This subject is part of the paradigm of sustainability and aims to provide ideas, criteria and instruments that facilitate the study of complex problems, related to the evolution and behavior of natural, social and technological systems. Therefore, tools and methodologies in the environment of system dynamics, network analysis and modeling with agents will be used. It is about developing criteria and skills that allow analyzing the behavior of the systems in a qualitative and quantitative way, and their response to certain actions, strategies, policies or action plans.

Learning objectives of the subject

This subject is part of the paradigm of sustainability and aims to provide ideas, criteria and instruments that facilitate the study of complex problems, related to the evolution and behavior of natural, social and technological systems. Therefore, tools and methodologies in the environment of system dynamics, network analysis and modeling with agents will be used. It is about developing criteria and skills that allow analyzing the behavior of the systems in a qualitative and quantitative way, and their response to certain actions, strategies, policies or action plans.

Study load

<table>
<thead>
<tr>
<th>Total learning time: 150h</th>
<th>Hours large group: 30h</th>
<th>20.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours medium group: 30h</td>
<td>20.00%</td>
</tr>
<tr>
<td></td>
<td>Self study: 90h</td>
<td>60.00%</td>
</tr>
</tbody>
</table>
### Unit 1: Fundamentals on complexity and systems thinking

**Learning time:** 30h  
- Theory classes: 6h  
- Practical classes: 6h  
- Self study: 18h

**Description:**  
1.1 From determinism to complexity. Historical summary  
1.2 Characteristics of complex systems  
1.3 Complexity in socio-ecological systems  
1.4 Resilience, collapse and the paths towards unsustainability

**Related activities:**  
- Readings  
- Practices with Excel  
- Practices with NetLogo

**Specific objectives:**  
- Understand the evolution of science from the determinist paradigm to complexity.  
- Know how to define the characteristics of complex systems / problems.  
- Recognize the complexity of socio-ecological systems.  
- Recognize the causes of unsustainability in socio-ecological systems.

### Unit 2: Introduction to modelling

**Learning time:** 30h  
- Theory classes: 6h  
- Practical classes: 6h  
- Self study: 18h

**Description:**  
2.1 Computational models and complex systems  
2.2 The modelling cycle  
2.3 Abstractions vs. agents  
2.4 NetLogo as a modelling tool

**Related activities:**  
- Readings  
- Practices with Excel  
- Practices with NetLogo

**Specific objectives:**  
- Describe the modeling cycle and identify individual tasks within this cycle  
- Describe and compare the main features of equation-based and agent-based modeling  
- Compare and describe bottom-up and top-down modelling approaches  
- Differentiate modeling and simulation  
- Apply the NetLogo programming language to import and export data in and from a computer and carry out basic operations of arithmetic and calculation in this environment  
- Solve mathematical problems by applying NetLogo encoding and procedures  
- Modify existing NetLogo codes
### Unit 3: Equation modeling

<table>
<thead>
<tr>
<th>Description:</th>
<th>Learning time: 30h</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Regime and catastrophic shifts</td>
<td>Theory classes: 6h</td>
</tr>
<tr>
<td>3.2 Definitions and characteristics of dynamical systems</td>
<td>Practical classes: 6h</td>
</tr>
<tr>
<td>3.3 From conceptual maps to causal diagrams</td>
<td>Self study: 18h</td>
</tr>
<tr>
<td>3.4 From causal diagrams to stock and flow diagrams...and differential equations</td>
<td></td>
</tr>
<tr>
<td>3.5 Examples on equation modelling: social collapse, population growth and environmental damage</td>
<td></td>
</tr>
<tr>
<td>3.6 Stability analysis</td>
<td></td>
</tr>
<tr>
<td>3.7 The adaptive cycle and the concept of panarchy</td>
<td></td>
</tr>
</tbody>
</table>

### Related activities:
- Readings
- Practices with Excel
- Practices with NetLogo
- Midterm Exam

### Specific objectives:
- Recognize the mathematical form of a differential equation
- Explain the differences between iterated functions and differential equations
- Classify iterated functions and differential equations into linear and non-linear
- Calculate the trajectory of an iterated function (i.e., iterate a function)
- Find and categorize fixed points in an iterated function
- Translate conceptual maps into causal diagrams, stock and flow diagrams and differential equations
- Employ NetLogo System Dynamics Modeller to implement stock and flow diagrams and numerically solve differential equations
- Execute experiments with NetLogo System Dynamics Modeller to analyze the influence of the parameters in the temporal evolution of a dynamic system.
- Use a spreadsheet (or similar tool) to analyze the results of iterating a function
- Design and write a description of a model following the ODD protocol
### Unit 4: Agent-based modeling

<table>
<thead>
<tr>
<th>Description:</th>
<th>Learning time: 30h</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 From equations to agents</td>
<td>Theory classes: 6h</td>
</tr>
<tr>
<td>4.2 Unbounded growth</td>
<td>Practical classes: 6h</td>
</tr>
<tr>
<td>4.3 Bounded growth</td>
<td>Self study: 18h</td>
</tr>
<tr>
<td>4.4 Consumption of non-renewable resources</td>
<td></td>
</tr>
<tr>
<td>4.5 Consumption of renewable resources</td>
<td></td>
</tr>
<tr>
<td>4.6 Interaction and emergence</td>
<td></td>
</tr>
<tr>
<td>4.7 Theory development, parameterization and calibration</td>
<td></td>
</tr>
<tr>
<td>4.8 Analysing and understanding agent-based modelling</td>
<td></td>
</tr>
</tbody>
</table>

**Related activities:**
- Readings
- Practices with Excel
- Practices with NetLogo

**Specific objectives:**
- Define the concept of probability as used in agent-based modelling.
- Define sensitivity experiment and emergency as used in agent-based modelling.
- Explain the differences between parameterization and calibration.
- Edit an experiment using NetLogo's BehaviourSpace.
- Perform sensitivity experiments in agent-based models using NetLogo's BehaviourSpace.
- Modify NetLogo procedures and codes.
- Use a spreadsheet (or similar tool) to analyze the results of sensitivity experiments by means of pivot tables and graphs.
Qualification system

The weights in the evaluation are the following:
1st written exam (25%)
2nd written exam (25%) with option to reconduct the 1st written exam (*)
Tasks and questionnaires (50%)

(*) This reconduction can be accessed by students with a mark less than 4.0 points corresponding to the 1st exam. It will consist of a series of questions that will allow you to obtain 4.0 points if you respond correctly. The mark obtained by the application of the conversion will replace the initial qualification of the 1st exam whenever it is higher.
Bibliography

Basic:


Others resources:

Those suggested as the course goes on