IDENTITIES

Enlightening Interdisciplinarity in STEM for Teaching

Curricular interdisciplinarity and advanced STEM topics: teaching modules for an interdisciplinary preservice teacher education

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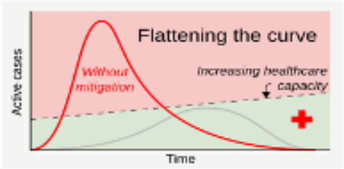
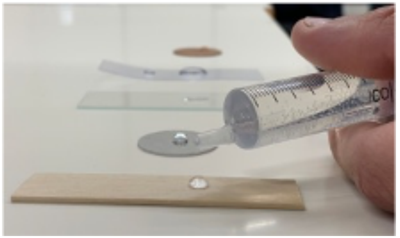
1. Overview on the structure of the modules
2. The module on COVID-19
3. Models and simulations as boundary objects



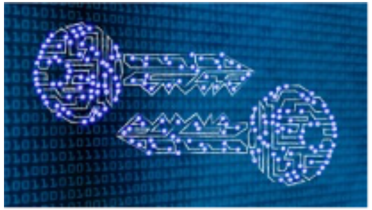


Interdisciplinarity in advanced STEM topics

- Interdisciplinarity at the service of society: interpreting the evolution of COVID-19
- Nanotechnology in everyday life

Interdisciplinarity within the curricula

- Parabola and parabolic motion
- Cryptography

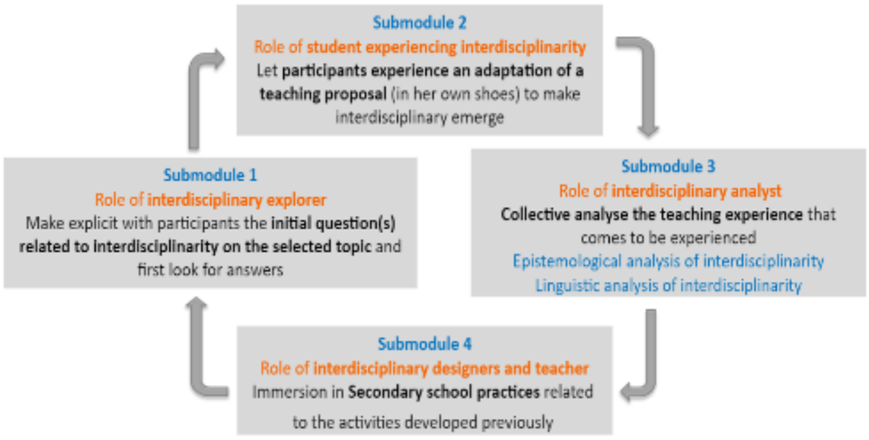


The modules have a similar **general structure** described in terms of submodules, based on an adaptation of the SRP-TE model (Ruiz-Olarria, 2015; Barquero, Bosch & Romo, 2018)

The Study and Research Paths for Teacher Education (SRP-TE) as proposed in the framework of the Anthropological Theory of the Didactics (ATD)

Participants are asked to adopt different roles:

- Becoming “explorers”
- Becoming “students”
- Becoming “analysts”
- Becoming “designers and teachers”



Adaptation of the submodules' structure of the Study and Research Paths for Teacher Education (Ruiz-Olarria, 2015; Barquero, Bosch & Romo, 2018)

Previous research has shown how **SRP-TE is a useful** tool to:

- Enable teachers' **epistemological and didactic questioning of dominant paradigm** (What does it exist? What can it be done differently? What new epistemological and didactic tools are needed?)
- Transpose **research tools to teaching practice tools** for the epistemological and didactic analysis
- Help teachers **progress in the critical issue of identifying institutional constraints** hindering a **change of paradigm** in current school systems

Submodule 1

Role of **interdisciplinary explorer**

Make explicit with participants the **initial question(s) related to interdisciplinarity on the selected topic** and first look for answers

Initial questions related to interdisciplinarity to address as 'explorers'

- The initial questions can be of different nature:
  - Closer to the role of the discipline and of their interaction related to the topic addressed in the module, such as:

    How have the different disciplines address a certain topic? How have these disciplines interacted to address certain problems or questions related to the topic?
  - Closer to the teaching profession, such as:

    How can interdisciplinarity practice can be transposed into Secondary school classrooms?

Submodule 2

Role of **student experiencing interdisciplinarity**

Let **participants experience an adaptation of a teaching proposal** (in her own shoes) to make interdisciplinary emerge

Submodule 1

Role of **interdisciplinary explorer**

Make explicit with participants the **initial question(s) related to interdisciplinarity on the selected topic** and first look for answers

Experiencing interdisciplinarity under the role of student

➔ Participants are asked to work in groups and experience themselves some activities related to the interdisciplinary topic

➔ This work in groups requires an active participation working in group, reporting, exposing and debating your work

➔ This submodule is crucial to build together a shared *milieu* to 'talk' and 'analyse' (inter)disciplinary practice

Submodule 2

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Submodule 1

Role of **interdisciplinary explorer**

Make explicit with participants the **initial question(s) related to interdisciplinarity on the selected topic** and first look for answers

Submodule 3

Role of **interdisciplinary analyst**

Collective analyse the teaching experience that comes to be experienced

Epistemological analysis of interdisciplinarity

Linguistic analysis of interdisciplinarity

Progression on the tools to become interdisciplinarity analyst

- ➔ Instruments to help and progress on the interdisciplinarity analysis: *Guides for the interdisciplinary analysis* or *Analytics grid for disciplinary and interdisciplinary features* or...
- ➔ Video recorded lecture + Q&A sessions

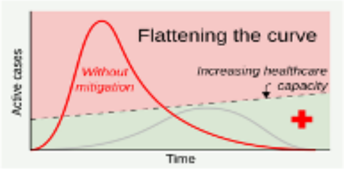
Submodule 2
Role of **student experiencing interdisciplinarity**
Let **participants experience an adaptation of a teaching proposal** (in her own shoes) to make interdisciplinary emerge

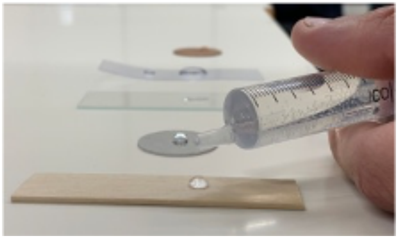
Submodule 3
Role of **interdisciplinary analyst**
Collective analyse the teaching experience that comes to be experienced
Epistemological analysis of interdisciplinarity
Linguistic analysis of interdisciplinarity

Submodule 4
Role of **interdisciplinary designers and teacher**
Immersion in **Secondary school practices** related to the activities developed previously

Submodule 1
Role of **interdisciplinary explorer**
Make explicit with participants the **initial question(s) related to interdisciplinarity on the selected topic** and first look for answers

Adaptation of the submodules' structure of the Study and Research Paths for Teacher Education
(Ruiz-Olarría, 2015; Barquero, Bosch, & Romo, 2018)





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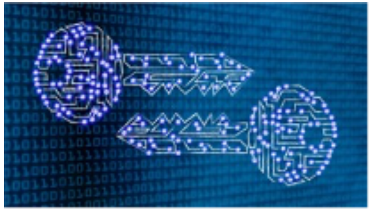

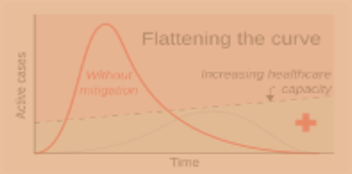

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Submodule 1
Role of **interdisciplinary explorer**
Make explicit with participants the **initial question(s) related to interdisciplinarity on the selected topic** and first look for answers
Science and interdisciplinarity ←→ Society
←→ Teacher Education ←→ Secondary school

Initial questions related to interdisciplinarity
Interpreting the evolution of COVID-19

$Q_{0.1}$: How have the S-T-E-M disciplines interacted to investigate the evolution of COVID-19? What answers have been given and how have their advances spread to society?

$Q_{0.2}$: What role has each discipline play and how can we analyse interdisciplinarity when addressing complex issues related to the evolution of COVID-19?

$Q_{0.3}$: How can this interdisciplinary practice transposed and disseminated into secondary schools?

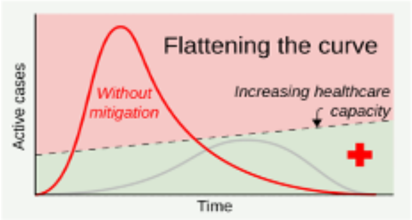
Activity proposed in submodule 1, as interdisciplinary explorers

- Analysis of a selection of news about the scientific contributions to the understanding of COVID-19 evolution

March 2020 — June 2021

What is the number of confirmed cases of COVID-19 in different countries? What does it mean that number of infected people grow exponentially?

What is R? Which models are used? How is R defined?



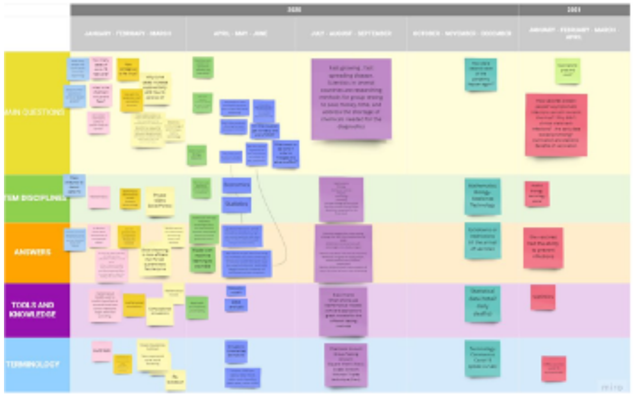
How to forecast when will the curve reach its maximum? What does it mean to flatten the curve?

What model simulation can tell us about effects do the different socio-political decisions

Activity proposed in submodule 1, as interdisciplinary explorers

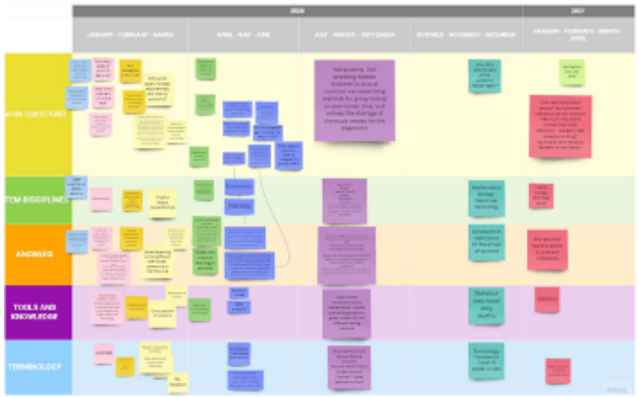
- Analysis of a selection of news about the scientific contributions to the understanding of COVID-19 evolution
- Collecting students' answers through the 1st guide of analysis of interdisciplinarity
  - Which have been the **main questions** that the research community has been addressing?
  - Which **disciplines** can be detected that have contributed to the discussion?
  - Which **tools and disciplinary knowledge** can be detected through the answers provided?
  - Which **specific terminology** was used for the dissemination of the questions addressed and answers provided? Which was known, which one new?
- Group discussion on the **evolution of different issues** asked in the 1st of analysis of ID

Figure 1. Example of answers from participants to the collected through the MIRO platform



About the evolution on the questions and answers

- Detection of **more open questions** than answers
- Detection of different kinds of questions:
  - **“How many?” questions** about numbers of the epidemics: number of cases, deaths, countries, vaccinations... → Issues of quantity
  - **“What/How” questions** about the nature of the disease: infectivity, what happens to asymptomatic, what protection do vaccine provide → Issues of description
  - **“Why” questions** about , for instance, the exponential increase of the curve, modelling the epidemic, second wave... → Issues of explanation
  - **“What to do?” questions** about methods for testing people, models of prediction, vaccination strategies... → Issues of decision making



About the disciplines intervening and their interaction

- Most of questions were difficult to be addressed by only one discipline, most of them call for the interaction among disciplines
- What, who and how a discipline is defined?

About the the tools, knowledge and terminology used

- Important “key-word” were detected
  - Raw data
  - Validity of data
  - Models
  - Simulation of models
  - Simulation of scenarios
  - Predictions
  - Contrast and validation of the simulation against reality
  - … among others….

Submodule 2

Role of **student experiencing interdisciplinarity**

Let **participants experience an adaptation of a teaching proposal** (in her own shoes) to make interdisciplinary emerge, distributed into some particular "lines of ID inquiry" about the Covid evolution

1st line of ID inquiry

Delimiting the system to look at and formulating hypothesis about the evolution of the pandemic

What can data reveal about the evolution of COVID-19? What hypothesis can we address? How data can help us to enquire into our hypothesis?

2nd line of ID inquiry

The role of mathematical models in approaching the evolution of the pandemic

What is the role of models and of modelling in investigating the evolution of COVID-19? Which are the aims and uses that we can give to models?

3rd line of ID inquiry

Simulating scenarios to make decisions on social restrictions

How can computational simulations support decision-making processes about future actions in the context of the pandemic (from political, economic, medical, etc. perspectives)? What is their validity and function?

Submodule 3

Role of **interdisciplinary analyst**

Collective analyse the teaching experience that comes to be experienced

Introduction of tools for the epistemological analysis of interdisciplinarity

Questions-answers map

as tool for the epistemological analysis of the activity

- Construction in group of the **questions and answers map** for each line of inquiry, starting from given initial questions:
  - Make explicit the **questions** you were addressing and the **link** they established among them

Big group sharing and comments to highlight links among the lines.

Submodule 3

Role of **interdisciplinary analyst**

Collective analyse the teaching experience that comes to be experienced

Introduction of tools for the epistemological analysis of interdisciplinarity

Questions-answers map

as tool for the epistemological analysis of the activity

Q&A map as

→ Tool to detect **intersections among the lines of ID inquiry**

→ Tool to detect possible **boundary objects** (Q, A, terminology, methods, etc.)

Let's focus on an example of boundary object that can be identified within the issue of COVID-19 evolution

The epidemiological models and simulations (e.g. SIR)

How do different models of the same phenomenon allow to emphasize the interdisciplinarity between disciplines such as physics, mathematics and computer science?

During the COVID-19 pandemic (and also with the climate emergency), the whole **society has been exposed to computational models and simulations**

Tools that were routine for experts became part of the **popular vocabulary** and were used to make decisions.

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.

How modelling Covid has changed the way we think about epidemics

Adam Kucharski

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

Equation-based models

- In these models, the dynamics of the system is **described** with differential equations
- Solving the equations with simulations we can **derive** the future of the system from the present
- The system is modeled at a global level (**macroscopic** perspective)

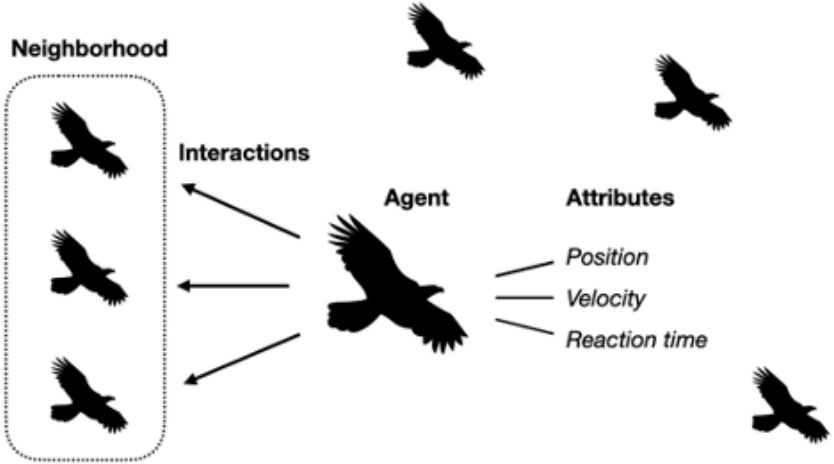
Agent-based models

- In these models, the dynamics of the system is **generated** by making the individual agents evolve according to behavioral rules.
- There is no description of the macroscopic properties of the system, which **emerge** as a result of the simulation
- The system is modeled at the level of individuals, the agents (**microscopic** perspective)

Equation-based models

$$\begin{pmatrix} \dot{x}_h \\ \dot{y}_h \end{pmatrix} = \overbrace{\begin{pmatrix} \cos\theta & -L\sin\theta \\ \sin\theta & L\cos\theta \end{pmatrix}}^{A} \begin{pmatrix} v \\ \omega \end{pmatrix}$$

Agent-based models



	Equation-based simulations	Agent-based simulations
Relationship between system's levels	The equations do not emphasize the microscopic entities explicitly but estimate the behavior at the macroscopic level.	The local interactions among the agents lead to emergent phenomena observed by the macroscopic behaviors at the aggregate level.
Probabilistic character	The equations are deterministic: from the present state, the numerical methods used by the simulation lead to the future state of the target system in a univocal and pre-determined way.	The presence of elements of stochasticity and non-linearity in the interactions at the micro-level of agents leads to probabilistic results of the simulations.
Presence of elements of discretization	The system is modelled as an undifferentiated whole and the differential equations are continuous both with regard to population and time which vary in $\mathbb{R}$. The discretization follows for solution purposes through numerical methods.	The system is modelled as divided in its discrete minimum components, i.e. the agents, which are a finite number in $\mathbb{N}$. Time is also a finite sequence of discrete time steps.

The SIR model was the first model of diffusion of an epidemic

Basic idea: study the spread of a disease in a population by dividing it into 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 temporal evolution of the three compartments is described by a set of three ordinary non-linear differential equations

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

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

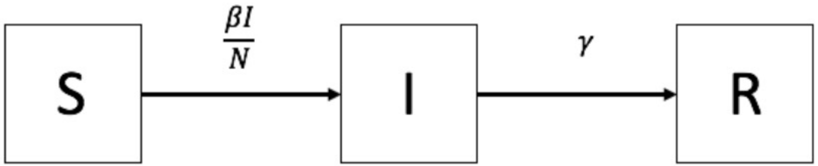
$$\frac{dR(t)}{dt} = \gamma I(t)$$

$\boldsymbol{\beta}$ = rate of infection

$\boldsymbol{\gamma}$ = rate of recovery or death

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

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



- 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

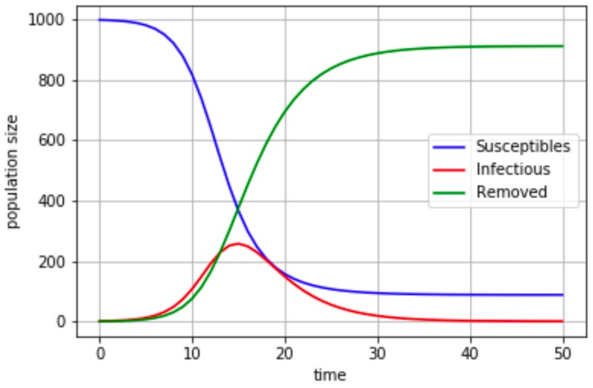


Figure 3. Results of the simulation of the computational equation-based model with odeint integration method: in blue the evolution of susceptible population size, in red the infectious, in green the removed ($\beta = 0.8, \gamma = 0.3, N = 1000, S(0) = 999, I(0) = 1, R(0) = 0, time = [0, 1, \dots, 50]$).

```
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)
```

Finite differences integration

The discretization of the original equations leads to a formulation of the differential equations as finite difference equations

$$\frac{dS}{dt} = \frac{S_{t+1} - S_t}{\Delta t} \rightarrow S_{t+1} = S_t + \frac{dS}{dt} \cdot \Delta t$$

$$S_{t+1} = S_t - \frac{\beta S_t I_t}{N} \Delta t$$

$$I_{t+1} = I_t + \left[\frac{\beta S_t I_t}{N} - \gamma I_t \right] \Delta t$$

$$R_{t+1} = R_t + \gamma I_t \Delta t$$

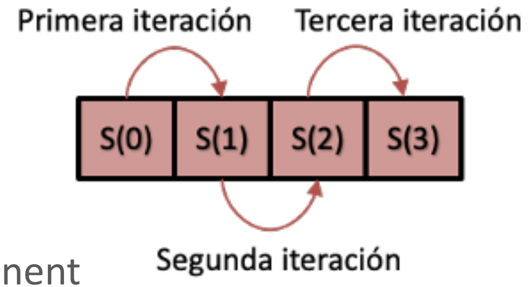
```
S = [N-1]
I = [1]
R = [0]
```

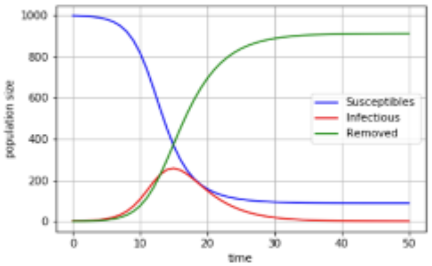
← Initialization of three vectors

```
def population_t1():
    susceptibles_t0 = S[-1]
    infected_t0 = I[-1]
    recovered_t0 = R[-1]
    susceptibles_t1 = susceptibles_t0 - beta*infected_t0*susceptibles_t0/N
    infected_t1 = infected_t0 + beta*infected_t0*susceptibles_t0/N - gamma*infected_t0
    recovered_t1 = recovered_t0 + gamma*infected_t0
    S.append(susceptibles_t1)
    I.append(infected_t1)
    R.append(recovered_t1)
    return S, I, R

for i in range(t):
    SIR = population_t1()
    S = SIR[0]
    I = SIR[1]
    R = SIR[2]
```

← Vectors are built one component at a time: each new component is computed taking the last existing component as the initial condition





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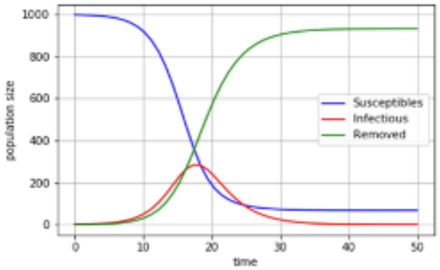


Figure 5. Results of the simulation of the computational equation-based model with finite difference integration method: in blue the evolution of susceptible population size, in red the infectious, in green the removed ($\beta = 0.8$, $\gamma = 0.3$, $N = 1000$, $S(0) = 999$, $I(0) = 1$, $R(0) = 0$, $time = [0, 1, \ldots, 50]$).

- Both the methods seen so far are based on equations
  - The first simulated the model by integrating the system of differential equations using a standard numerical method
  - The second simulated the model making a priori discretization of the equations, converting them into finite difference equations and calculating the populations at each time from the values of the previous time.
- Both methods for simulating the SIR model follow naturally from the model formulation
- In neither case can the single agent be traced (only population variations)

Reformulation of the equations

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

Probability that a susceptible becomes infectious

=

Probability that a susceptible meets an infectious

x

Probability that the infectious infects the susceptible

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

β_c = contact rate

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

β_i = infectivity

Reformulation of the equations

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

Probability that a susceptible becomes infectious

=

Probability that a susceptible meets an infectious

x

Probability that the infectious infects the susceptible

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

β_C = contact rate

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

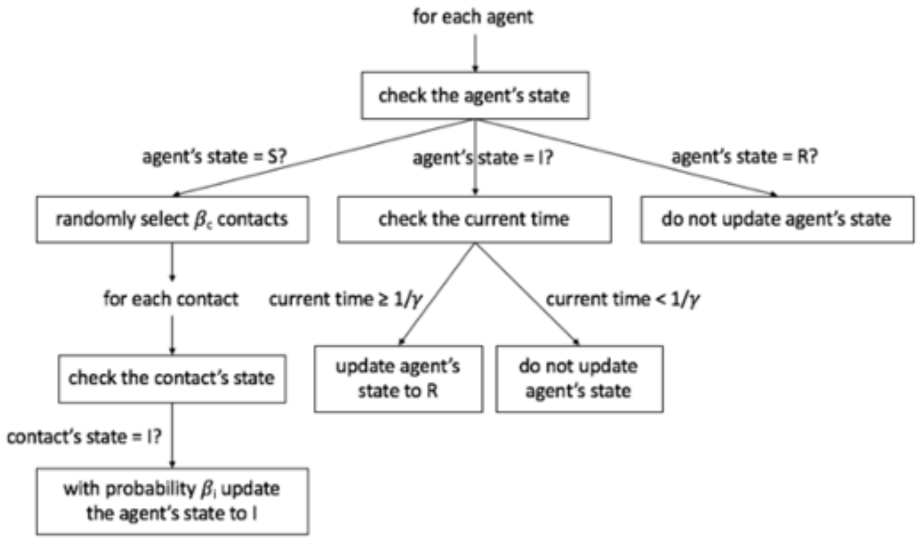
β_i = infectivity

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

What does it change?

The **interpretation of the variables** in the equations underlying the model

Equation-based models	Agent-based models
Frequences/rates of infection and removal	Contacts between individuals Probability of infection Duration of the infective time
Focus on the variation of magnitude of the population (increase or decrease)	Focus on what happens to the agents



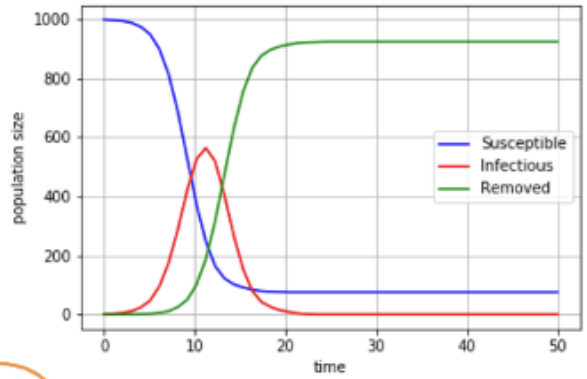


Figure 8. Average results of 100 simulation runs of the computational agent-based model: in blue the evolution of susceptible population size, in red the infectious, in green the removed ($\beta_i = 0.8$, $\beta_c = 1$, $\gamma = 0.3$, $N = 1000$, $S(0) = 999$, $I(0) = 1$, $R(0) = 0$, $time = [0, 1, \dots, 50]$).

Rules

Results

Comparison of methods

- The results obtained by the different modeling methods are similar but not exactly equivalent.
  - The agent model produces different results each time it is executed.
  - This is not the case with equation methods.
- The equation methods also contain information about the probability, but this probability appears in the form of frequencies that are parameterized in the model as constants.

```
betac = 1
betai = 0.8
gamma = 0.3
N = 1000

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

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

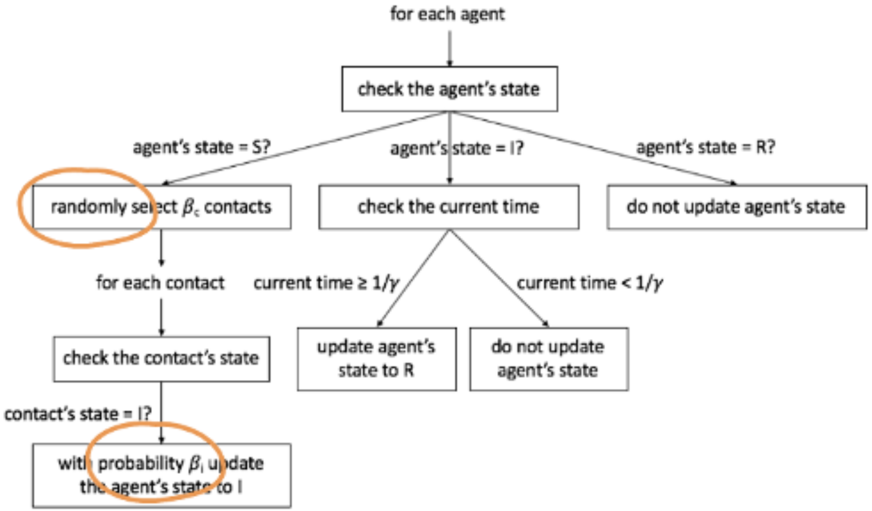
Parameter for the average number of contacts

Parameter of average infection probability

Parameter of average duration of infection

- The agent model is the only one that genuinely includes the stochasticity of the system in its formulation

- Goes beyond the determinism of differential equations



Relationship between system's levels

- equation-based model is top-down, because examines the population as a whole
- agent-based model is bottom-up since the global behaviour of the population emerges from measures on the dynamics of the single agents and on its probabilities to become infected or recovered

Probabilistic character

- probability as constant rates vs
- a given probability at each iteration

Presence of elements of discretization

- Differential equations are continuous both in population and in time (time discretization only due to our need to solve the continuous equations)
- Agent-based model is intrinsically discrete both in population and in time

- In the two types of models and simulations that we have presented, **different STEM disciplines** can be recognized
- This not only refers to the SIR model, but is a common feature of the process that leads to the construction of all computational simulations.

A system S is a simulation of an object or process M if and only if S is a concrete computational device that produces, through a temporal process, solutions for a computational model that correctly represents M.
(Humphrey, 2004)

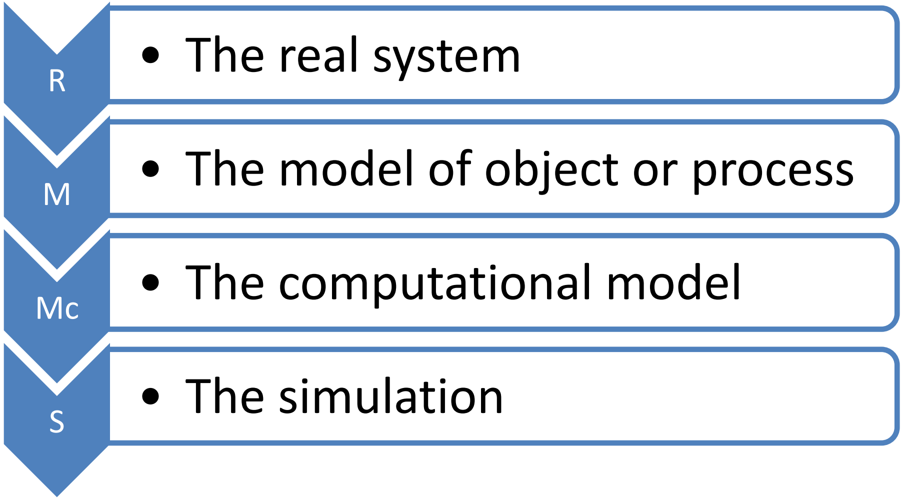
R
- The real system

M
- The model of object or process

Mc
- The computational model

S
- The simulation

- The "physical" model allows moving from the real system to its representation as a model (simplify, reduce, “cut nature at its joints”, Plato)
- From the physical model of the problem to its mathematization
- From the mathematical model to its discretization in space and time to create the computational model



- The "physical" model allows moving from the real system to its re… n as a model … uce, "cut nature at its joints", Plato)
- From the physical model of the p… mathematization
- From the mathematical m… sp… e computational model

Physics

Mathematics

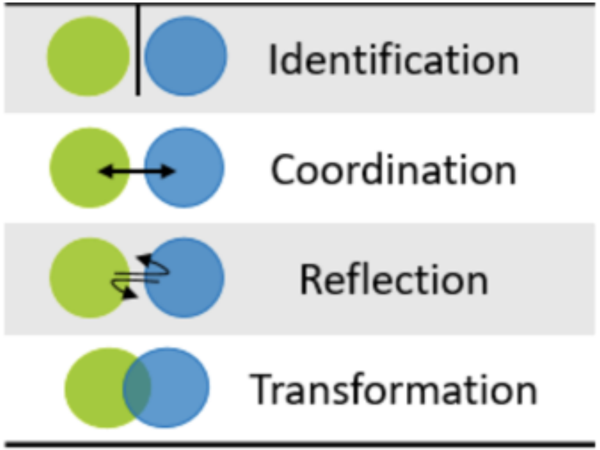
Computer science

R
- The real system

M
- The model of object or process

Mc
- The computational model

S
- The simulation



Identification: identify the different disciplines involved in the interdisciplinary theme and their contributions

Coordination: investigating how different disciplines collaborate together to address an interdisciplinary issue

Reflection: each discipline learns something new about itself thanks to the interaction with other disciplines

Transformation: thanks to the interdisciplinary theme, profound changes in practices occur, potentially even creating a new intermediate practice, sometimes called "boundary practice"

- At the end of the coronavirus module, we guide students to recognize, in the different models explored, the role of disciplines and interdisciplinarity
- We guide them through some questions inspired to the boundary-crossing mechanisms

Identification

What disciplines can you identify in the activities you have experienced? What has been the role of each one? What tools and insights have these disciplines contributed to the overall theme of the module?

Applied Physics for modeling the real system

Mathematics for the writing and interpretation of differential equations and the transition to the discrete version

Computer science to write the code and implement the mathematical model

How would you describe the relationship that has been established between the disciplines involved in the module?

a) Are there problems or issues where the type of knowledge coming from a particular discipline has been sufficient to advance?

b) On the contrary, what problems or issues have required knowledge from different disciplines and their interaction? What were the points that opened the need for disciplinary interaction?

- When it comes to analyzing the components of mathematical equations (for example: positive and negative terms) or determining which computational function is best suited to write the code, there is reasoning that can remain within the single discipline.
- When comparing different types of modeling, on the other hand, we have a dialogue between the disciplines.
    - The comparison between the two modeling strategies based on equations shows the intertwining between the mathematical model and the computational model in terms of the discretization procedures, necessary to obtain the temporal evolution of the compartments.

Reflection

What changes can be observed between the role of each of the disciplines in this interdisciplinary context and the role traditionally assigned to them?

- Comparing the different approaches to simulating a virus simulation may be a way to view the disciplines in a less stereotypical way.
- This reflection allows us to go beyond the dichotomy: “equation based methods are mathematical agent based methods are physical or computational”
- A key concept is that of probability, which appears differently in the two methods.
- Facing this type of confrontation in teaching allows enriching a disciplinary vision that otherwise runs the risk of "flattening"

Transformation

What new knowledge and new interdisciplinary practices have been established thanks to the interaction between disciplines on this topic?

- The epidemiological model becomes, thanks to the comparison between the two methods, a "boundary object"
- The modeling practice itself can be interpreted as an interdisciplinary practice, with its own characteristics that go beyond the characteristics of the disciplines taken individually.
- In particular, agent-based models can be considered boundary objects themselves.
  - Because they have less mathematical formality than equation-based models, they can become a basis for comparison between experts from very different disciplines, allowing for a genuine exchange of skills.

Simulations of epidemiological models can be useful tools in teaching because:

- allow to address a socially relevant problem through authentic scientific tools
- highlight great epistemological debates based on specific problems
- help develop the skills required by society (for example: transformative skills)
- show a real interdisciplinarity between STEM disciplines

IDENTITIES

Enlightening Interdisciplinarity in STEM for Teaching

Thank you for the attention!

Questions…?

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