INTRODUCING COMPLEXITY SCIENCE IN HIGHER EDUCATION FOR PREPARING THE NEW GENERATIONS TO BE AWARE AND PROMOTE A SUSTAINABLE FUTURE.

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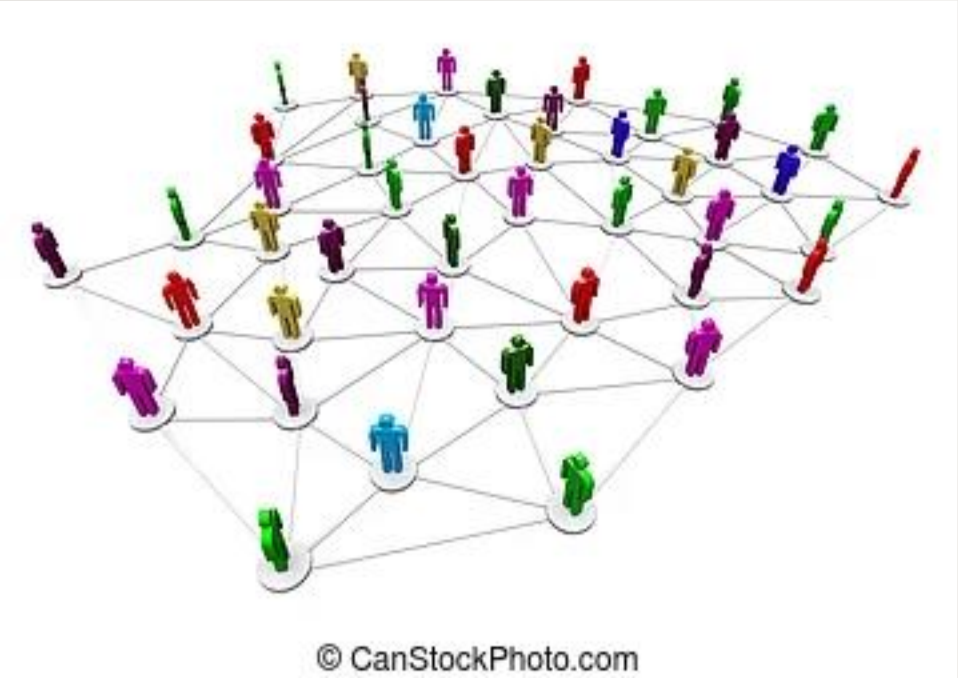
International Conference New Perspectives in Science Education

One Relevant Purpose of Science is Solving Problems and Improving the Psychophysical Wellbeing of Humans.

PERSONAL NEEDS

GLOBAL CHALLENGES

MEANS OF TRANSPORT
and
INFORMATION AND COMMUNICATION TECHNOLOGIES



GLOBAL CHALLENGES

1) **They might regard almost everyone on Earth**

2) **They might be multi-sectorial because they encompass humanity under different points of view, such as health, social, political, cultural, ethical, and economical.**

GLOBAL CHALLENGES REQUIRE **GLOBAL AGENDAS** TO BE FACED AND WON

human beings

their societies

world economy

urban areas

natural ecosystems

climate

MONODISCIPLINARY TEACHING

↓

SPECIALISTS

COMPLEX SYSTEMS

SPECIALISTS
and
POLYMATHS (GENERALISTS, HYBRID FIGURES)

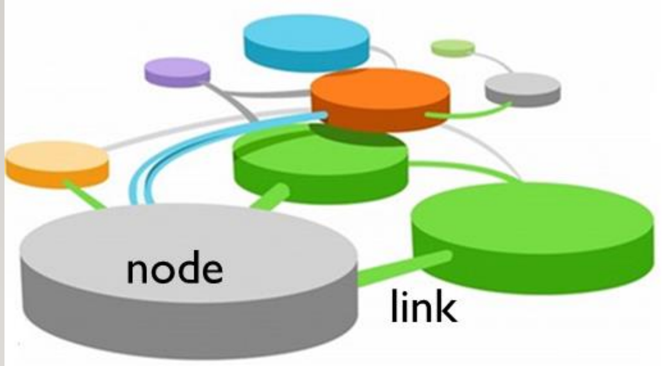
COMPLEXITY SCIENCE

Complexity Science outlines
the phenomenology and laws of Complex Systems
and gives
the thinking skills to tackle global challenges.

- Human beings
- Human societies
- World economy
- Urban Areas
- Natural ecosystems
- Climate

THREE RELEVANT FEATURES

COMPLEX SYSTEMS CAN BE DESCRIBED AS NETWORKS



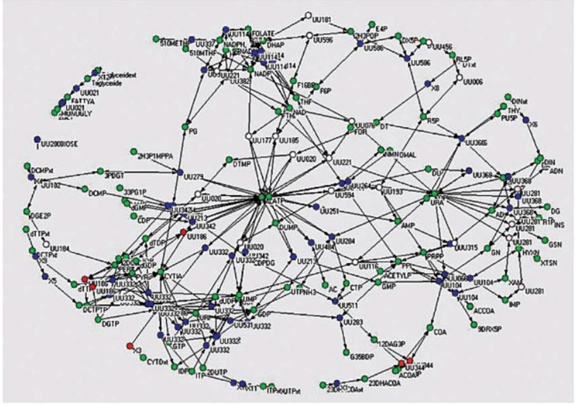
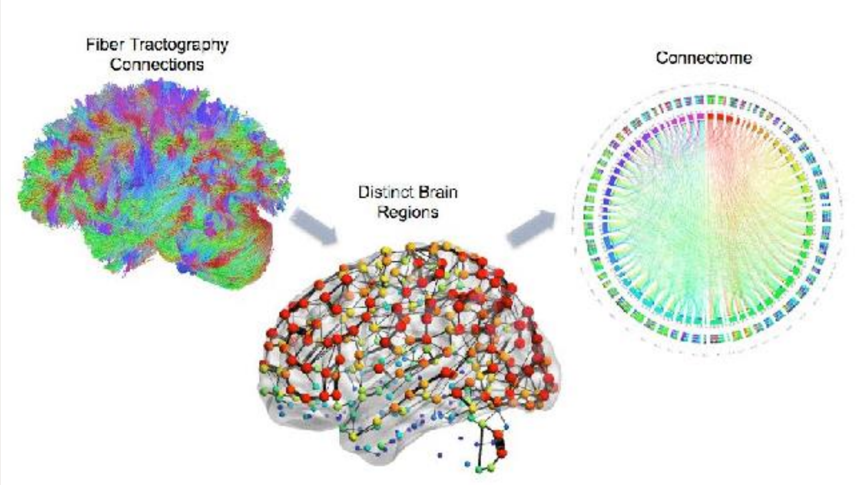
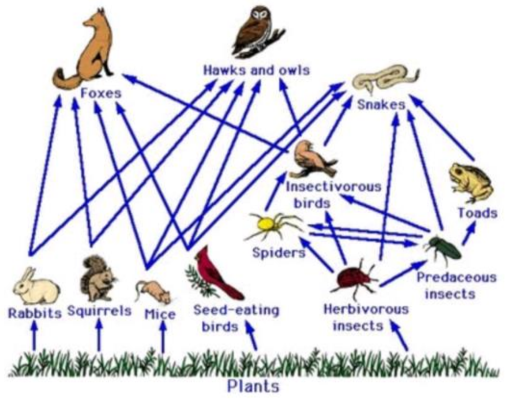


Figure 2. Bipartite graph of the metabolic network of *Ureaplasma urealyticum*. Dark gray and white nodes represent enzymes and light gray nodes represent metabolites (Lemke et al., 2004).

Metabolic Network



https://www.researchgate.net/figure/Brain-Network-Connectome-The-fiber-tractography-DWI-structural-connections-are-used_fig2_335341120



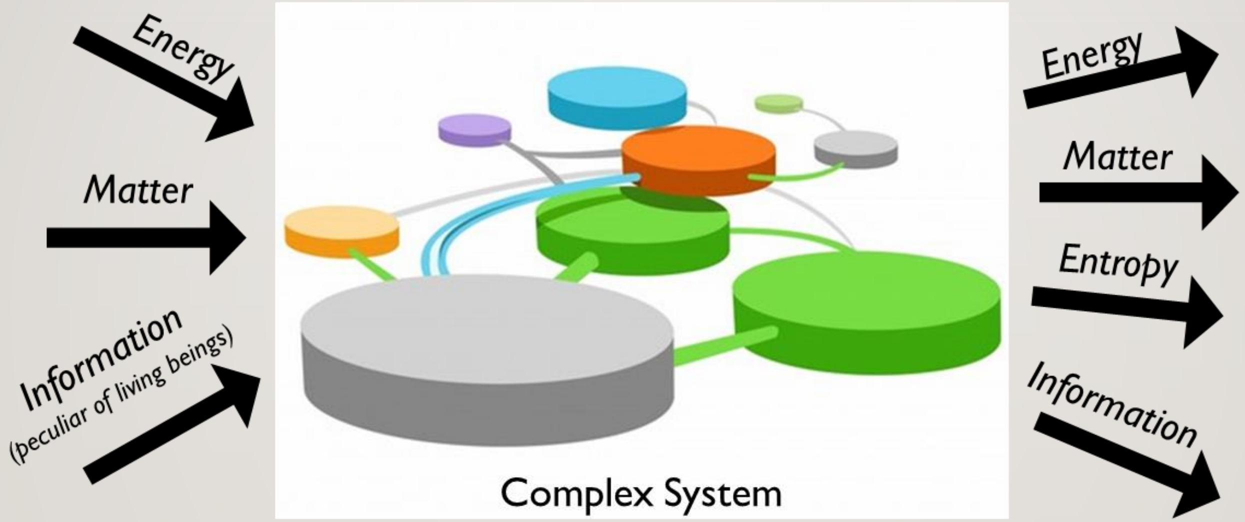
Food Web

http://1.bp.blogspot.com/_vIFBm3t8boU/SBhzqbchIeI/AAAAAAAAAXk/RsC-Pj45Avc/s400/food%2Bweb.bmp

- **Different Complex Systems have distinct architectures.**
- **For most Complex Systems, nodes and links are diverse and their behavior variable.**
- **There are numerous feedback actions, and networks are characterized by high degrees of non-linearity.**

NETWORK SCIENCE

COMPLEX SYSTEMS ARE "**OUT-OF-EQUILIBRIUM**" IN THE **THERMODYNAMIC SENSE**.

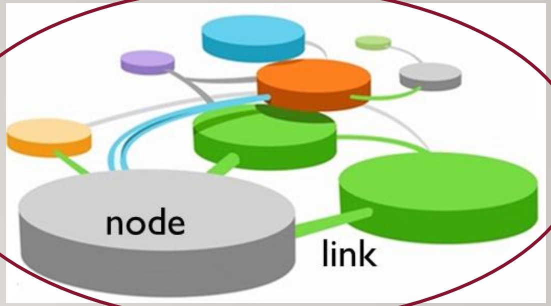


If inanimate,
it is driven by ***FORCE FIELDS.***

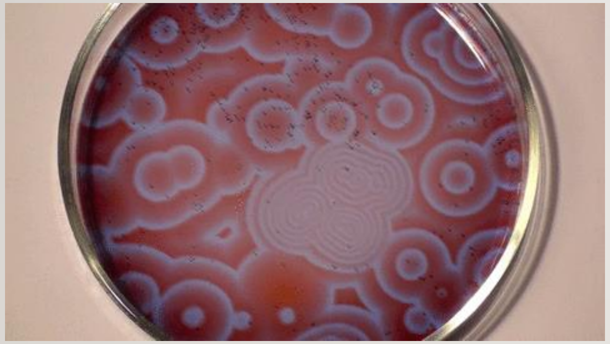
If it involves living beings, its behavior also depends on the **INFORMATION** that the living beings collect, store, process, and send to pursue their **GOALS**.

OUT-OF-EQUILIBRIUM THERMODYNAMICS

COMPLEX SYSTEMS EXHIBIT **EMERGENT PROPERTIES**



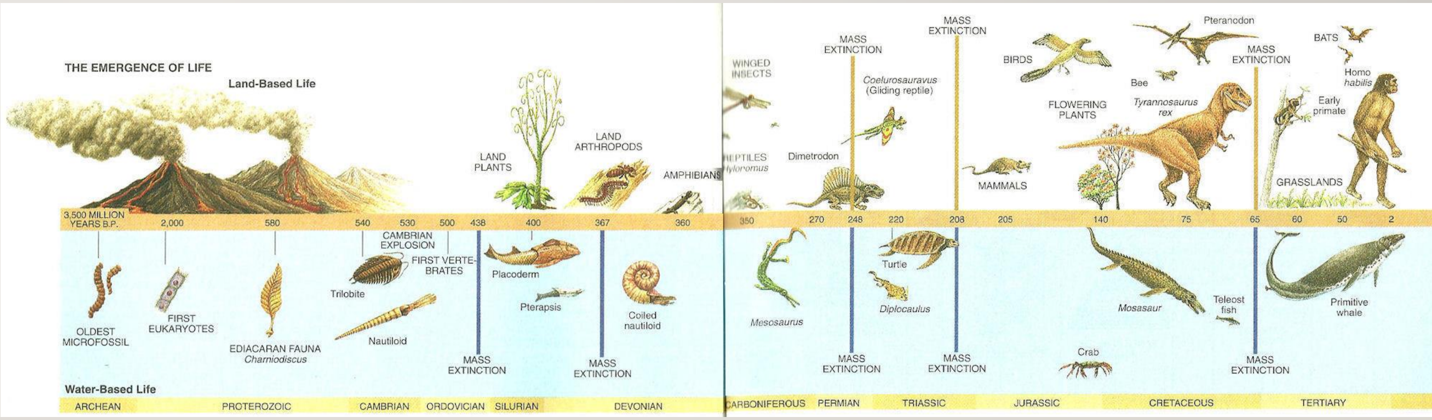
The emergent property belongs to the network as a whole

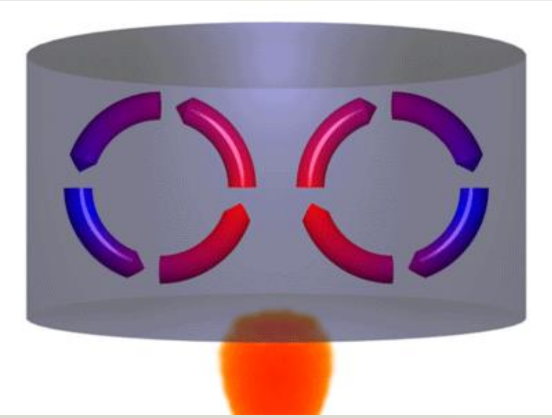


https://www.pinterest.de/peggygeibig/animated-gifs/

Some emergent properties are not fully understood and predictable

The phenomenon of life, its appearance on Earth and its evolution





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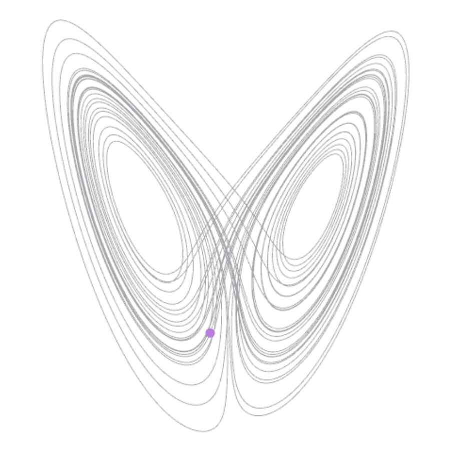


https://haowen-math.com/

NON-LINEAR DYNAMICS

Why?

EPISTEMOLOGICAL COMPLEXITY

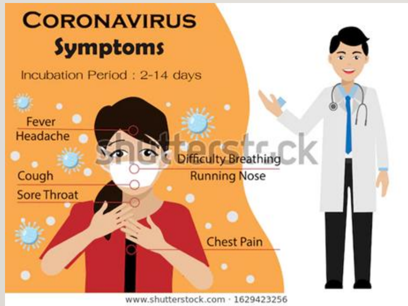
I) DESCRIPTIVE COMPLEXITY

Difficulties in describing Complex Systems, which depend on:

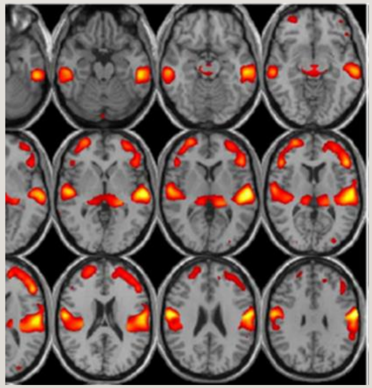
- **The number of nodes, their diversity, and variability of behaviour;**
- **The number of links, their diversity, and variability;**
- **Sensitivity of all these features to the context.**

Some emergent properties of Complex Systems have the features of «Variable Patterns»:

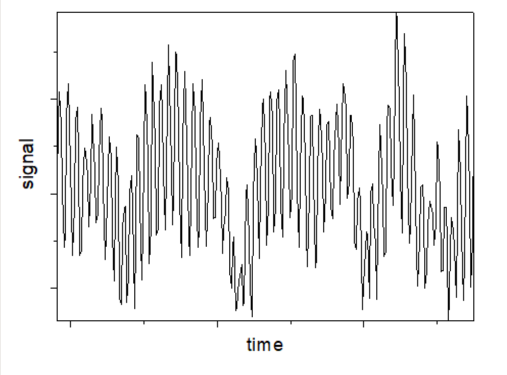
Biological species



Patterns and symptoms in medical diagnosis



Social, political, and economic events



Deterministic Chaos or Stochastic process?

There are no universally valid and effective algorithms for recognizing variable patterns

EPISTEMOLOGICAL COMPLEXITY

2) COMPUTATIONAL COMPLEXITY

Most of the Computational Problems regarding Complex Systems are Solvable, but Intractable:

- *scheduling,*
- *Traveling Salesman Problem*
- *the Schrödinger equation*
- *machine-learning*
- *financial-forecasting*

$if\ N$ is the dimension of the problem

Polynomial (P) Problems
(Recognition problems)

$n° \, comp.steps \propto N^x$

$x = 1, 2, \ldots$

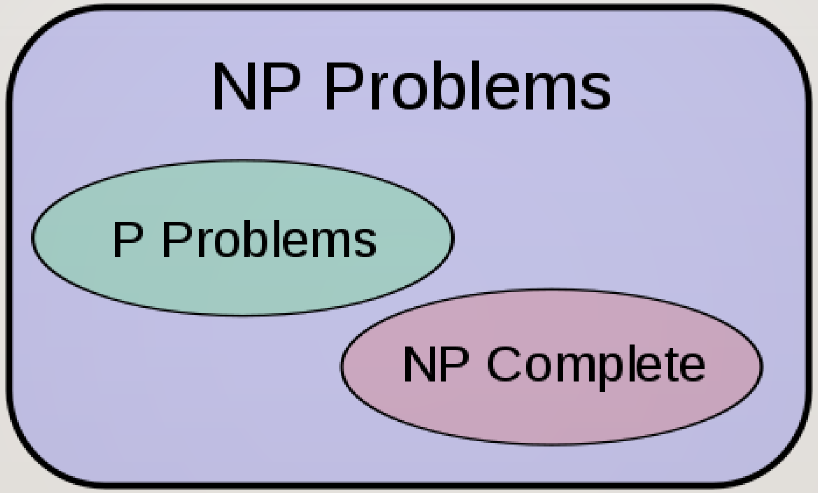
TRACTABLE

Exponential Problems $n° \, comp.steps \propto N! \approx N^N, 2^N$ ***INTRACTABLE***

EPISTEMOLOGICAL COMPLEXITY

2) COMPUTATIONAL COMPLEXITY

Exponential Problems → Non-Deterministic Polynomial (NP) Problems



The Clay Mathematics Institute in Cambridge (MA, USA) has declared **"P versus NP"** as one of its "Millenium" problems

It offers 1 million of dollars to anyone who provides a verified proof that either $NP = P$ or $NP \neq P$.

https://www.photofunky.net/i/c918fe

EPISTEMOLOGICAL COMPLEXITY

3) The Predictive Power of Science has Intrinsic Limitations

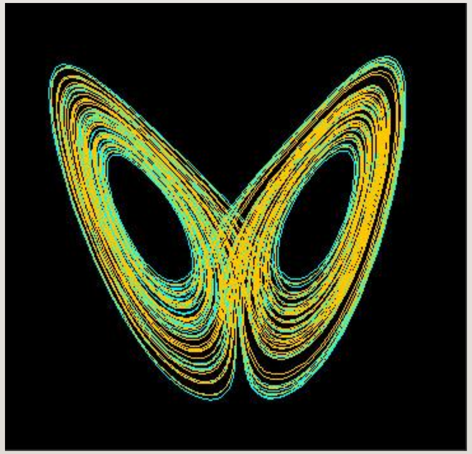
MICROSCOPIC WORLD

3a) The Heisenberg Uncertainty Principle

$$\Delta p \, \Delta x \geq \frac{1}{2} \hbar$$

MACROSCOPIC WORLD

Chaotic dynamics are aperiodic and expremely sensitive to the initial conditions



The determinations of the initial conditions are always affected by uncertainties and errors.

3b) If the Complex System exhibits chaotic behavior, its dynamic is unpredictable in the long term, by definition.

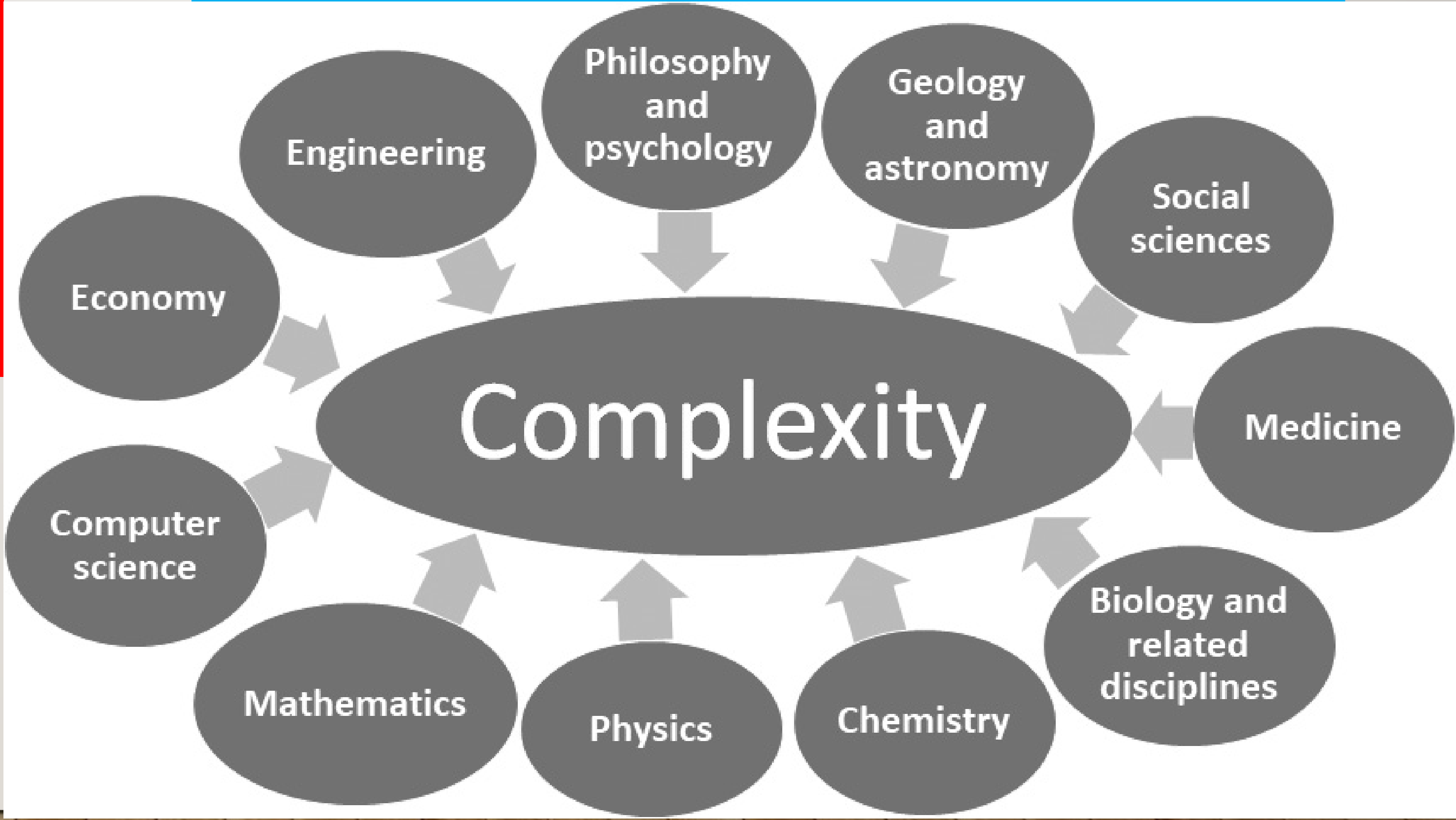
NATURAL COMPLEXITY

- Ontology of Complexity
  - Newtorks
  - Ouf-of-equilibrium
  - Emergent properties
- Epistemology of Complexity
  - Descriptive Complexity
  - Computational Complexity
  - The intrinsic limitations in the predictive power of science

How can we prepare the next generations to be aware and promote a sustainable future? How can we reach the goals of the 2030 Agenda, win any global challenge of the XXI century?

THINKING SKILLS

I) INTERDISCIPLINARY APPROACH in RESEARCH and TEACHING



JOURNAL OF CHEMICAL EDUCATION

Commentary

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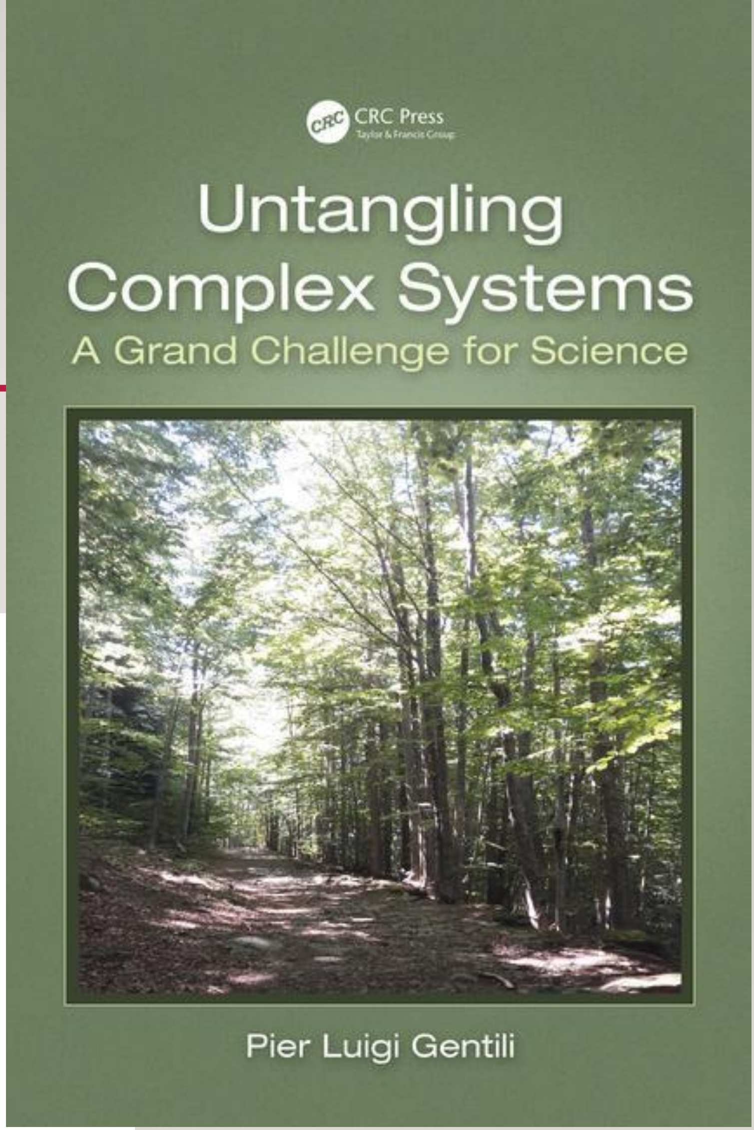
pubs.acs.org/jchemeduc

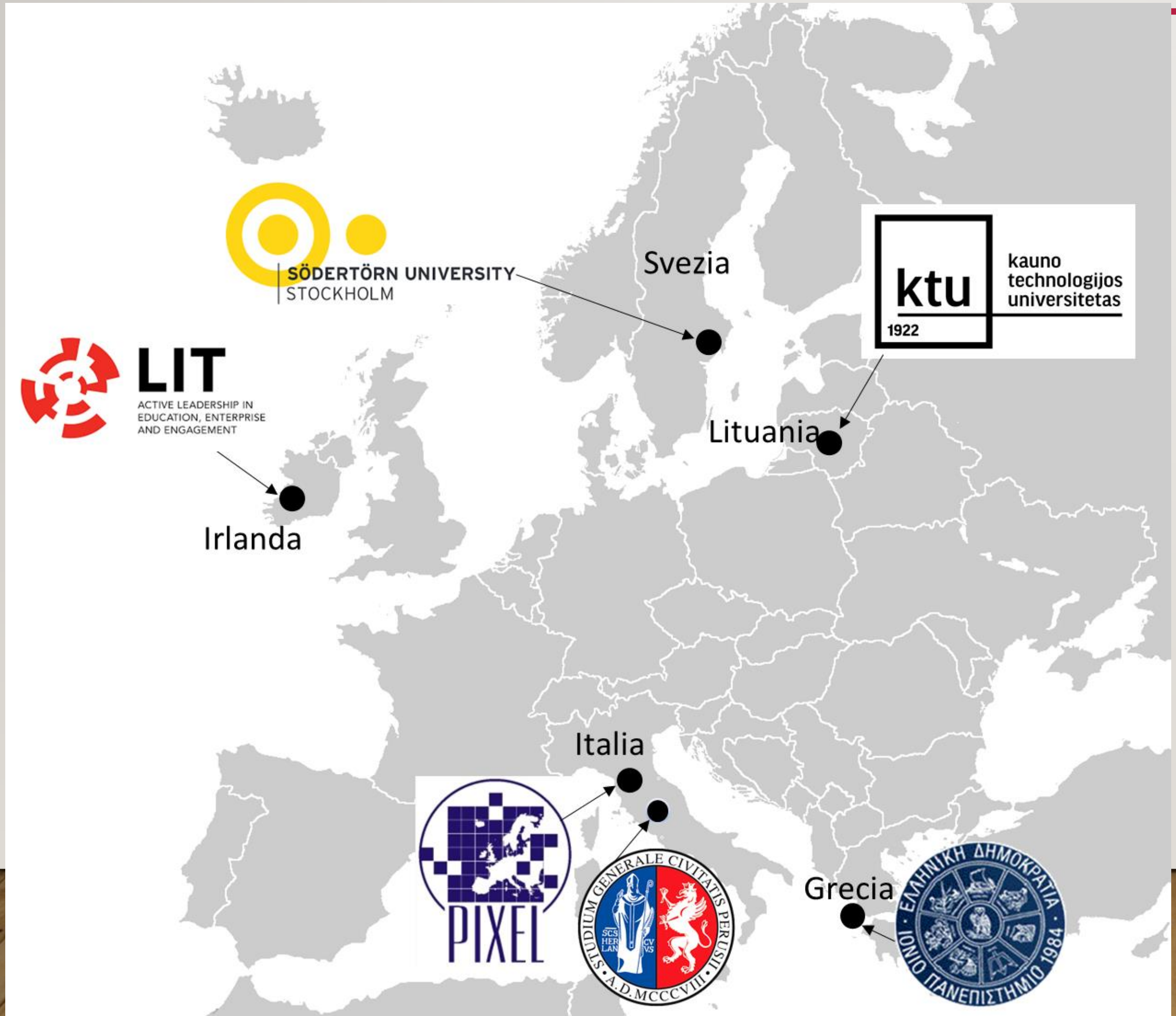
Designing and Teaching a Novel Interdisciplinary Course on Complex Systems To Prepare New Generations To Address 21st-Century Challenges

Pier Luigi Gentili*



Index of the book

«ENHANCING HIGHER EDUCATION ON COMPLEX SYSTEMS THINKING FOR SUSTAINABLE DEVELOPMENT»



Period: 01/09/2020 – 01/09/2023

CoSY Thinking

Overall fund: 347800 Euro

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THE INVESTIGATION OF COMPLEX SYSTEMS

(2)

SYSTEMIC APPROACH

- **Cognitive Maps, Systems Thinking Concept Map Extension (SOCME), and Geographical Information Systems (GISs).**
- **Service Learning**

- **Computer Simulations**
- **Agent-based Modeling**

(3)

NON-LINEAR MINDSET **Vs.** **CLOCKWORK MINDSET**

Positive and negative feedback actions,
Emergent phenomena,
Decentralized control

Reductive understandings,
Centralized control,
Linear cause-and-effect relationships

THE INVESTIGATION OF COMPLEX SYSTEMS

(4)

ALGORITHMIC THINKING

NATURAL COMPUTING

Rationale: ***any distinguishable physico-chemical state of matter and energy can be used to encode information, and every natural transformation is a kind of computation***

THREE-STEPS PROCEDURE:

A) Analysis at the COMPUTATIONAL LEVEL

B) Analysis at the ALGORITHMIC LEVEL

C) Analysis at the IMPLEMENTATION LEVEL

Replicas of Complex Systems

THE DIMENSIONS OF SUSTAINABLE DEVELOPMENT

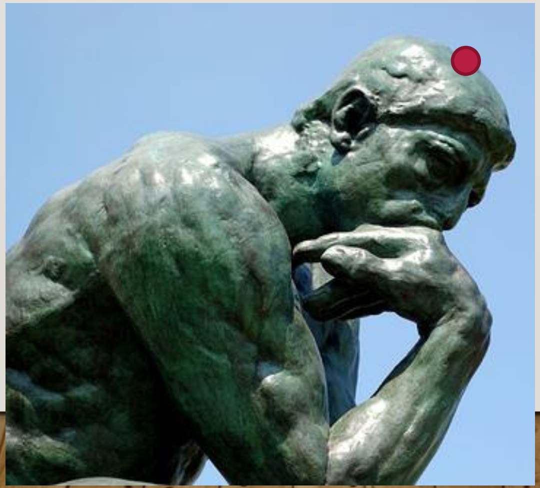
ECONOMIC

ETHICAL

SOCIETAL

ENVIRONMENTAL

"Is always fair to do what technology makes doable?"



The Thinker (by A. Rodin, Philadelphia)

SCIENCE AND OTHER FORMS OF KNOWLEDGE

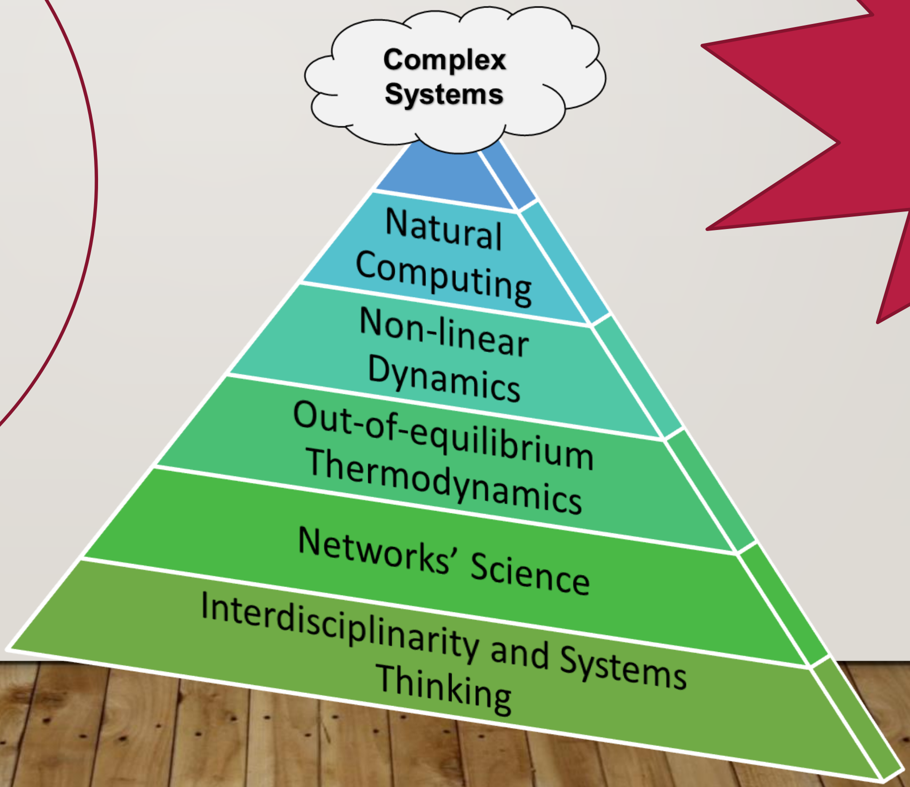
CONCLUSIONS

It is urgent to form polymaths who can face global challenges.

Their education should hinge on Complexity Science.

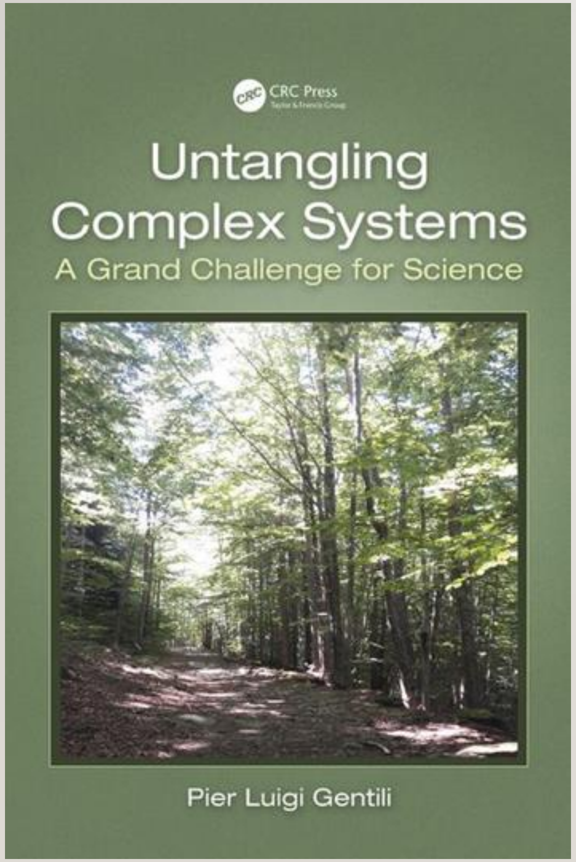
Wikipedia

As long as a branch of science tries to face an abundance of problems, so long it is alive; a lack of problems foreshadows extinction or the cessation of independent development.

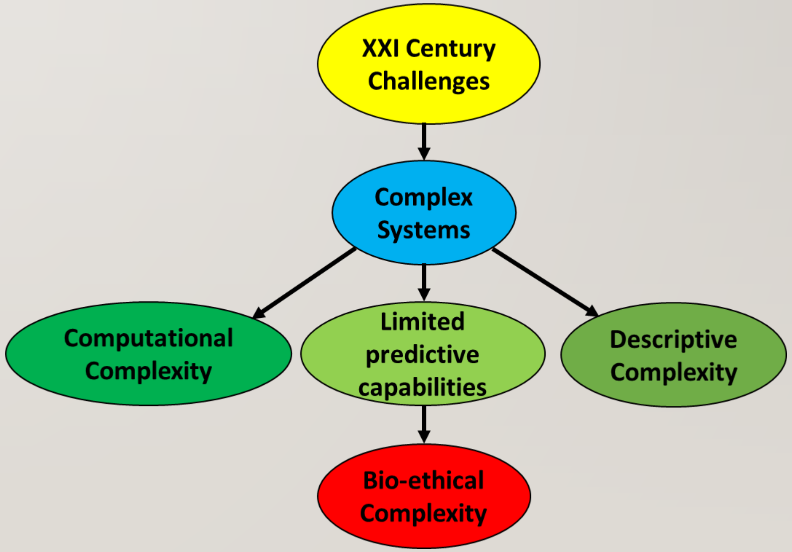


Complexity Science is particularly alive

MORE INFORMATION



Gentili, P.L.
"**Why is Complexity Science valuable for reaching the goals of the UN 2030 Agenda?.**"
Rend. Fis. Acc. Lincei 32, 117–134 (2021).
https://doi.org/10.1007/s12210-020-00972-0



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