It is evident that some of them have not prepared the presentation	There is no link between the various elements of the group; unorganized presentation	___/4
5. Clarity and objectivity	Clear and objective exposition and evidence of the fundamental aspects	Clear exposition, but with some superfluous aspects	Clear exposition, but not objective; They were presented many superfluous aspects	Unclear exposition, not objective and no evidence of the fundamental aspects	___/4
6. Presentation of the information	The information is presented and unread	The information is presented but accompanied by some notes reading	Most of the information is read instead of being presented	The information is read instead of being presented	___/4
7. Ability to raise interest	Well-rehearsed presentation, without mishaps and effective in attracting attention and audience interest	Presentation with a few mishaps but effective in attracting attention and audience interest	Presentation with some mishaps and not always effective in attracting attention and audience interest	Presentation with mishaps and ineffective in capturing the attention or interest of the audience	___/4
8. Audiovisual support	It is used audiovisual elements of great quality to support or enhance the content of the presentation (pictures, diagrams / graphics, videos)	It is used audiovisual elements of quality but not properly exploits	It is used some audiovisual elements of poor quality	It is not used any visual element to support or enhance the content of the presentation (pictures, diagrams / graphics, videos)	___/4
9. Creativity	Extremely creative presentation both in terms of methodology and of the used materials	Presentation with various creative aspects in terms of methodology and of the used materials	Presentation little bit creative in terms of methodology and of the used materials	Uncreative presentation both in terms of methodology and of the used materials	___/4
10. Time management	Excellent management of time available for the presentation	The presentation exceeds slightly the time period that was intended for it	The presentation considerably exceeds the time period that was intended for it	Does not respect the time at all	___/4
11. Use of the voice	Audible speech throughout the presentation, good articulation of voice with audiovisual media	Audible speech for most of the presentation, with inflection and expression	Speech by large swings in voice volume, but expressionless	Speech inaudible, with monotonous, uninflected and expressiveness voice	___/4
Total					___/28

Exhibit object

	4	3	2	1	
1. Scientific Accuracy	Object revealing excellent domain of concepts and information	Object without any inaccuracies at the level of concepts or information	Object with some inaccuracies at the levels of concepts or information	Object with several errors at the level of concepts or information	___/4
2. Message	Clear and objective message, emphasizing the most important topics	Clear message, but with some superficial aspects	Clear message, lacking objectivity; many superficial aspects	Message not clear, lacking objectivity, and without emphasizing the main topics	___/4
3. RRI	There is a very explicit relationship between the topic and RRI	There is an explicit relationship between the topic and RRI	The relationship between the topic and RRI is not explicit	RRI is absent	___/4
4. Dimensions of RRI	All 6 dimensions of RRI are present	4 or 5 dimensions of RRI are present	2 or 3 dimensions of RRI are present	Only one dimension of RRI is present or none	___/4
5. Interactivity [object raise questions, promote individual and collective reflection, promote interaction between visitors, allow visitors to leave their mark?]	The object is very interactive	The object is moderately interactive	The object allows for little interactivity	The object is not interactive	___/4
6. Activism [object's ability to alert the visitor and motivate to action]	Very explicit	Moderately explicit	Little	Absent	___/4
7. Graphic aspect	Very aesthetically pleasant	Moderately aesthetically pleasant	Not very aesthetically pleasant	The object is not aesthetically pleasant	___/4
Total					___/28

Exhibition

	Excellent 5	Very Good 4	Adequate 3	Needs Improvement 2	Not Acceptable 1
ORGANIZATION: Information is well-organized for the visitor					
The big idea of the exhibit is clear					
There is a coherent relation between the objects throughout the exhibit					
Exhibit components make sense when viewed alone and together					
CONTENT: Information is clear, complete, and accurate and generates interest in the subject					
The exhibit makes it possible to develop the main idea					
There is a explicit connection between the exhibit and RRI					
The exhibition presents information, generates curiosity, changes ideas or feelings about the topic and/or motivates action					
The information presents scientific correction					
PRESENTATION: The visual appeal, organization and structure of the exhibit make visitor interpretation easy					
The overall graphic appearance of the exhibit fits to the theme					
The overall graphic appearance of the exhibit facilitates the understanding of the message					
EFFECT: The exhibit attracts visitors, holds their attention, and teaches the intended message.					
The exhibit is engaging; it attracts visitors and holds their attention					
The exhibit changes visitors' perspectives by enriching what they already know, teaching them something new, changing their ideas or feelings about the topic, or motivating them to action					

Adapted from D'Acquisto, Linda. (2006). Learning on display: Student-Created museums that build understanding. Alexandria, VA: Association for Supervision & Curriculum Development. pp. 116-117

Total score: _____

What do you elect as the most positive aspect of the exhibit and why?

What do you elect as the least positive aspect of the exhibit and why?

How could we improve? List one or two aspects.