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THE DESIGN OF FUTURE- AND PRESENT-ORIENTED TEACHING MODULES ON THE SCIENCE OF COMPLEX SYSTEMS FOR UPPER SECONDARY SCHOOL STUDENTS

Speaker
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Introduction

- Many researches and reports highlight that the young generation have difficulties in projecting themselves into the future, and in developing scope as future professionals.
- Science and technology are not perceived as positive possibilities for addressing societal challenges, but as sources of fears and unmanageable uncertainty.

The I SEE Project

- Our goal within the project: designing activities for developing future-scaffolding skills
  - Future-scaffolding scientific-hard skills
  - Future-scaffolding transversal skills

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The Research Questions

- What scientific concepts of complex systems science are worth addressing at the secondary school level and what teaching activities can be designed to foster their learning?
- Can this scientific knowledge be transformed into scientific skills? If so, what kind of activities can be designed?
- Can the scientific skills be turned into transversal ones that can be identified as future-scaffolding skills? If so, what kind of activities can be designed?




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The structure of the talk

- Presentation of three sets of activities
- Context of the pilot study with secondary school students, data collection and methodologies of analysis
- Main results

The activities

- Each research question corresponds to a set of activities
  - Activities to develop scientific knowledge
  - Activities to turn scientific knowledge into scientific skills
  - Activities to turn scientific skills into specific transversal skills that can be identified as future-scaffolding skills

Activities to develop scientific knowledge

- Lotka-Volterra predator-prey model
- Feedback Ted-Ed lesson
- Schelling's segregation model
- "Game of life" simulation

Each activity has

a disciplinary content

an application context

a form of presentation

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Activity	Disciplinary content	Application context	Form of presentation
Lotka-Volterra predator-prey model	non-linearity	ecological science	mathematical description and simulation
Feedback Ted-Ed lesson	feedback and circular causality	ecology, climatology, economics, computer science, molecular biology	video-lesson and interactive test
Schelling's segregation model	self-organization and emergent properties	sociological modelling	simulation
"Game of life" simulation	self-organization and emergent geometrical patterns	biology as modelled by computer science	applet based on a simulation

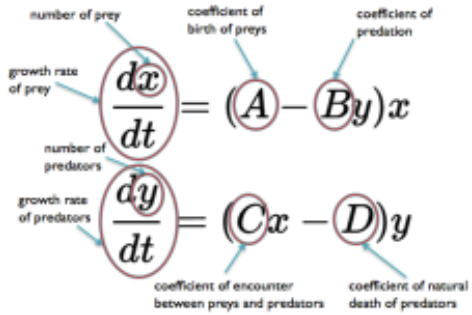
Lotka-Volterra predator-prey simulation

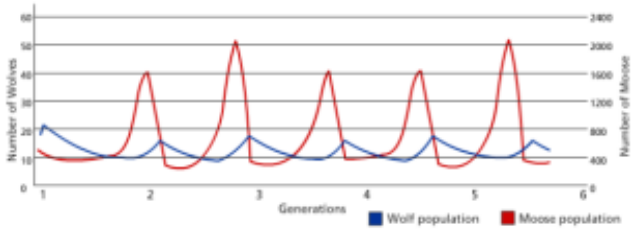
- Disciplinary content → concept of non-linearity
- Application context → ecological science
- Form of presentation → mathematical description and simulation

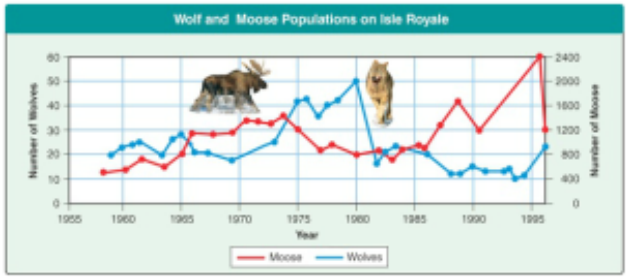



Lotka-Volterra predator-prey simulation

- Presentation of mathematical equations
- Simulation to make the students “see” the mode of operation of the model
- Results of simulation are compared with real data







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Feedback Ted-Ed lesson

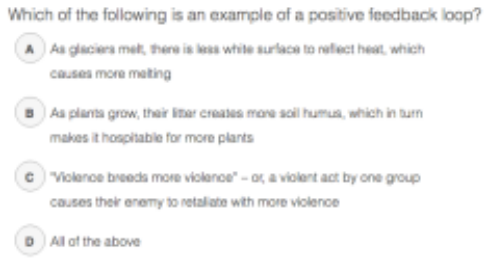
- Disciplinary content → concept of feedback and circular causality
- Application context → ecology, climatology, economics, computer science, molecular biology
- Form of presentation → video-lesson and interactive test




Feedback Ted-Ed lesson

- 5-minutes video-lesson

- Questions to allow an on-line learning about the topic



- Oral discussion and extension of the “span” of the concept

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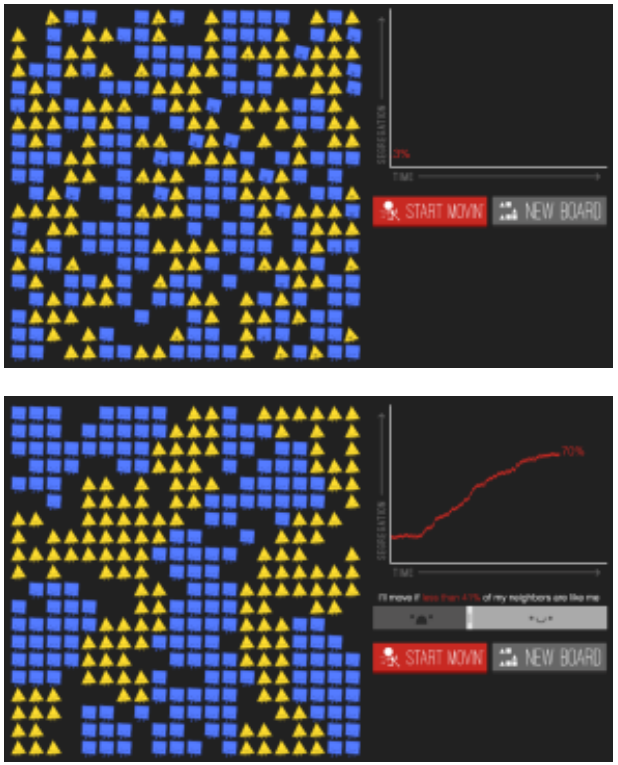
Schelling's segregation model simulation

- Disciplinary content → concept of self-organization and emergent properties
- Application context → sociological modelling
- Form of presentation → simulation

Schelling's segregation model simulation

- A "playable post" with a 2-dimensional world populated by squares and triangles
- Simple cohabitation rules convert themselves in scenarios of racial segregation



Agency can make the difference!

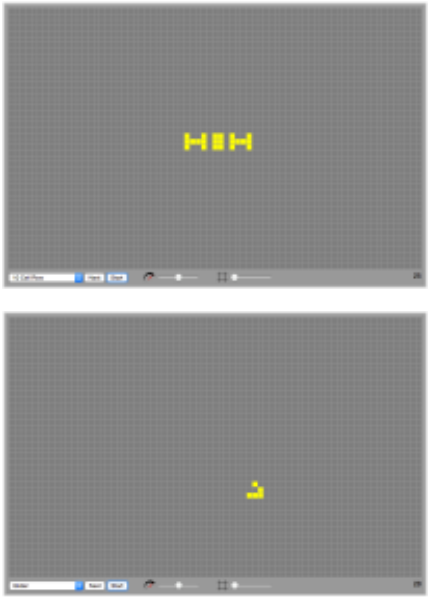
The “Game of life” simulation

- Disciplinary content → concept of self-organization and emergent geometrical patterns
- Application context → biology as modelled by computer science
- Form of presentation → applet based on a simulation




The “Game of life” simulation

- Students can choose their favourite initial conditions and leave the system evolve
- The emergent property is the formation of geometrical patterns starting from basic rules



Activities to turn scientific knowledge into scientific skills

- **Object:** The Biodiesel Story

- **Goal:** turn scientific knowledge into abilities to decipher a scientific text, in order to recognize and reformulate the logical and causal structure of the phenomena described in it

The Biodiesel Story

Use and Production of Bio Fuels: Biodiesel

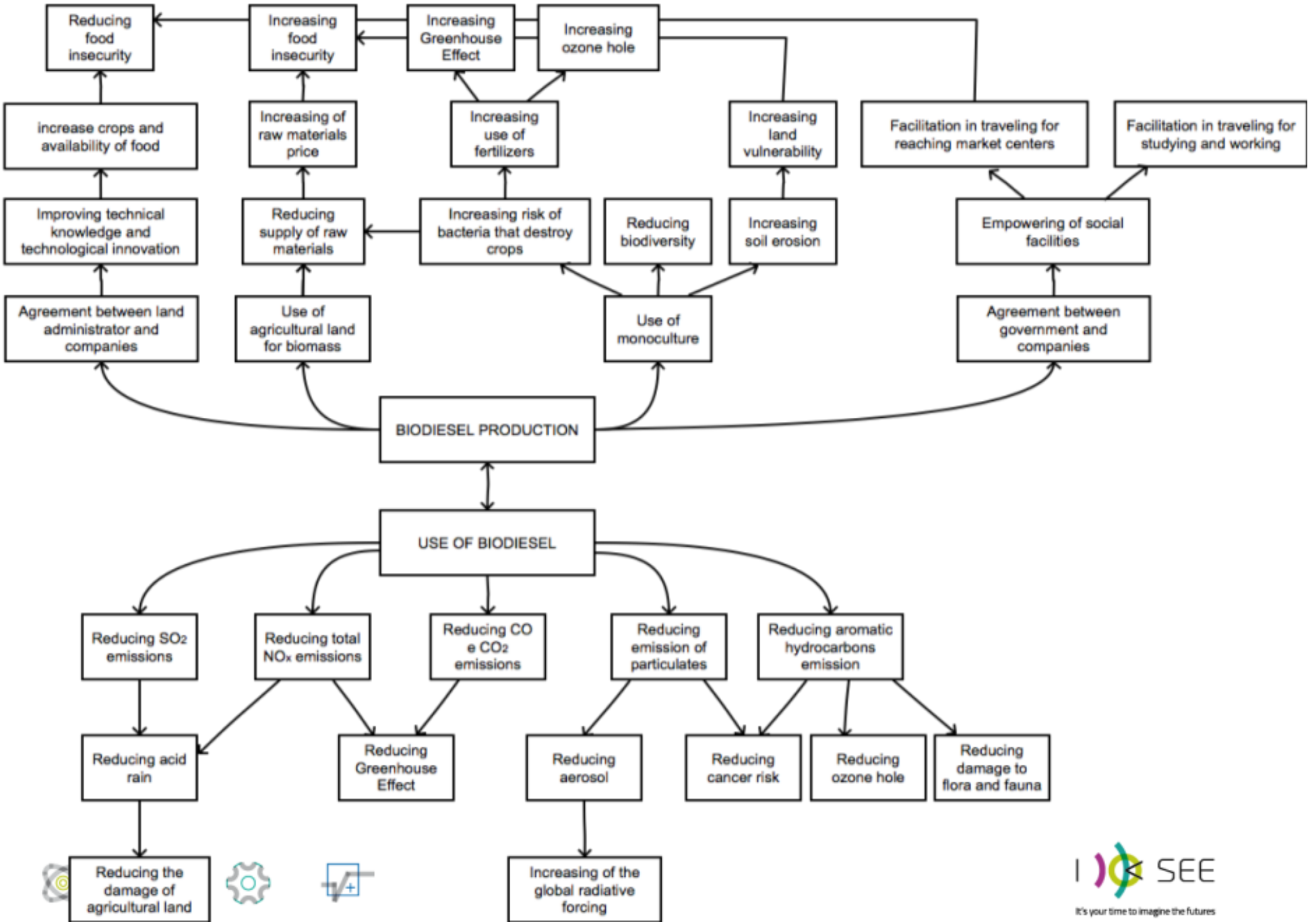
[…]

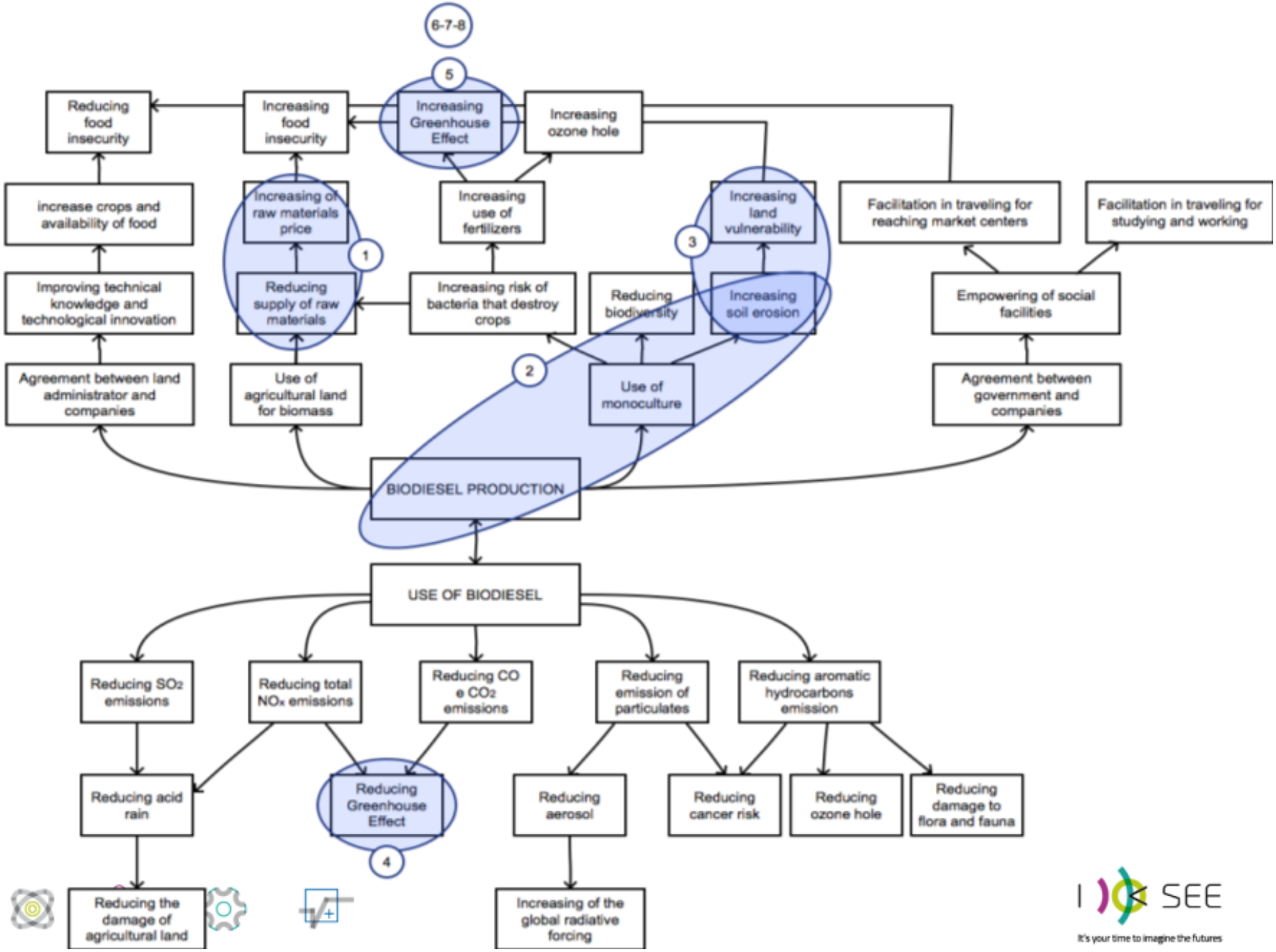
As to the reduction of emissions related to the mechanism of production of the biomass itself, using biodiesel brings about a reduction of two well-known greenhouse gases emission, CO (50%) and CO_2 (78,45%), since the carbon emitted during combustion is the one already existing in the atmosphere, fixed by vegetables during their growth. The carbon is not, as is the case with gasoline, the offset which has been sedimented under the earth's crust from time immemorial.

Besides, a 71% reduction of the emission of aromatic hydrocarbons is also reported; these compounds, that are naturally present both in oil and in carbon are extremely toxic to the environment, human beings and animals as well as to flora and are numbered among the substances responsible for the ozone hole.

Furthermore using biodiesel, sulfur dioxide (SO_2) emissions are almost totally eliminated; yet, these, once entered the atmosphere, interact with oxygen and water vapor and form sulfuric acid[4]. […]

An example of effect of the production process is the following: he conversion of terrains destined to the growing of plantations into areas where biodiesel is produced implies an increase of the price of raw materials in the Third World (compared to high transport costs of food imported from other Countries), resulting in the increase of food insecurity[7] both from the point of view of availability and of access to food. […]




6-7-8
5
Reducing food insecurity
Increasing food insecurity
Increasing Greenhouse Effect
Increasing ozone hole
increase crops and availability of food
Increasing of raw materials price
Increasing use of fertilizers
Increasing land vulnerability
Facilitation in traveling for reaching market centers
Facilitation in traveling for studying and working
1
3
Improving technical knowledge and technological innovation
Reducing supply of raw materials
Increasing risk of bacteria that destroy crops
Reducing biodiversity
Increasing soil erosion
Empowering of social facilities
2
Agreement between land administrator and companies
Use of agricultural land for biomass
Use of monoculture
Agreement between government and companies
BIODIESEL PRODUCTION
USE OF BIODIESEL
Reducing SO2 emissions
Reducing total NOx emissions
Reducing CO e CO2 emissions
Reducing emission of particulates
Reducing aromatic hydrocarbons emission
Reducing acid rain
Reducing Greenhouse Effect
Reducing aerosol
Reducing cancer risk
Reducing ozone hole
Reducing damage to flora and fauna
4
Reducing the damage of agricultural land
Increasing of the global radiative forcing
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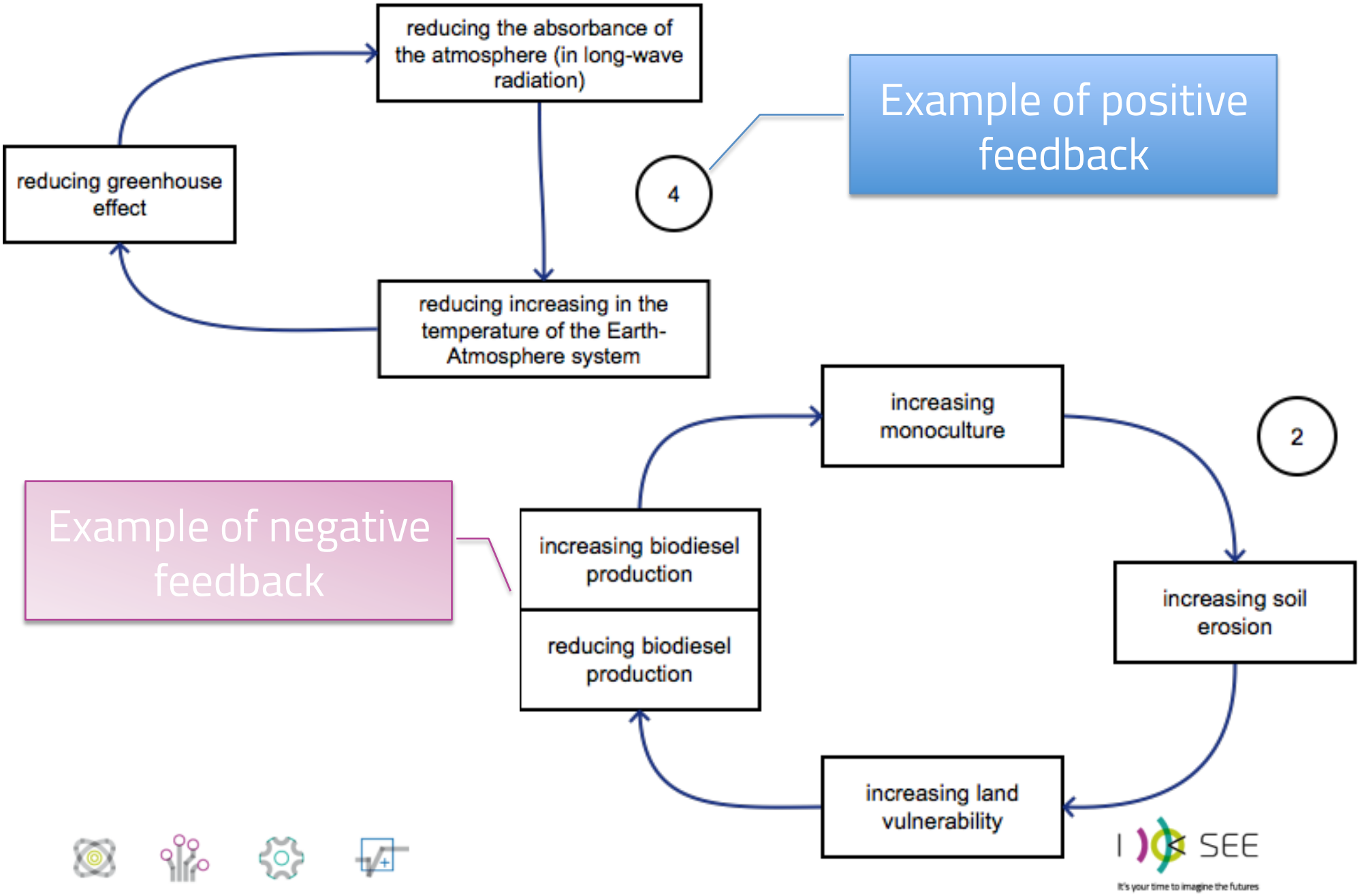
reducing the absorbance of the atmosphere (in long-wave radiation)
reducing greenhouse effect
reducing increasing in the temperature of the Earth-Atmosphere system
4
Example of positive feedback
increasing monoculture
2
increasing soil erosion
increasing land vulnerability
increasing biodiesel production
reducing biodiesel production
Example of negative feedback
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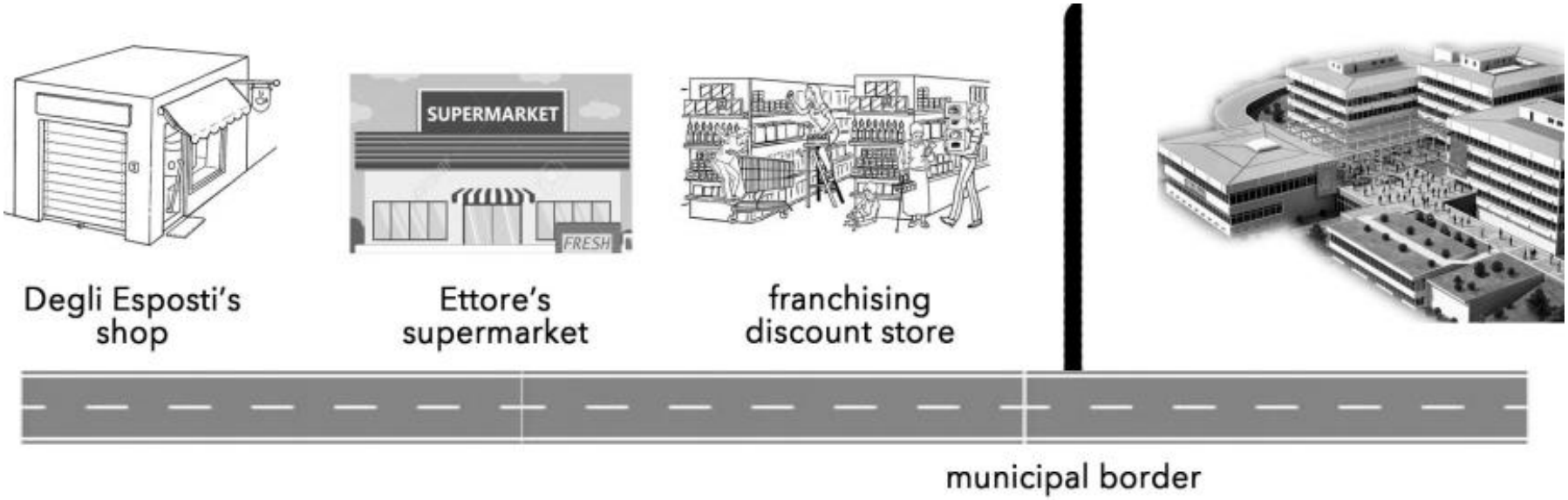
Activities to turn scientific skills into transversal skills

- **Object**: "Near, possible and desirable futures for the Town *Irene*"
- **Goal**: reach transversal skills that are future-scaffolding skills because the distinction between the three types of future, after a solid analysis of the present situation, is the starting point for a conscious and personal agency

Probable, possible and desirable futures for the Town *Irene*



- Does the Municipal Council have to permit the expansion of the discount store?

Analysis of the present situation and identification of possible scenarios

Imagine you are the public administrator requested to make a choice on whether to grant the plan alteration asked for by the owner of the discount. Before you make a decision, analyse and outline a planning scheme of the situation acknowledging :

a) the stakeholders,
b) their needs and interests,
c) the existing interactions between them.

Use a map as a mean for outlining your analysis.

[...]

Starting from the plan scheme of the present situation, now make sense of any potential effects (social, economic, occupational, environmental) which the two possibilities may arise (expansion allowed or denied). Identify and describe two probable scenarios at 2025: the first will have to illustrate a possible condition of evolution of the system as a consequence of *granted expansion*; the second must envisage a possible situation of evolution after a *denied expansion*.

Identification of feedback loops arising from given scenarios

Beside the already identified scenarios, we now supply you with two more scenarios in the view of an evolution of the town Irene from 2017 to 2025. We now ask you to detect, at least, one outcome from the positive and/or the negative feedback for each of the given scenarios and to justify it.

Scenario A) In 2025 the town has become an attractive center thanks to its many commercial activities which have developed beyond the commercial area, all along the large communication road, [...] but the historical centre has become progressively empty. [...]

Scenario B) In 2025 the town has become a centre of attraction for a local and diversified tourism, thanks to the gastronomic offer of special homemade products the shops and the restaurants make; in fact they are still present in the centre and very looked-after, though not exclusive. [...]

Imagination of a desirable scenario and plan of an action

Discuss with the members of your group in order to find a catchphrase that characterizes Irene as the ideal town where to live or to visit in 2025. Also provide a description in terms of "*desirable scenario*".

Your group and you plan an action which you may undertake (as singles and/or as a group) in the present, in order to favour the realization of your desired scenario. As you plan the action to undertake, describe:

a) who you are and the position you hold when realizing the action [...],
b) what you intend to do,
c) why you think this action favours the realization of your desirable scenario.

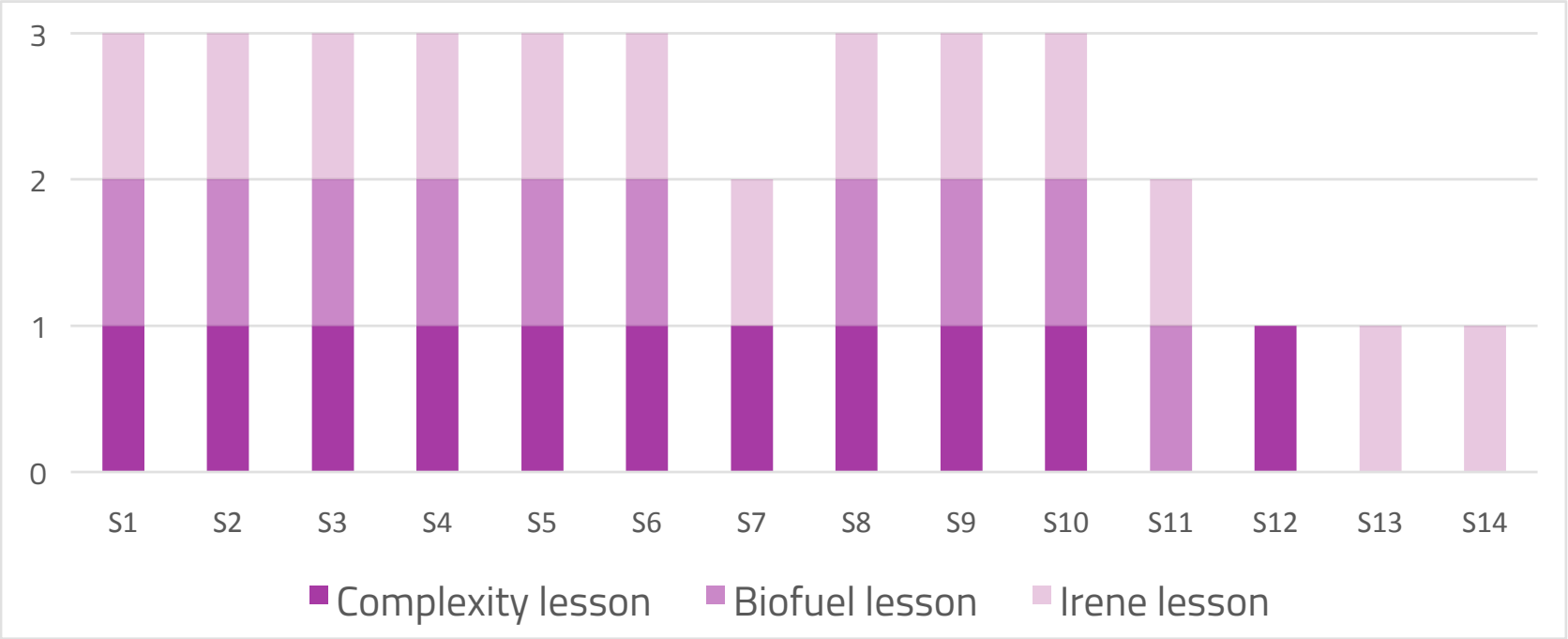
Decision

Will you allow expansion or not? Why?

Context of the pilot study

- A teaching **laboratory-course** about the topic of climate change (Piano Lauree Scientifiche project) for secondary school students
- **14 voluntary** boys and girls (17-18 years old)
- 6 afternoons, 2 main parts (9 hours per part)
  - Lessons concerning climate science (climate system as a complex one, modelling, greenhouse effect)
  - Activities described before

Sample



Focus on the 9 students who participated to the whole course (including the first part)

Data collection

- **Pre- & post- questionnaires** about the dimensions of the module (disciplinary, epistemological, personal)
- An **intermediate questionnaire** after the complexity lesson to check the level of understanding of the main scientific contents.
- **Audio-recording**, **notes** of the researchers who attended the lessons, **students' outputs** produced during the working groups.

Methodology

- **Qualitative analysis** carried out with a bottom-up strategy
- We want to provide a **synthetic picture** of what happened by identifying types (**categories**) of possible answers and recognizing **trends** during and after the activities

Have the students developed **scientific knowledge** about complex systems science?

Yes, most students reached the level of knowledge that we hoped because they could

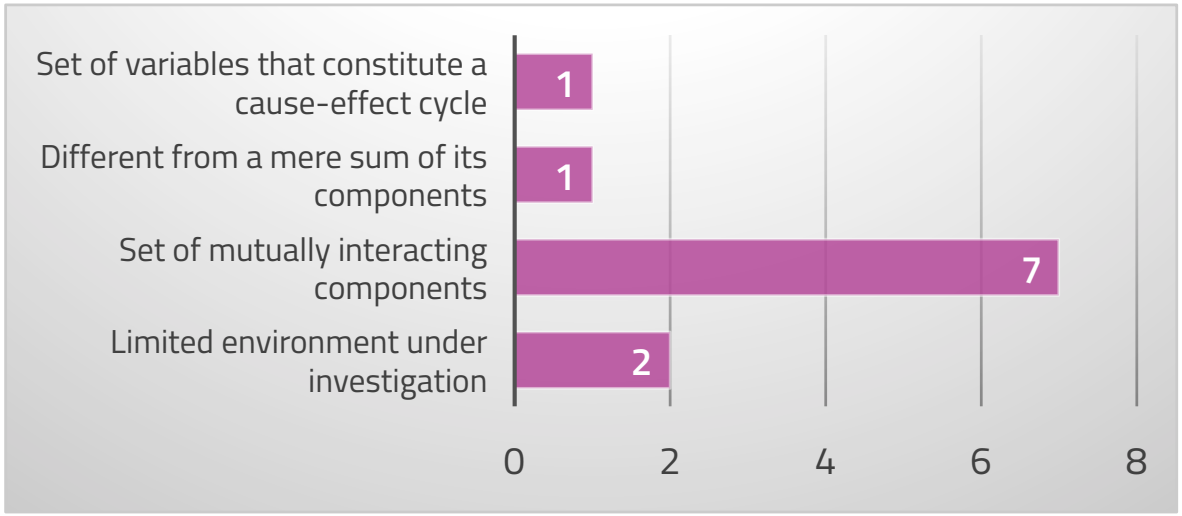
- focus their attention on crucial aspects of the concepts we introduced as typical of complex systems science
- manage the meaning of feedback and the distinction between positive and negative feedbacks

The concept of system

BEFORE THE ACTIVITIES

- Something close and isolated, that does not exchange either matter or energy with the environment

AFTER THE ACTIVITIES



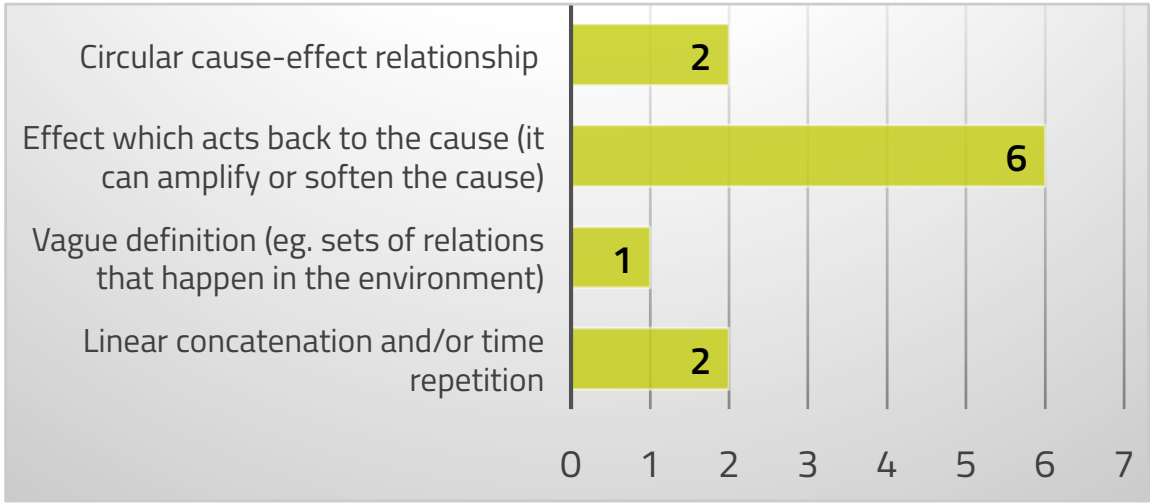
- 9 relational/interactional character of a system
- 2 “space” description

The concept of feedback

BEFORE THE ACTIVITIES

- Related to the evaluation (in e-commerce)
- Response to an input/event within a system

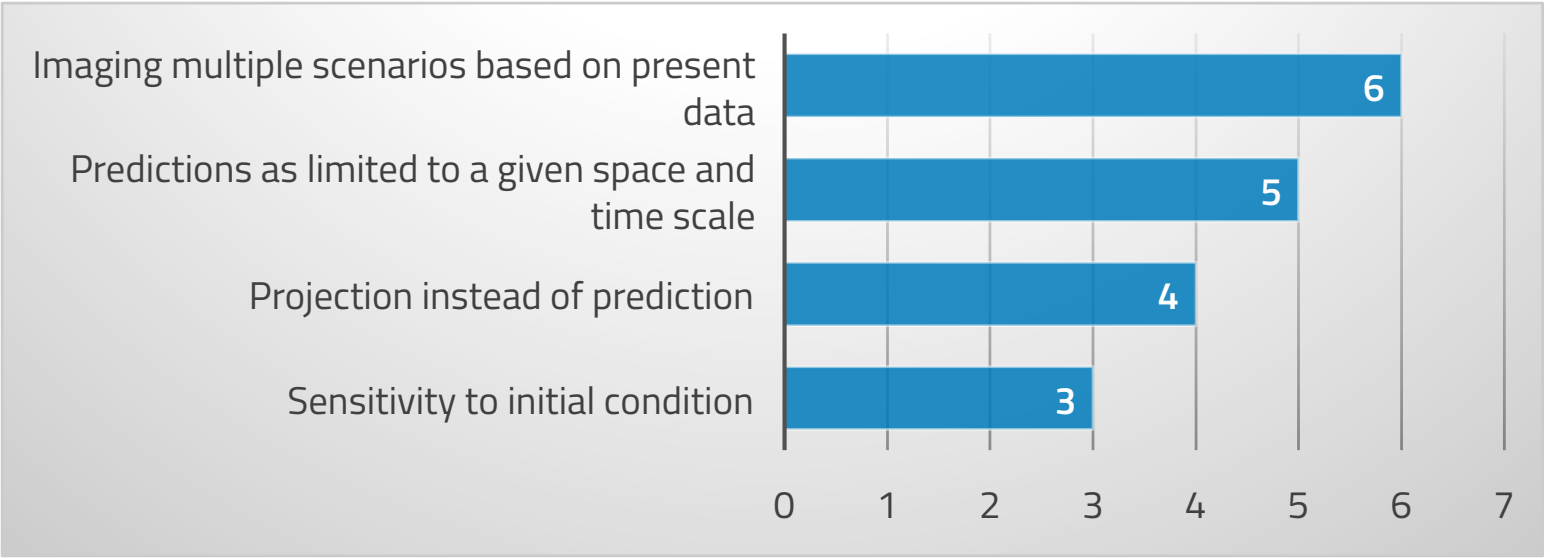
AFTER THE ACTIVITIES



- Evaluation completely disappeared
- 8 out of 11 are correct features

The concept of prediction

AFTER THE ACTIVITIES



- Sense of prediction in climate change science is different from its meaning in classical physics for 10 students out of 11

Have the students developed **scientific skills**?

Yes, most students reached the level of skills that we hoped because

- most of them were able to move from the knowledge of the disciplinary concepts toward their application in the analysis of a multidimensional problem such as the Biodiesel Story
- the circular causality learnt from the complex systems science became a lens through which analysing a scientific text

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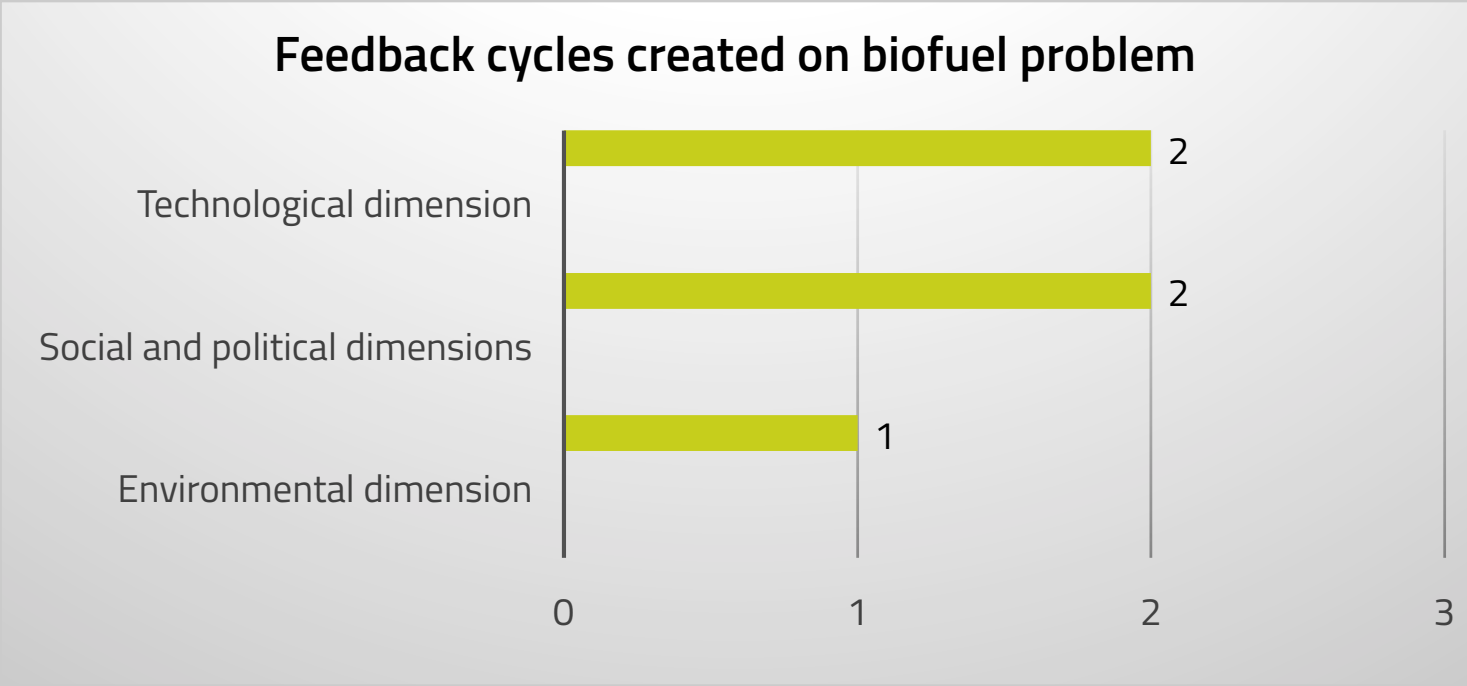
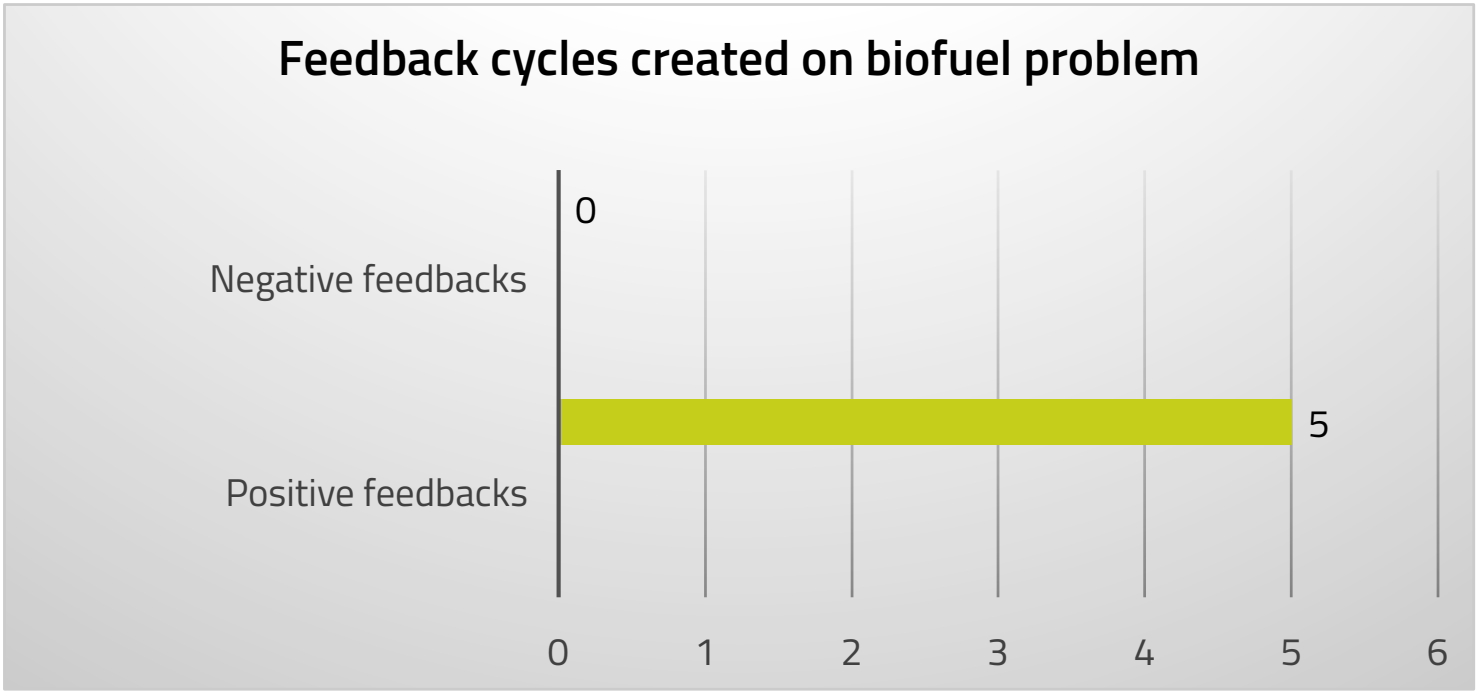


1. **Multidisciplinary perspective:** the students created feedbacks on the biodiesel issue not only related to the environmental dimension, but were able to invent feedbacks related to the social and political dimensions as well as the technological one



2. **Types of feedback:** all the feedback loops found by students were positive ones and this is an index of the difficulty of recognizing the dynamism of the equilibrium situations

Have the students developed **transversal skills**?

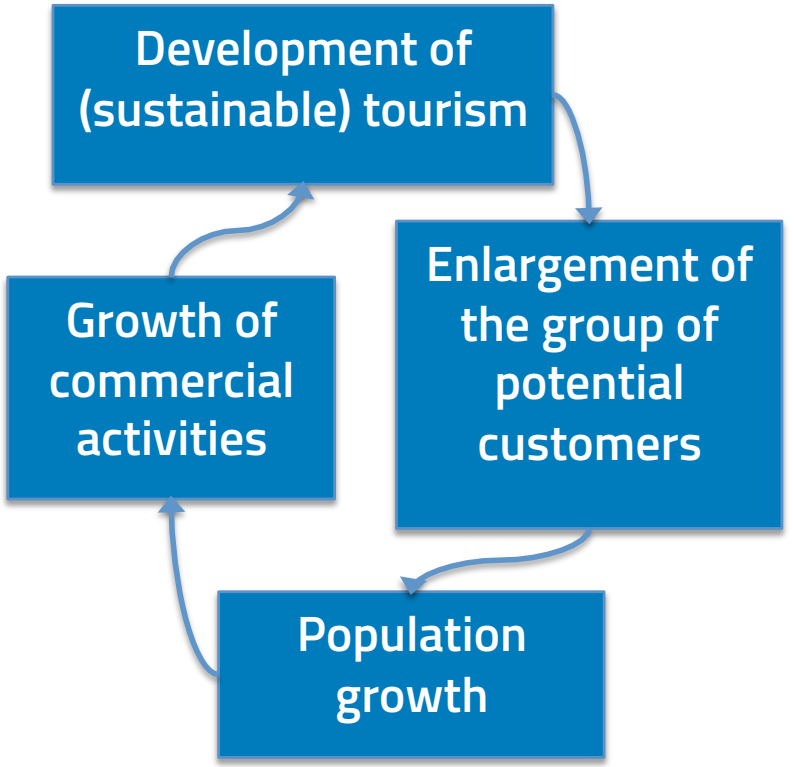
The **success** of the activity about the Town *Irene* went beyond our expectations but we identified some **criticalities** about students' ability to imagine a desirable future scenarios

The success of the activity (1/4)

A) The concept of feedback as analytic and imaginative tool

Students were able to:

- apply the concept of feedback in this urban planning activity
- invent interesting feedback loops to analyse the possible scenarios of the town of Irene



The success of the activity (2/4)

B) The students felt personally engaged and found this "apparently" strange activity as perfectly consistent with the previous activities on climate change

"We started from the analysis of the present situation and imagined possible scenarios; at the end we analysed the different choices that could have been brought to the best scenario, the desirable one… Then, trying to link this with what we have done before [during the course], maybe this choice has been guided from the fact that, ***also with regard to climate change, it is the weight of single choices that can cause wider mechanisms that influence, in a complex system, a lot of other variables****."* (Claudia, 17)

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The success of the activity (3/4)

C) The students could appreciate to what extent the course impacted their approach to the present (widening up possibilities, dimensions, challenges/ problems but also chances)

*"Today I realized **how much my approach has been changed** [throughout the course]. Two months ago I would have made the decision yes/no [on the city of Irene] **in two seconds**. Today we discussed **two hours** and I am not yet sure about the decision. I discovered that there are **many things to take into account**". (Erika, 17)*

The success of the activity (4/4)

D) The activity stimulated, in some cases, interesting creative processes that led them to push their imagination toward their future, by inventing also inexistent professions

*"We are **competition regulators** for Irene tourism office. We listen to the needs of manufacturing activities, propose compromises when conflicts occur, provide legal and fiscal advice, offer promotional campaigns, propose prizes for the most innovative start-ups that work with renewable energy."*

Conclusions…

- The contents of science can be rethought and turned into transversal skills, that are analytic and imaginative tools to interpret the complexity of the world
- The activities appear to impact significantly the ways students think about their present with an eye on the horizon

… and open questions

- How can we integrate our activity to improve students' ability to move more freely within the desirable future? Are there examples of activities that can support this?
- Can our data be analysed so as to check - and to measure – at a finer-grained level how the module impacted students' relationship with the future? Are there empirical studies that addressed this methodological issue and against which we can contrast our results?
- Are there gender and culture differences that can be observed in activities like these and that we can expect to capture in future replications of the module?




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Partners

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