NARST 94TH ANNUAL INTERNATIONAL CONFERENCE

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Scientific simulations as educational tools for the post-pandemic era:

the case of the Susceptible-Infectious-Removed model

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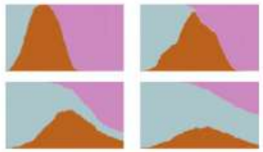

Health

Why outbreaks like coronavirus spread exponentially, and how to "flatten the curve"

By Harry Stevens March 14, 2020

NEWS

New COVID-19 Modelling Suggests Slower Spread, But More Deaths Expected

Ontario and Quebec account for about 80 per cent of cases in Canada.

Laura Osman, Canadian Press

Health | Local News | Northwest | Science

Mathematical models help predict the trajectory of the coronavirus outbreak. But can they be believed?

May 3, 2020 at 6:00 am | *Updated May 3, 2020 at 12:42 pm*

How modelling Covid has changed the way we think about epidemics
Adam Kucharski

- During the COVID-19 pandemic, the whole society has been exposed to models and computational simulations
- Tools that were routine for experts became part of the popular vocabulary and were used to make decisions
- Simulations embody epistemic and methodological knowledge that deeply changed the ways in which the scientific community today addresses complex problems (Galison, 1996; Winsberg, 1999)

The goal of the study

We want to show

- how to exploit in teaching (from high-school students to higher levels) the epistemic and societal value of scientific simulations to tackle with the issues raised by COVID-19 pandemic
- how scientific simulations can become an educational tool to implement the policy framework “OECD Future of Education and Skills” (OECD, 2018)

The framework: OECD Learning Compass 2030

- A non-educational framework that includes in a comprehensive picture outstanding issues that educational research is committed to investigate (skills for sustainable development, future-thinking and agency)

- Similarity with the framework of future-oriented science education and future-scaffolding skills (Levrini et al., 2019, 2021), elaborated within science education research

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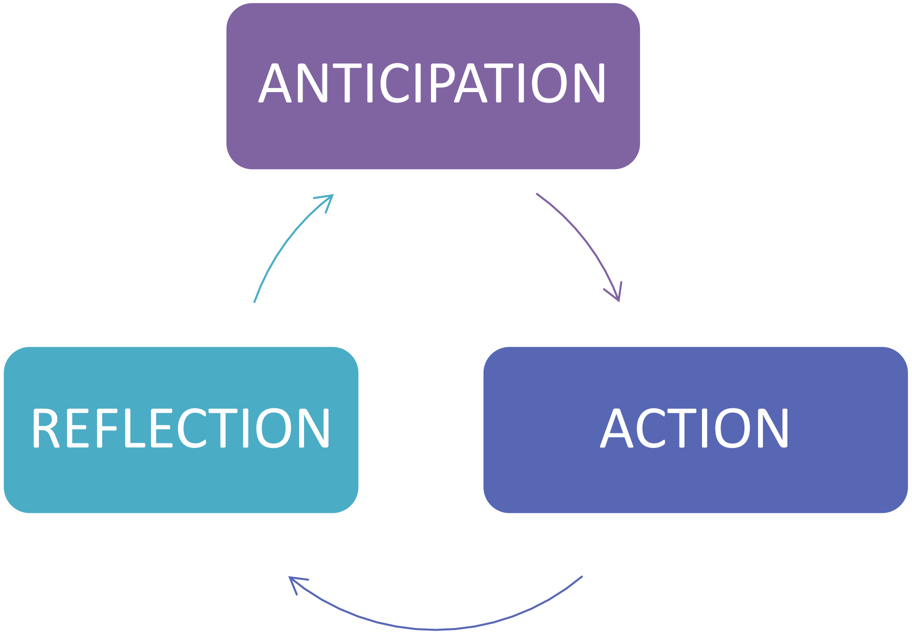
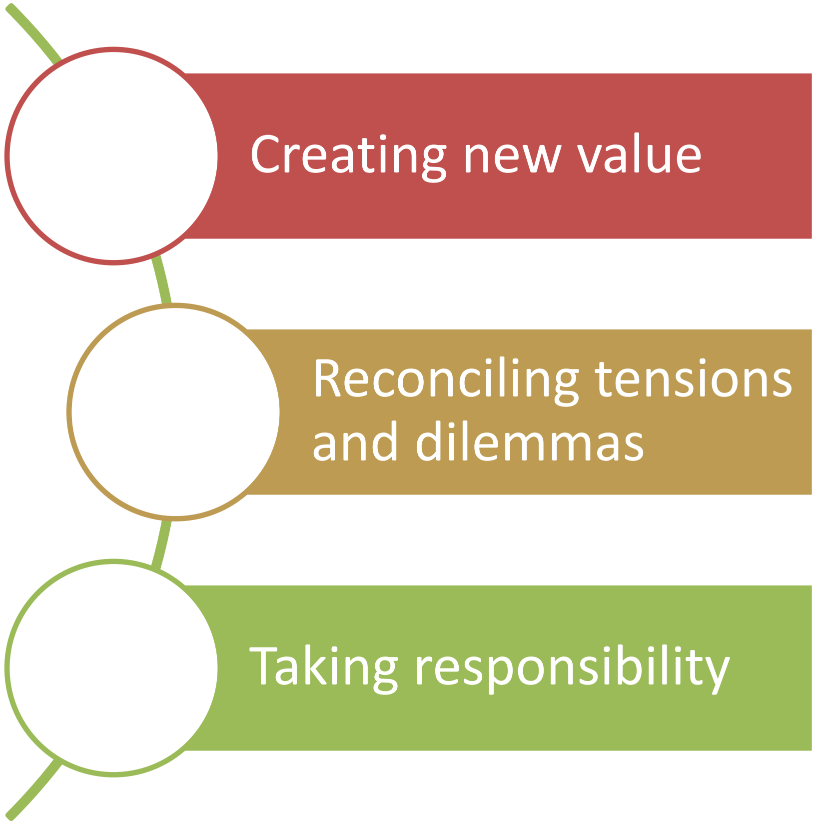
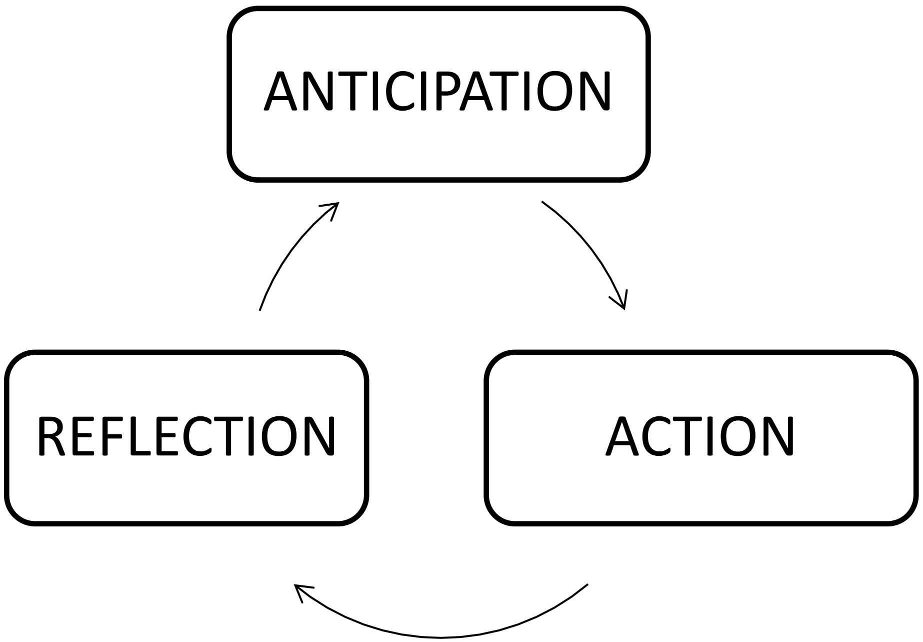
The framework: OECD Learning Compass 2030

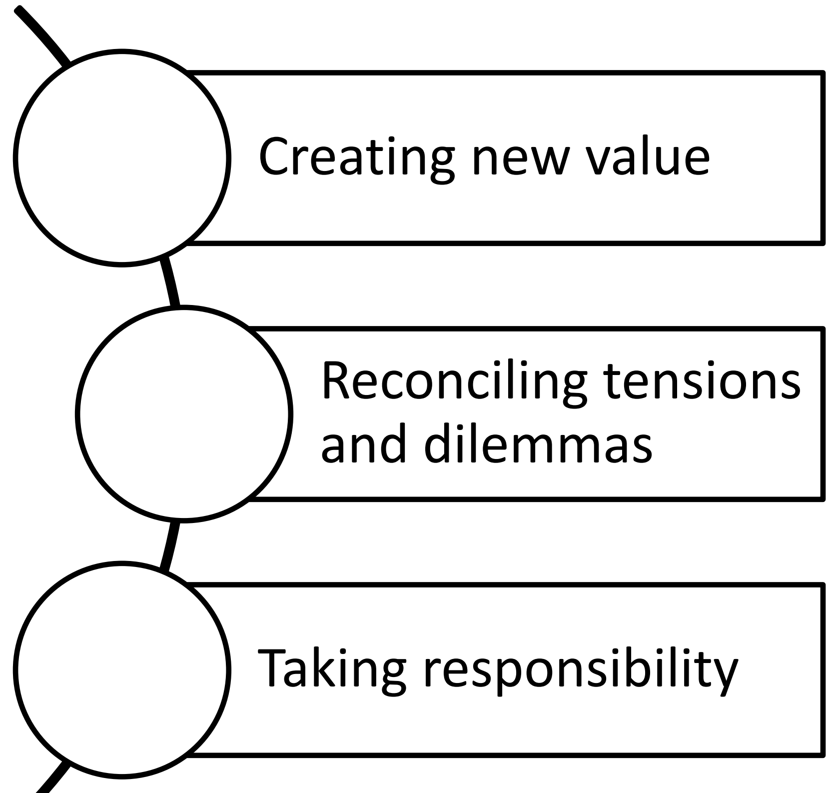




AAR cycle and Transformative Competences

The framework: OECD Learning Compass 2030





To show how simulations can be related to the elements of the framework, we examine the **epistemic details** of SIR simulations as they emerge from the comparison between **equation-** and **agent-based** approaches

Equation-based vs agent-based approaches

Equation-based simulations

- The evolution of the system is described by **differential equations**
- **Deterministic** solutions
- **Macroscopic** model

Agent-based simulations

- The dynamics of the system is generated making the individual agents evolve according to **behavioral rules**
- **Probabilistic** in nature
- **Microscopic** model

(Grüne-Yanoff & Weirich, 2010)

The SIR model (Kermack & McKendrick, 1927)

The population is divided in three compartments

S
- Susceptible = compartment of healthy individuals that can contract the disease

I
- Infectious = compartment of individuals that have contracted the disease and can infect others

R
- Removed = compartment of individuals that have recovered from the disease and have been immunized, or that have died due to the disease

The SIR model (Kermack & McKendrick, 1927)

The temporal evolution of the three compartments is described by a set of three ordinary non-linear differential equations

$$\frac{dS(t)}{dt} = -\frac{\beta I(t)S(t)}{N}$$

$$\frac{dI(t)}{dt} = \frac{\beta I(t)S(t)}{N} - \gamma I(t)$$

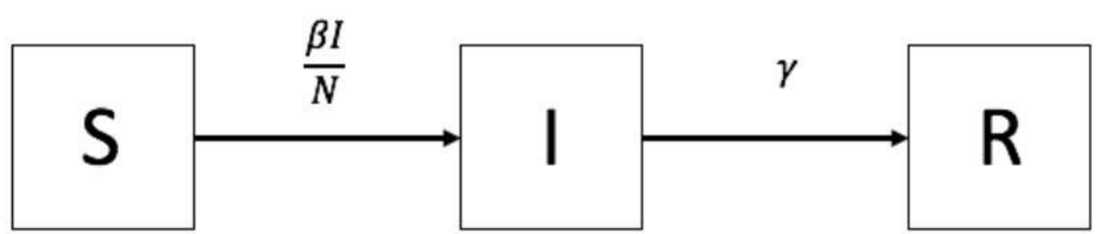
$$\frac{dR(t)}{dt} = \gamma I(t)$$

β = rate of infection

γ = rate of recovery or death

$$S(t) + I(t) + R(t) = N = cost$$

$$\frac{dS}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0$$



Equation-based simulation of the SIR model

- The model is already expressed as a system of differential equations
- It is usually simulated with an equation-based approach
- **Numerical integration** of the system of equations

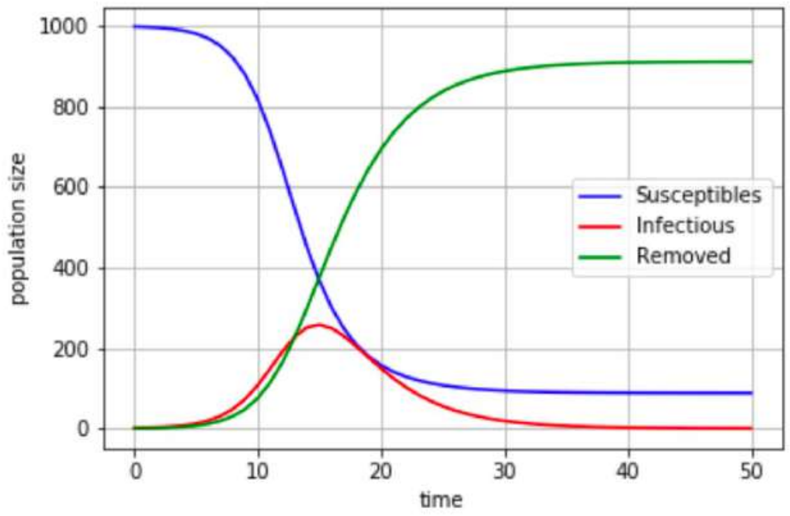


Figure 3. Results of the simulation of the computational equation-based model with odeint integration method: in blue the evolution of susceptible population size, in red the infectious, in green the removed ($\beta = 0.8, \gamma = 0.3, N = 1000, S(0) = 999, I(0) = 1, R(0) = 0, time = [0, 1, \dots, 50]$).

```
def dX_dt(X, t=0):
    return array([ - beta*X[0]*X[1]/N ,
                    beta*X[0]*X[1]/N - gamma*X[1] ,
                    gamma*X[1] ])

from scipy import integrate
t = linspace(0, 50, 50)

X0 = array([N-1, 1, 0])

X = integrate.odeint(dX_dt, X0, t)
```

Reformulation of the equations

$$\frac{dS(t)}{dt} = -\frac{\beta I(t)S(t)}{N}$$

β_c = contact rate

$\frac{I(t)}{N}$

Mean number of contacts for each individual x Probability that the contact is infectious

Probability that a susceptible becomes infectious = Probability that a susceptible meets an infectious

x

Probability that the infectious infects the susceptible

β_i = infectivity

Reformulation of the equations

β_C = contact rate

$\frac{I(t)}{N}$

Mean number of contacts for each individual x Probability that the contact is infectious

$$\frac{dS(t)}{dt} = -\frac{\beta I(t) S(t)}{N}$$

Probability that a susceptible becomes infectious = Probability that a susceptible meets an infectious

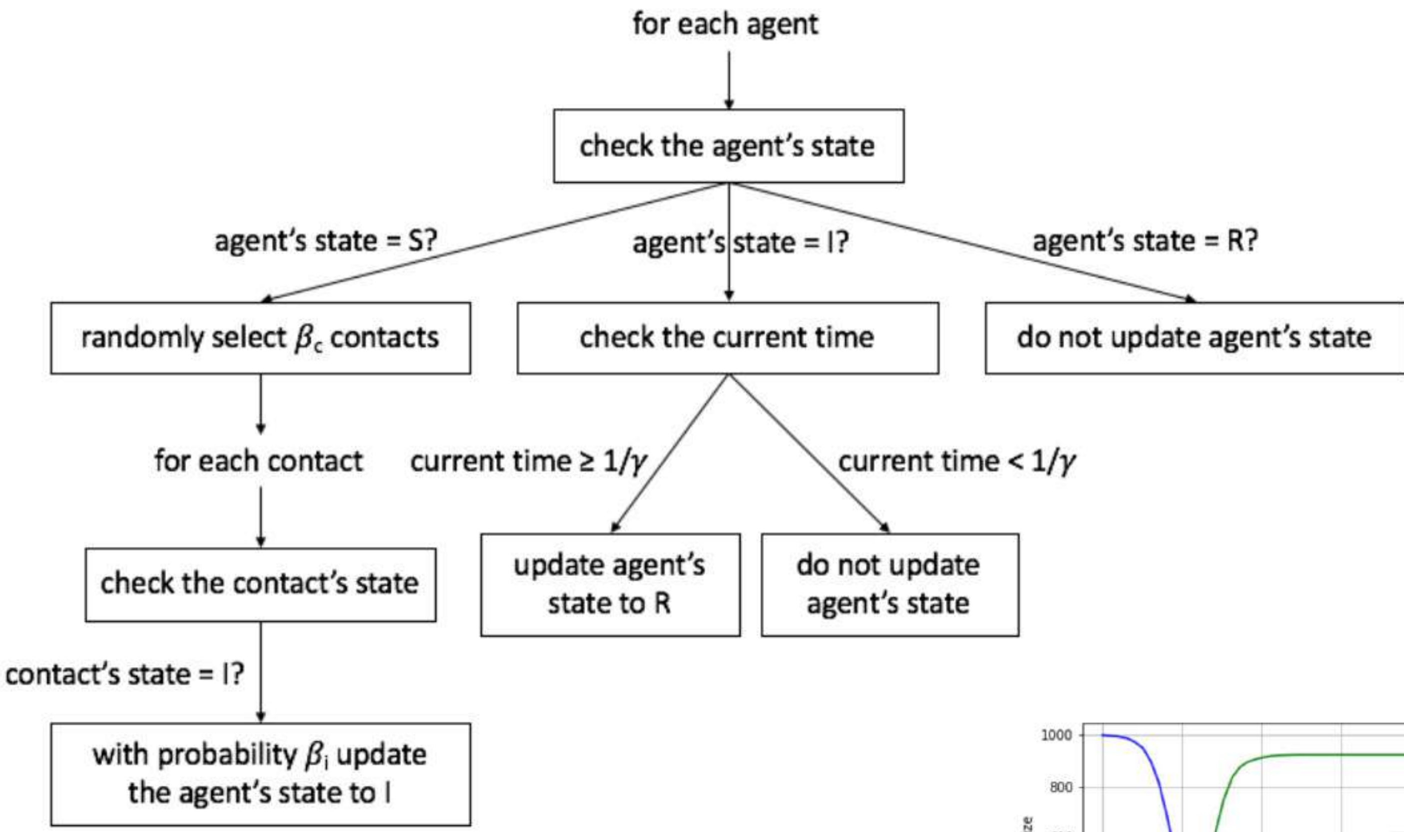
x

Probability that the infectious infects the susceptible

β_i = infectivity

The probability that a susceptible becomes infectious now depends on the probability that a susceptible meets an infectious and on the probability that a susceptible actually becomes infectious

Agent-based simulation of the SIR model



(Adapted from Macal, 2011)

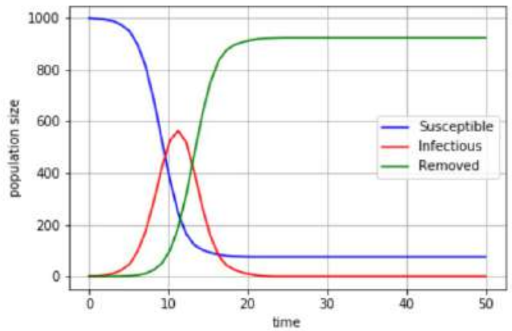
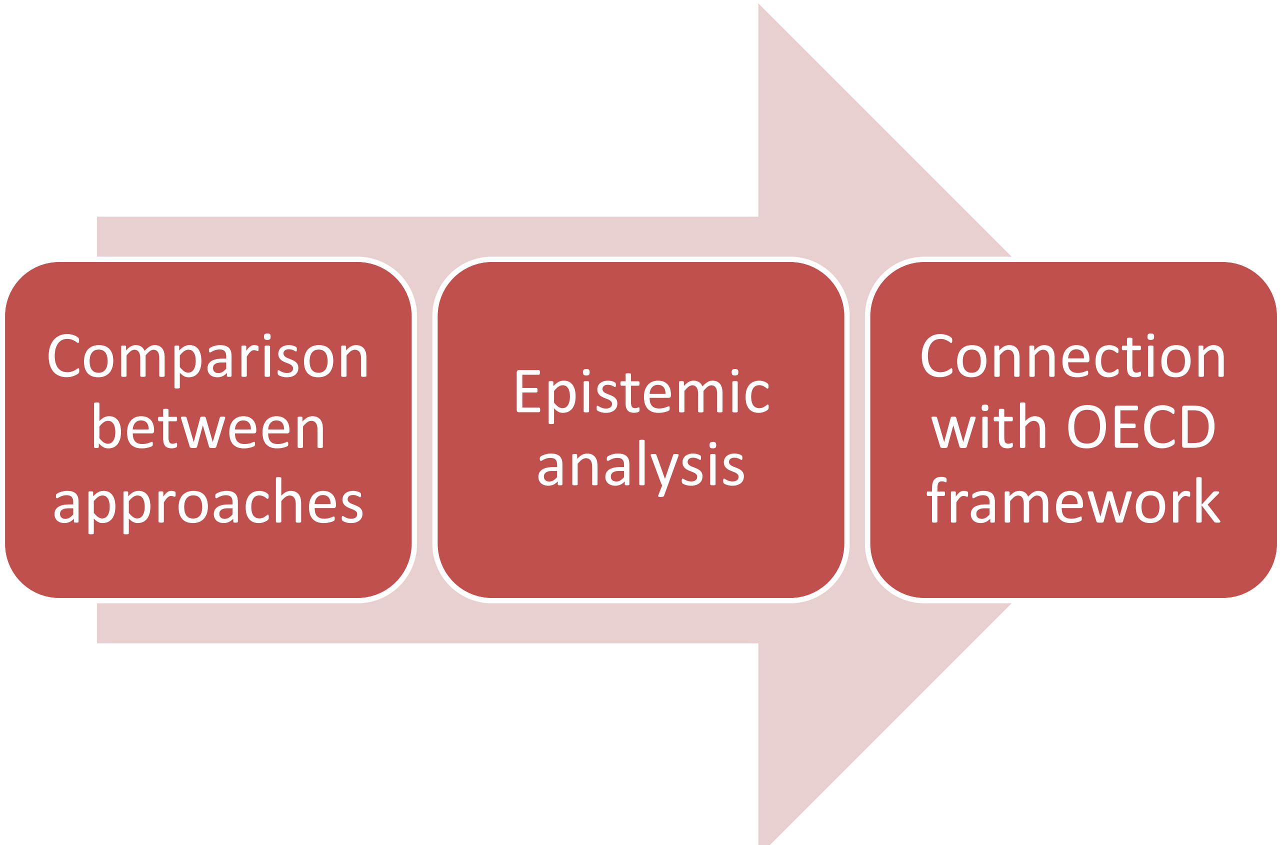


Figure 9. Average results of 100 simulation runs of the computational agent-based model: in blue the evolution of susceptible population size, in red the infectious, in green the removed ($\beta_i = 0.8, \beta_c = 1, \gamma = 0.3, N = 1000, S(0) = 999, I(0) = 1, R(0) = 0, time = [0, 1, \ldots, 50]$).


Comparison between approaches
Epistemic analysis
Connection with OECD framework

Epistemic analysis of the approaches to exploit AAR cycle and transformative competence

The nature of agent-based simulations is intrinsically probabilistic

Problematize the Newtonian deterministic paradigm

ANTICIPATION

ACTION

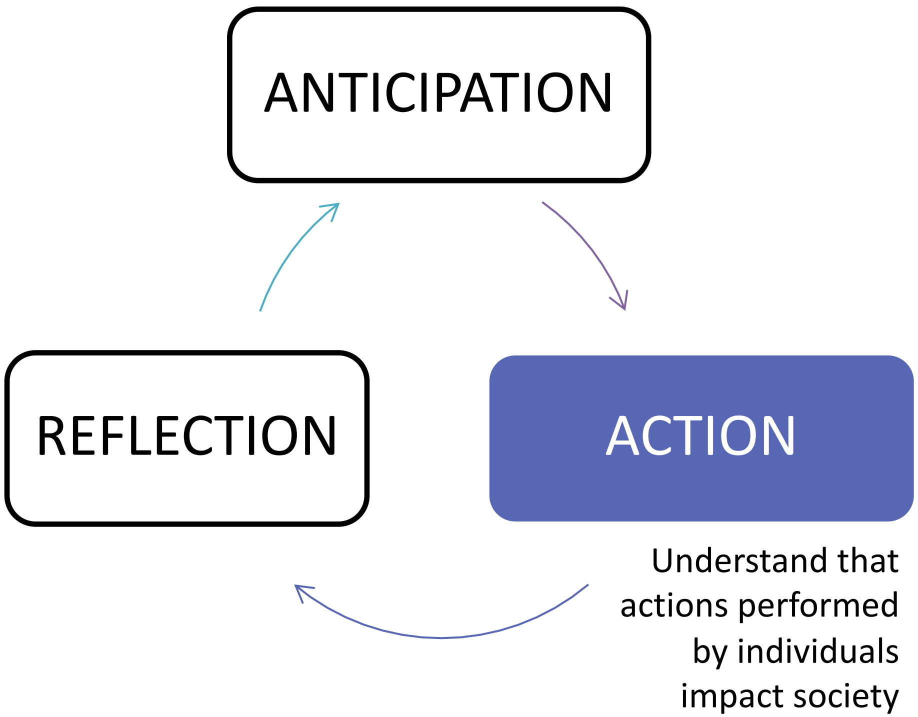
REFLECTION

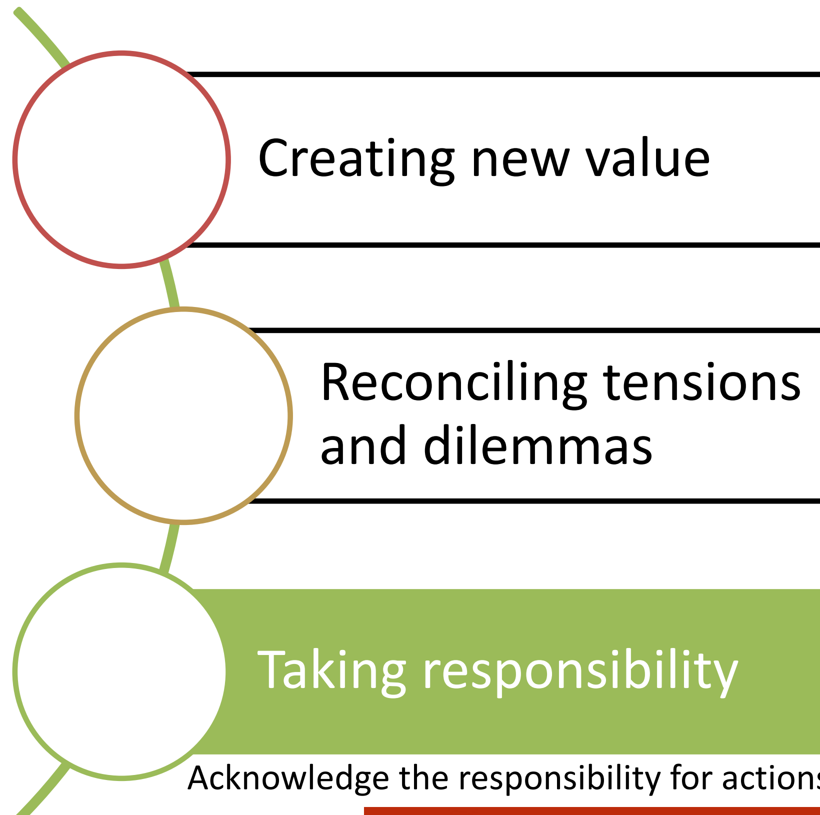
Recognize the existence of different levels of uncertainty

- Creating new value
  - Avoid to stick to already explored scenarios
- Reconciling tensions and dilemmas
- Taking responsibility

Epistemic analysis of the approaches to exploit AAR cycle and transformative competence

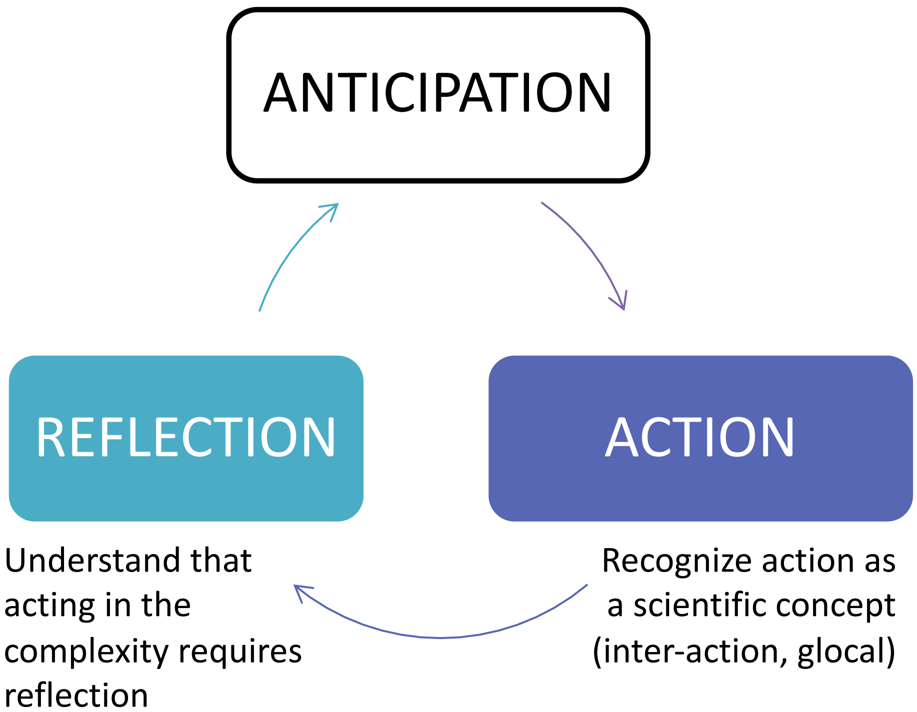
In the agent-based approach,
the population consists of individuals, the agents

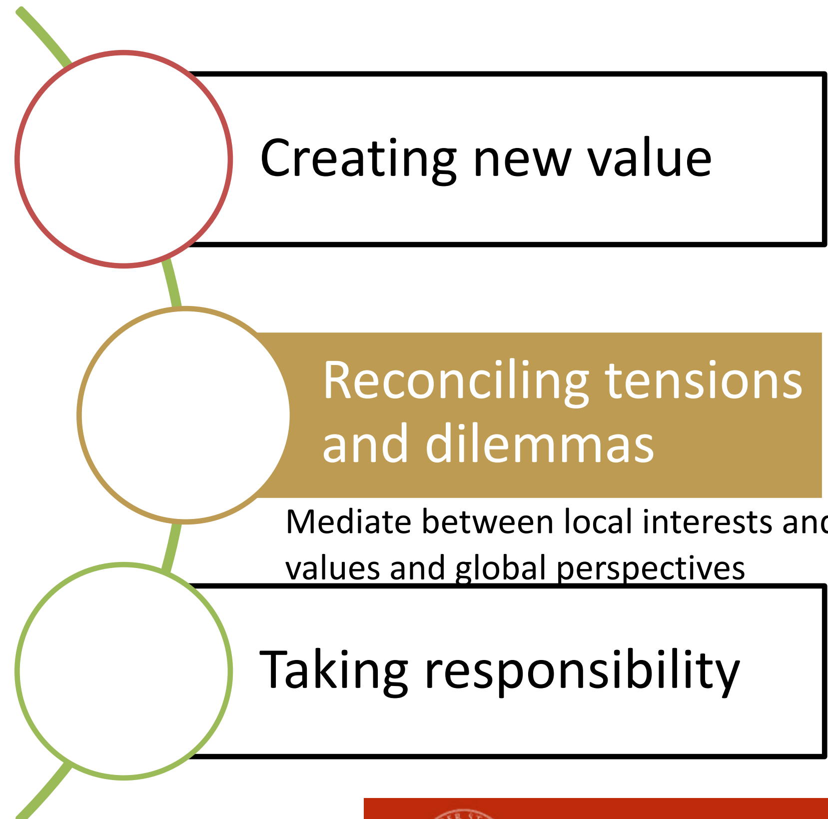




Epistemic analysis of the approaches to exploit AAR cycle and transformative competence

The global behaviour is an emergent property that depends non-linearly from local agents' interactions





Conclusions

- We have addressed a very concrete teaching issue, related to the problem of exploiting scientific simulations in teaching and equipping students with knowledge and skills needed to navigate a complex society
- In particular, we examined the case study of the SIR epidemiological model comparing equation- and agent-based approaches to simulation
- Framing the analysis within the OECD recommendations allowed us to:
    - contribute to find concrete ways to implement visionary educational frameworks and to bridge the gap between policy recommendations and classroom practices
    - point out the epistemological, societal value of a scientific tool like simulations and flesh out, in education, their transformative potential

Next steps

- Characterize disciplinary and interdisciplinary the equation- and agent-based approaches to SIR model

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IDENTITIES
Enlightening
Interdisciplinarity
in **STEM** for Teaching

- Study the role of future-oriented science education and future-scaffolding skills to facilitate the transition from the conceptual and epistemic analysis to AAR and transformative competences

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