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ARTIFICIAL INTELLIGENCE

Teaching-learning module - July 28th 2019

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I SEE

It's your time to imagine the futures

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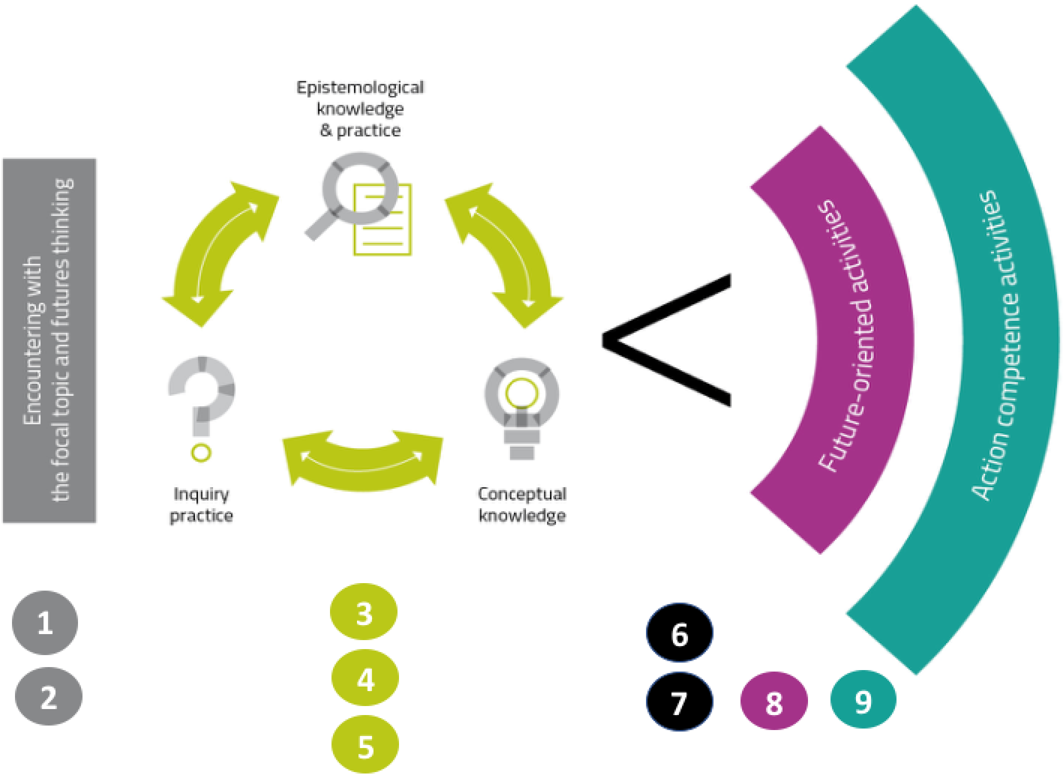
Overview of the module

This module aims to develop upper secondary school students' future-thinking skills, imagination and agency on societal issues in the context of artificial intelligence (AI).
The topic has been chosen for its increasing impact on society, for the epistemological change that AI underwent through its development over the 19th century up to the 'Big Data' sciences, and for its relevance for future-oriented activities.
The module is articulated in three main phases. In the first phase, students are introduced to the contexts of AI applications *now, in the present,* through a lecture and a group activity. In the second phase, through experts' lectures and interactive activities, students are guided in a comparison of different approaches to AI: symbolic approaches (imperative or logic programming) and the sub-symbolic (neural networks). In the third and final phase, future-oriented activities are proposed, with the aim of turning the addressed STEM concepts into future-scaffolding skills: the students are required to project themselves into a desirable future in 2040, and then identify, in this scenario, a problem solved through AI and propose an action that, in 2018, contributed to addressing it.
The module has been implemented and tested in five contexts (119 students in total): at the 'Liceo Einstein' in Rimini and at the Department of Physics and Astronomy of the University of Bologna (January-February 2018, about 20 hours for each implementation, 50 students in total); during a summer school at the Department of Physics and Astronomy, University of Bologna (June 2018, 36 hours, 40 students); at the 'Liceo Einstein' in Rimini (November-December 2018, 20 hours, 20 students). In February 2019, the module was adapted for implementation in a Finnish context for 9 students.
The materials here reported are the result of a multiphase process of refinement. The Finnish re-adaptation of the module led to the production of an alternative activity and a different combination of the existing activities. The Finnish "path" and an outline of the re-adapted module are described in the Annex.
The general philosophy and overall approach to the module are described in the *I SEE module guide*, which we suggest consulting before tackling the activities.

Summary

Activities in the overall module structure



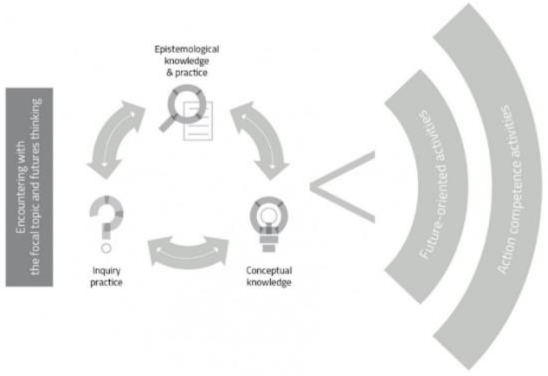
Preliminary essay, before the implementation

If the teacher wishes, he/she may give students a preliminary assignment, in which students are asked to write an essay about a summer day in 2035 (or another year about 20-25 years from now). The aim of the assignment is to highlight students' assumptions, hopes and fears about the future.

In the Back to the Future and/or Backcasting activities, students are helped to revise their earlier future visions in light of the new knowledge and perspectives acquired during the module and see how their ideas have changed.

The assignment can be found here.

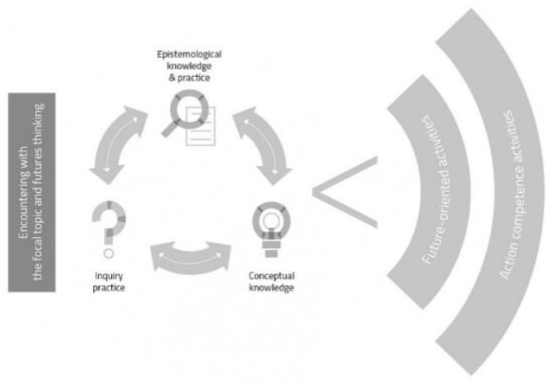
ACTIVITY 1:
OVERVIEW LECTURES ON ARTIFICIAL INTELLIGENCE
AND THE PERSPECTIVE OF COMPLEXITY

<table>
<tr><td>Position in the module</td><td>
</td></tr>
<tr><td>Encountering the focal topic</td><td>The activity consists of two overview lectures: the first held by an expert in AI (Prof. Paola Mello, University of Bologna), the second held by an expert in science of complex systems (Prof. Gianni Zanarini, University of Bologna).
The lectures aim to introduce conceptual and epistemological knowledge that will be developed and examined in depth in the module.
Focus is on:
the development of (AI) over the last few years (first lecture);
the different approaches to teaching a machine “to reason” and to solve a problem (first lecture);
the significance of studying a problem from the point of view of complexity (second lecture).</td></tr>
<tr><td>Goals</td><td>conceptual
to introduce the concept that AI applications have implications today in different dimensions (political, social, economic, ethical, professional ...)
to know that there are different approaches to teaching a machine “to reason” and solve a problem;
to begin to understand that the main difference between the approaches is that of top-down/symbolic and bottom-up/sub-symbolic directions;
to begin to understand that the bottom-up/sub-symbolic approach represents a deep paradigm shift from the top-down/symbolic model;
to understand that AI opens up new opportunities and perspectives in the job market;
to begin to understand what it means to study a problem from the point of view of complexity;
to begin to understand the most significant aspects that characterise a complex system.
epistemological
to begin to recognise the importance - in evaluating the impact of an AI application - of taking into account different dimensions; (political, social, economic, ethical, environmental, professional...);
to begin to recognise the importance of taking into account the point of view of complexity.
social/emotional</td></tr>
</table>

	• to begin to reflect on the risks and potentialities of different AI applications; • to begin to widen the imagination about possible future STEM careers.
Time required	2/2.5 hours for lecture with time for discussion
Materials	***Slides of the first lecture*** • the development of AI, from its emergence to recent years: the different fields of applications and implications in different dimensions (political, social, economic, ethical, professional...); • the different approaches to reasoning and solving a problem (top-down/symbolic and bottom-up/sub-symbolic); • focus on a selection of significant aspects that characterise each approach. In particular: ✓ the nature of the knowledge base and of the strategy ✓ why an approach is top-down or bottom-up ✓ why an approach is symbolic or sub-symbolic ***Slides of the second lecture and written text*** • the meaning of *complex system* (examples from everyday life such as the flock of birds or cars on a traffic roundabout); • focus on a selection of significant aspects that characterise a complex system; • the behaviour of a complex system studied via computer: the simulations; • the brain as a complex system made up of a huge number of elements (neurons); • brain simulation and neural networks.
Teaching methods	During the lecture: everyone is invited to comment or request clarification where necessary. At the end of the lecture: everyone is invited to participate in the debate with comments or personal knowledge.
Tips for teachers from previous classroom experiences	It is very important to think of the lecture as an overview of concepts that will then be addressed during the module. If a teacher decides to invite an expert speaker, it is important to decide the concepts and the focus, so as to avoid sidetracking.
Additional resources	• P. Domigos. A Few Useful Things to Know about Machine Learning. • P. Domingos. The Master Algorithm: How the Quest for the Ultimate Learning Machine Will Remake Our World. Basic Books, New York, NY, 2015. • Gutierrez-Osuna, Course introduction about pattern recognition, http://faculty.cse.tamu.edu/rgutier

ACTIVITY 1bis:
THE WORDS OF COMPLEXITY

<table>
<tr><td>Position in the module

Encountering the focal topic</td><td>

The activity consists of two teamwork tasks, aimed at reinforcing the concepts of complexity introduced in the overview lecture (section: Encountering the focal issue)</td></tr>
<tr><td>Goals</td><td>conceptual
to understand what it means to study a problem from the point of view of complexity;
to understand the most significant aspects that characterise a complex system;
to understand the necessity of a new lexicon, the words of complexity
epistemological
to recognise the importance of taking into account the point of view of complexity;
to recognise the importance of adopting a new lexicon, the words of complexity
social/emotional
to become actively engaged in group or collective discussion</td></tr>
<tr><td>Time required</td><td>20 minutes for the first teamwork task
15 minutes for the discussion
30 minutes for the second teamwork task
15 minutes for the discussion</td></tr>
<tr><td>Materials</td><td>The materials consist of two worksheets and two simulations in Net Logo - the flight of a flock of birds and the spread of a virus.

The first worksheet
A sentence taken from the site www.pluchino.it, “experimenting with the Physics of Chaos and Complex Systems” is stated. The sentence, which introduces a series of simulations of complex systems, sets out the main features of a complex system.
The worksheet includes the following steps:
read the sentence very carefully and try to identify the words/phrases that you think characterise a complex system; also, highlight the words/phrases that are not clear to you or whose meaning you do not know.
write down your observations highlighting those that, from your discussion, have emerged as fundamental features of a complex system</td></tr>
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<tr><td></td><td>The second worksheet
Two simulations are described, the first regarding the flight of a flock of birds, the second regarding the spread of a virus.
The worksheet includes the following steps:
explore the two simulations;
for each one, highlight the typical characteristics of the complex systems as discussed in the first teamwork task</td></tr>
<tr><td>Teaching methods</td><td>Teamwork
The groups are made up of four/five students and are formed spontaneously; the only constraint is a similar number of males and females.
The students of each group are encouraged to:
read the document carefully
discuss together in the group
report the group's observations on the sheet.
At the end of the first teamwork task:
the teacher writes up on the blackboard what has emerged from the groups, compiling a "list" of shared features of a complex system to be defined as “the words of complexity”
At the end of the second teamwork task:
each group reports on what emerged from the exploration of the simulations and the group discussion.
For each simulation, the features of the complex system considered are written on the blackboard and the results are shared.</td></tr>
<tr><td>Tips for teachers from previous classroom experiences</td><td>This activity was introduced in the lesson following the overview lecture in the third implementation of the module in class. During the first two implementations, the complexity was introduced in the overview lecture and then its main features were addressed during the activities in the central phase of the module, highlighting its links with the topic; the mode of presentation was frontal lessons.
In the final interviews, however, the students showed that they had poorly internalised the concepts; they had not fully understood what it means to look at a problem from the perspective of complexity. The features of a complex system could, at first sight, appear to be simple concepts because we can encounter them in our daily experiences, almost comparable to common sense; it is necessary to adopt the concepts in order to realise how deeply the situation changes when dealing with a problem via the approach of complexity.
This activity, presented immediately after the introduction of the main concepts, is intended to highlight (in concrete activities and with collective discussions) the peculiarities and difficulties of the point of view of complexity, but also to find, in the end, a shared vocabulary of complexity with which to discuss and reflect.
In the final interviews, the students showed greater awareness of the importance of addressing and elaborating these concepts which are necessary to negotiate the complexity of the world.</td></tr>
<tr><td>Additional resources</td><td>E. Morin, On complexity, Hampton Press, 2008.
R. Serra, G. Zanarini, Complex Systems and Cognitive processes, Springer-Verlag, 1990.</td></tr>
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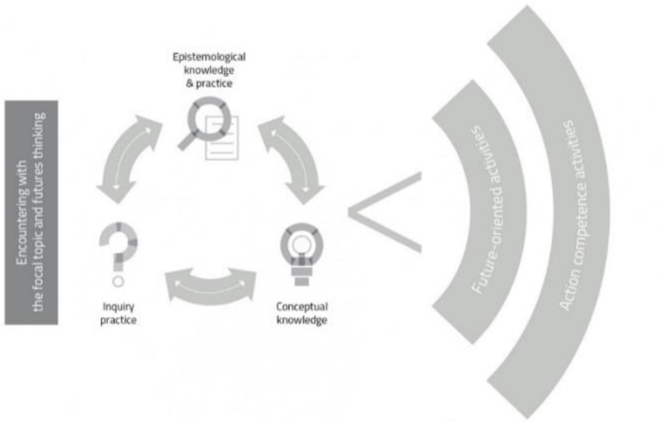
ACTIVITY 2:
AI EVERYWHERE!

Position in the module *Encountering the focal issue*	 The activity sets out to build a map of the state of the art of AI, i.e. an *overall picture* of where AI can be encountered. Particular emphasis is placed on: • the different fields of AI applications (archaeology, art, services, scientific research, …) • the risks and potentialities of AI applications • future changes in the job market and STEM careers
Goals	***conceptual*** ● to understand that AI applications involve different fields (scientific, social, artistic, …) ● to understand that each AI application has implications in different dimensions (political, social, economic, ethical, environmental, professional. ...) ● to understand that AI opens up new opportunities and perspectives in the job market ● to be introduced to the AI specific language ***epistemological*** ● to begin to recognise the importance - in evaluating the impact of an AI application - of considering different dimensions (political, social, economic, ethical, environmental, professional...) ***social/emotional*** ● to begin to reflect on the risks and potentialities of different AI applications according to own world view and values ● to widen imagination about possible future STEM careers ● to actively engage students in group discussion, according to their own interests ● to learn to share different points of view ● to acquire the ability to mediate between different points of view
Time required	1 hour for teamwork. 5 minutes (per group) to distribute the workload.

Materials	***Six cards***
	Each card refers to an application of AI in different fields (Archaeology, Art, Astronomical Observations, Services, Scientific Research, Autonomous Vehicles)
	Each card has the same format; the description comprises three sections:
	● definitions
	● examples
	● links to external resources with a short description of each link
	
	Worksheet
	The worksheet includes three activities:
	1. the group is asked to decide which applications and/or aspects are more interesting/preferable for them, specifying why; which applications and/or aspects are more worrying/frightful, specifying why
	2. the group is asked to focus on one application (following their own criterion of choice) and
	  ● to indicate what potential and what risks are considered to be related to the application
	  ● to indicate what possible changes can be produced by a large-scale dissemination of that application in different dimensions: political, social, economic, ethical, environmental, professional…
	  ● to think about new professions, and which professions could be replaced by the applications
	3. to imagine a possible scenario in 2040 indicating at least two or three serious changes that the progress of the chosen AI application could make in daily life and in the surrounding reality

Teaching methods	***Teamwork*** The groups are made up of four/five students and are formed spontaneously; the only constraint is an equal or similar number of males and females. The teacher guides the discussion between the members of the group and helps to orient them in reading and becoming acquainted with the materials. The students of each group have to ● quickly read the cards ● discuss together and elaborate on the identified links when they consider it appropriate ● reach an agreement ● report the group's answer to questions on the sheet
Tips for teachers from previous classroom experiences	The teacher can choose whether or not the activity should be introduced by a shared definition of AI. In our experience, if the activity is not introduced by any definition, a productive "surprise effect" can be created. The activity appears very effective in fostering deep and active discussions. In our experience the students showed interest and were surprised to discover the wide spectrum of AI applications. Activity 3 of the worksheet can be assigned as homework to allow more time and foster imagination for the following activities. In our experience the students struggle to imagine, in a creative way, future implications of AI.
Additional resources	• E. Brynjolfsson and A. McAfee. *The Second Machine Age: Work, Progress, and prosperity in a Time of Brilliant Technologies*, Norton & Co, 2014. • John E. Kelly III and S. Hamm. *Smart Machines, IBM's Watson and Era of Cognitive*

	Computing, Columbia University Press, 2013. • C. B. Frey and M. A. Osborne. *The future of employment: how susceptible are jobs to computerisation?* Technological Forecasting and Social Change, vol. 114, pp. 254-280, 2017. • https://www.accenture.com/se-en/insights/artificial-intelligence-index • https://www.weforum.org/system-initiatives/shaping-the-future-of-education-gender-and-work

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ACTIVITY 3:
INTRODUCTION TO THE IMPERATIVE APPROACH

<table>
<tr>
<td>Position in the module

Epistemological Knowledge & Practice

Conceptual Knowledge

Inquiry Practice</td>
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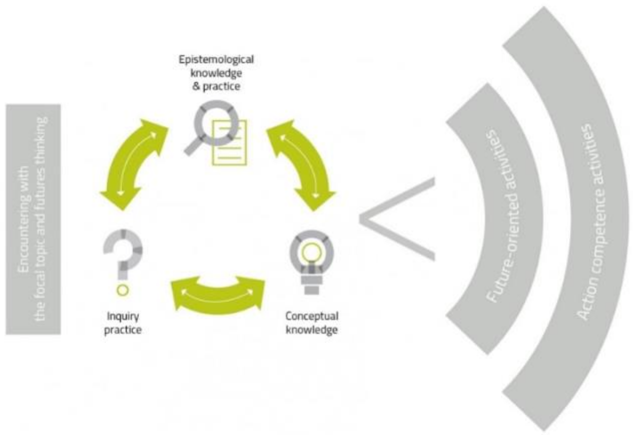

The activity envisages an introduction to the imperative approach, highlighting the form of reasoning that is employed and, in particular, stressing:
✓ what an algorithm is;
✓ what it means to take a decision within this approach;
✓ what it means that the imperative approach is symbolic and top-down.

The activity focuses on conceptual and epistemological knowledge already introduced in the overview lecture, where three possible approaches were presented for how to teach a machine to reason and to solve a problem
✓ the imperative approach (implemented in many of the traditional programming languages, for example, in PYTHON)
✓ the logical-declarative approach (implemented, for example, in PROLOG language)
✓ the example-based approach (implemented, for example, in MATLAB)
</td>
</tr>
<tr>
<td>Goals</td>
<td>
conceptual
● to understand that to solve a problem, in general, you need a knowledge base and a strategy;
● to understand that an AI system/solution in an imperative approach is comprised of:
  ✓ data (variables, constants, etc.);
  ✓ an algorithm: finite and unambiguous sequence of steps that indicate exactly what actions the machine has to perform;
● to understand that, in an imperative approach, the actions on the data, carried out by a machine implementing the algorithm, are executed in a rigid and pre-established order that means:
  ✓ an action “cause” the next action to be completed in a predictable manner, as established by the algorithm;
  ✓ actions “unroll” in time in a predictable manner;
● to understand and/or to consolidate the concept of linear causality;
</td>
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<table>
<tr><td></td><td>
to understand and/or to consolidate the concept of deterministic paradigm of prediction.
epistemological

to consolidate the idea that an imperative approach is one of a set of different approaches to reasoning and solving a problem;
to gradually become acquainted with the idea that each approach to reasoning implies a structure of causal reasoning and a paradigm of prediction;
to recognise that behind an imperative approach there is a linear causality structure and a deterministic paradigm of prediction;
to recognise that an imperative approach to reasoning is a symbolic approach (i.e. that the machine represents a knowledge base, intermediate computation states, and results within symbols that are readable and understandable by humans);
to recognise that an imperative approach to reasoning is a top-down approach (i.e., the strategy is already known by the programmer and is implemented into an algorithm);
to use this approach to think about and become aware of possible problem-solving strategies and forms of reasoning.

social/emotional

to become actively engaged in discussion;
to receive feedback on one's own personal approach to problem-solving, learning and reasoning (in and out of school).

</td></tr>
<tr><td>Time required</td><td>Group discussion: 15 minutes, Dialogic lesson: 30 minutes</td></tr>
<tr><td>Materials</td><td>
Worksheet for the brainstorming activity
The worksheet includes the following steps:

play some tic-tac-toe games, reflecting on the strategies that are necessary to win.
to discover a way to explain to Lucy – a robot that must learn the tic-tac-toe game – the best strategy to win against a human player.

Slides for the dialogic lesson

brief introduction to explain that there are different approaches to reasoning and to solving a problem (imperative, declarative, example-based);
focus on a selection of significant aspects that characterise an approach; aspects that will be investigated in greater depth for each approach:
✓ the nature of the knowledge base and of the strategy;
✓ the distinction between top-down and bottom-up and between symbolic/subsymbolic;
✓ the implied structure of causal reasoning and the implied paradigm of prediction;
✓ the meaning of making a choice and solving a problem;
focus on the characteristics of the imperative approach: its knowledge base and the procedural nature of strategy; its top-down and symbolic nature;
focus on the concept that behind an imperative approach lies a linear causality structure and a deterministic paradigm of prediction.

</td></tr>
<tr><td>Teaching methods</td><td>
The activity starts with a short brainstorming activity carried out in groups.
The groups are formed of four students sitting close to each other.

Each group has:

to play some tic-tac-toe games while thinking about the strategies adopted to win;
to make explicit the strategy to win so as to identify the single steps to be explained to Lucy;
to write up the group's discussion and strategy decision.

</td></tr>
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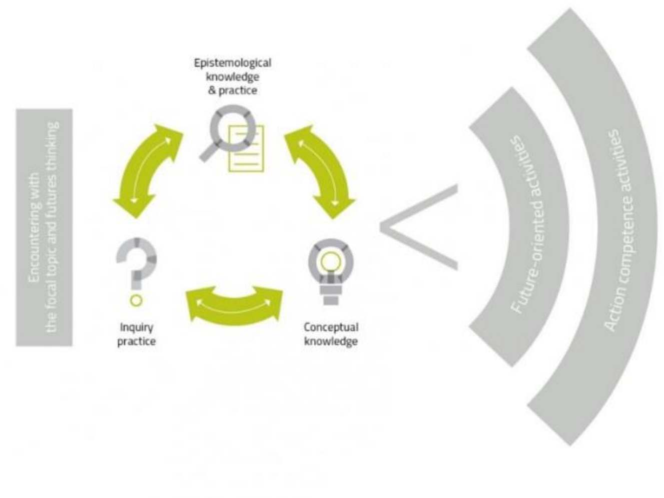
	After the group task, the reflections are shared with the whole class, and the teacher helps highlight the different strategies and how many details are needed to teach a machine to learn. The brainstorming activity is followed by a dialogic lesson. During the dialogic lesson: all students are invited to compare their strategy with an imperative approach to reasoning.
Tips for teachers from previous classroom experiences	The activity appears very effective for fostering engaged discussion on strategies to be adopted. In our experience, the students showed interest in thinking about possible problem-solving strategies and the fact that there are different forms of reasoning

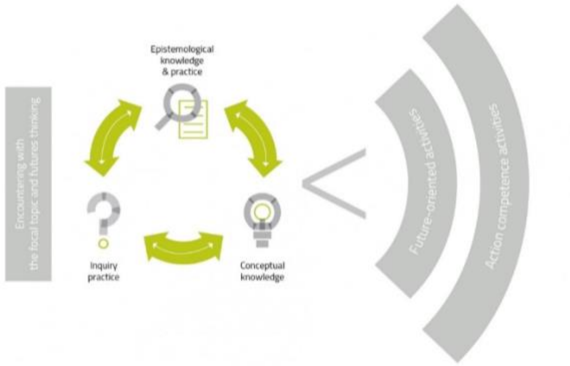
ACTIVITY 3bis:
TIC-TAC-TOE & IMPERATIVE APPROACH (PYTHON)

Position in the module ***Epistemological Knowledge & Practice*** ***Conceptual Knowledge*** ***Inquiry Practice***	 The activity illustrates a concrete example of an imperative approach used to teach a machine, Lucy (an ideal robot), to play and to win tic-tac-toe. The activity consists of presenting and commenting on a pre-established algorithm in order to flesh out its structure and logic. In particular, the activity focuses on one move that Lucy makes, so as to point out and reconstruct machine reasoning regarding a particular configuration of the game.
Goals	***conceptual*** ● to understand that writing a program for Lucy in an imperative language (Python) means writing "***Data + Instructions***"; ● to understand that *Data* are related to the configurations of the board (e.g. the position of all the Xs and Os, the possible configurations that allow Lucy to win, and so on. One example is: if the grid boxes are numbered from 0 to 9, a useful data structure is one that contains three numbers, those of a winning line); ● to understand that *Instructions* are the actions, on data, which Lucy executes to play (the strategy adopted by Lucy), ● to understand that Lucy performs the algorithm that she is commanded to execute – *Instructions* are executed in a rigid and pre-established order – (computer as a performer) ***epistemological*** ● to recognise that the execution of an algorithm, in the imperative language, is closely linked to linear causality: the instructions are executed to maintain step-by-step control of the process, and any action taken is the "cause" of the next action ● to recognise that the algorithm, in the imperative language, is closely linked to a deterministic paradigm of prediction: the algorithm "unrolls" the actions over time ● to become aware that whoever instructs Lucy (i.e., the person who writes the algorithm) knows exactly which actions are necessary to win; ● to become aware that for Lucy to make a decision (i.e. to choose between one move and another), she needs to try out and scan all the possibilities and her power (and limitations) lie in her memory and computation speed ("brute force")

	social/emotional ● to become actively engaged in discussion; ● to develop meta-reflection on what it means to learn, and to develop a reasoning to solve a problem.
Time required	45 minutes
Materials	• Program expressly written in PYTON to play tic-tac-toe: http://www.pythontutor.com/ To open, copy this URL in the browser address bar. Then, at the bottom of the page press "Visualize execution". An imperative program able to play tic-tac-toe has been written in Python language and the students are guided by the teacher to follow the structure of the program and its logics, without becoming swamped by technicalities. During the execution of the program, the teacher shows that ***Data*** are kept under control (systematically scanned) by the machine and that ***Instructions*** – the actions that Lucy performs – are followed by the machine step-by-step. In this way the teacher can: ● highlight Lucy's actions, i.e. the reasoning structure that is implemented; for example, given a configuration ✓ Lucy checks if there is a move that allows her to win; in this case, Lucy makes that move; ✓ if Lucy cannot win, she checks if the opponent can win and, in this case, prevents her/him from winning ● stress that Lucy's actions are carried out by the characteristic structures of the imperative language: sequence (one instruction is executed sequentially after another), cycle (a set of instructions is executed in several times) and selection (if a certain configuration occurs, Lucy can choose between two alternatives); ● stress that Lucy's actions and choice of move – i.e. *making a decision* – are performed in a pre-established order; ● stress that Lucy is a simple performer with a lot of memory and computational power: before a move, she can quickly evaluate all possibilities that the algorithm provides.
Teaching methods	***Dialogic lesson*** During the dialogic lesson: • the teacher encourages each student to participate actively and ensures that the whole class is engaged in the collective activity • the students are invited to compare their strategy with that used by Lucy The students are neither supposed to know any programming language nor be able to code; it was made clear that computing skills are not required. The students have to follow the reasoning structure that is implemented, Lucy's actions when faced with a particular configuration of the game. Both the forms of data representation and the instructions of the algorithm are translated into natural language.
	It can happen that the class ranges greatly in terms of knowledge, since it may occur that there are students who are familiar with coding and thus dominate the discussion or ask very technical questions that other students do not understand.

Tips for teachers from previous classroom experiences	For this reason, it is very important for the teacher to focus on the logics of reasoning as opposed to technicalities, and adopt strategies to avoid losing the attention of those students who are not acquainted with coding. In this type of lesson, the balance between (technical) det ails and general reasoning is the most delicate issue: on one hand, some details are fundamental to ground reasoning but too many can lead students to become stuck and lose the thread; on the other hand, the more general theme (about the logics of the approach) can help them grasp the details without become trapped in technicalities.
Additional resources	• Interactive books to learn how to code in Python language https://runestone.academy/runestone/books/published/thinkcspy/index.html and https://runestone.academy/runestone/books/published/StudentCSP/index.html • A book to learn using Python to automate repetetive tasks, design videogames and learn cryptography https://inventwithpython.com/ • A collection of resources for all levels from the Python site https://wiki.python.org/moin/BeginnersGuide

ACTIVITY 4:
INTRODUCTION TO THE LOGICAL-DECLARATIVE APPROACH

Position in the module ***Epistemological Knowledge & Practice*** ***Conceptual Knowledge*** ***Inquiry Practice***	 The activity envisages an introduction to the logical-declarative approach to deductive reasoning by stressing what form of reasoning is employed, in particular: ✓ what is meant by the fact that an explicit knowledge base of the problem is necessary, but it is not necessary to know the actions to be performed; ✓ what it means to take a decision within this approach; ✓ what it means that the logical-declarative approach is symbolic and top-down.

Goals	***conceptual***
	● to understand the concepts of logical proposition, formula, tables of truth, rule of inference (*modus ponens, modus tollens*);
	● to understand the difference between material conditional and classical logical inference;
	● to understand that, in a logical-declarative approach, it is not necessary to know the actions that must be performed (as in the imperative approach);
	● to understand that in a logical-declarative approach it is necessary to establish *a-priori:*
	  ✓ ***Facts*** (Knowledge base)***:*** propositions assumed as true;
	  ✓ ***Rules*** (Strategy): Formulas including material conditional assumed to be correct.
	● to understand that to solve a problem it is necessary to ask questions based on established facts and rules; the solution is an *answer* (true or false) to a question;
	● to understand that the ***Deductive Mechanism*** (i.e. ***Inference Procedure***) is a deterministic algorithm and is "upstream", i.e. independent from applications;
	● to understand the concept of ***Decision Tree*** and, in particular, to comprehend that a ***Decision Tree*** is generated by an Inference Procedure, and how a ***Decision Tree*** allows a solution to be deduced;
	● to understand that the actions that generate the decision tree are performed in a pre-established order based on correct rules. This means that:
	  ✓ the application of a rule is activated when pre-established conditions are verified;
	  ✓ rules "unroll" the deductions in time in a predictable manner.
	epistemological
	● to recognise that behind a declarative approach there is a linear causality structure and a deterministic paradigm of prediction;
	● to recognise that a declarative approach is a ***symbolic*** approach (i.e. to translate the knowledge base into symbols: facts and roles are known and declared, the inference procedures is also known and eventually executable by a human);
	● to recognise that a declarative approach is a ***top down*** approach (i.e., an algorithm – Inference Procedure – generates a decision tree);

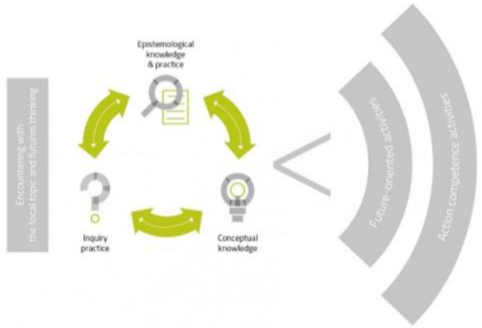
	● to use this approach to think about and become aware of possible problem-solving strategies and forms of reasoning. ***social/emotional*** ● to become actively engaged in discussion; ● to provide feedback on one's own personal approach to problem-solving, learning and reasoning (in and out of school).
Time required	45 minutes
Materials	***Slides for the dialogic lesson*** ● focus on some concepts of classic logic: ✓ proposition (true or false); ✓ formula (true or false); ✓ logical reasoning: *modus ponens, modus tollens*; ✓ implication and true table; ✓ logical inference and deduction ● focus on ***base knowledge*** and ***inference*** i.e. ***true facts*** (for example "Andrea is Giovanni's father", "Giovanni is Anna's father ", etc. …) and ***correct rules*** (for example "***If*** it is true that X is the father of Y and Y is father of Z, ***then*** X is the grandfather of Z " with X, Y, Z variables); ● focus on true or false ***conclusions*** that are answers to questions. False is what is not deduced as true. starting from the assumption of true facts and correct rules (for example. related to "being a grandfather" "Is it true that Andrea is Anna's grandfather? "); ● focus on Inference Procedure with valid forms of inference, independent of applications (computer as a demonstrator); ● focus on how Inference Procedure generates the decision tree (for example, to deduce if it is true that Andrea is Anna's grandfather); ● focus on the concept that behind a declarative approach lies a linear causality structure and a deterministic paradigm of prediction.
Teaching methods	***Dialogic lesson*** During the dialogic lesson: ● the teacher encourages each student to take an active part in the dialogic lesson and ensures that the whole class is engaged in the collective activity; ● the students are invited to compare the structure and logic of imperative language with those of declarative language.
Tips for teachers from previous classroom experiences	It is important that students recognise these concepts and forms of reasoning which are typical of mathematical thinking, so as to relate this lesson to their curricular knowledge and feel as familiar as possible with these forms of reasoning.
Additional Resources	• Deductive reasoning in Classical Logic https://plato.stanford.edu/entries/logic-classical/#Dedu

ACTIVITY 4bis:
TIC-TAC-TOE & LOGICAL-DECLARATIVE APPROACH (PROLOG)

<table>
<tr>
<td>Position in the module

Epistemological Knowledge & Practice

Conceptual Knowledge

Inquiry Practice</td>
<td>

The activity illustrates a concrete example of the declarative approach used to teach Lucy to play (and win) tic-tac-toe. The language used to write the program is PROLOG.
The activity consists of presenting and commenting on a pre-written program in order to flesh out its structure and logic.
In particular, the activity focuses on one move that Lucy makes, in order to highlight and reconstruct the reasoning she follows when faced with a particular configuration of the game.</td>
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<tr>
<td>Goals</td>
<td>conceptual

to understand that true Facts are, for example, configurations of the board that allow Lucy to win (for example: if the grid boxes are numbered from 0 to 8, the whole winning line of numbers represents true facts)
to understand that Rules are conditional formulas and Lucy knows how to win if she knows the appropriate rules (for example: if move X blocks the opponent's victory, then next move is move X)
to comprehend that, independent of applications, there is a Deductive Mechanism (i.e. Inference Procedure) that is a deterministic algorithm and it is “upstream” (i.e. part of Prolog implementation and not part of the program)
to comprehend that the Inference Procedure generates a Decision Tree that leads to a win.

epistemological

to comprehend that the person who instructs Lucy (whoever writes the program) does not know exactly which actions will lead to a win but only true facts and correct rules;
to comprehend better the fact that the decision “the move is a winning move or not” is the result of the decision tree;
to recognise that behind a program written in PROLOG language lies a linear causality structure and a deterministic paradigm of prediction.

social/emotional

to become actively involved in discussion;
to develop meta-reflection about what it means to learn and develop deductive reasoning to solve a problem.
</td>
</tr>
<tr>
<td>Time required</td>
<td>45 minutes</td>
</tr>
<tr>
<td></td>
<td>Program written expressly in PROLOG to play tic-tac-toe (https://swish.swi-prolog.org/p/TicTacToe_prolog_ENG.pl, adapted by Dr. Micheal Lodi from https://github.com/tsabsch/PGP-13/blob/master/ticTacToeCompleteForStudents.pl)
A Logic - Declarative program, capable of playing tic-tac-toe, has been written
in PROLOG language and the students are guided by the teacher to follow the structure of the program and its logic, without becoming swamped by technicalities.
In particular, at the beginning, the students are guided by the teacher to recognise two different levels:</td>
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<table>
<tr><td>Materials</td><td>

the first level regards what is known by the writer of the program: true facts and correct rules;
the second level regards what is unknown to the writer of the program but is part of the PROLOG language implementation: a deterministic algorithm (Inference Procedure) that acts on Facts and Rules to generate the decision tree.

During the execution of the program, the students follow the building of the decision tree step-by-step and the teacher shows how Lucy decides the next move by applying a strategy made explicit by the rules.
In this way the teacher can:

stress that Lucy knows only true facts and correct rules;
stress that “upstream” there is a deterministic algorithm that creates the decision tree;
stress that Lucy is a demonstrator that applies an inference procedure using correct and known rules.

</td></tr>
<tr><td>Teaching methods</td><td>
Dialogic lesson
During the dialogic lesson:

the teacher encourages each student to take an active part in dialogue and ensures that the whole class is engaged in the collective activity
the students are invited to

✓ compare their strategy with that used by Lucy;
✓ compare the strategy of the imperative language (how to achieve the goal) with that of declarative language (what goal to achieve);
✓ evaluate, in this context, which strategy is more effective, which one is more efficient…

The students are neither expected to know any programming language nor to be able to code; it was made clear that computing skills are not required.
The students have to follow the reasoning structures that are implemented, Lucy’s deduction in front of a particular configuration of the game.
The structures are translated into natural or classic-logic language.
</td></tr>
<tr><td>Tips for teachers from previous classroom experiences</td><td>
As in the activity on tic-tac-toe played with an imperative approach, the balance between (technical) details and general reasoning is the most delicate issue.
The teacher has to make sure to stress those details that are fundamental to ground reasoning but at the same time avoid those details that can lead students to become stuck and lose the thread.
The teacher, moreover, is reminded to maintain hold of the more general thread (about the logics of the approach) since this can help students to grasp the details without becoming trapped in technicalities.
In our experience, an excess of technical detail can compromise the involvement of less motivated students who become distracted and lose the thread of reasoning.
</td></tr>
<tr><td>Additional resources</td><td>

A detailed decision tree for the solution of Tic-Tac-Toe problem https://iseeproject.eu/wp-content/uploads/2019/08/trisnonanimatoENG.pdf
Bramer, M. (2005). Logic Programming with Prolog. Springer. ISBN: 978-1-85233-938-8 Free Download at: https://www.springer.com/it/book/9781447154860

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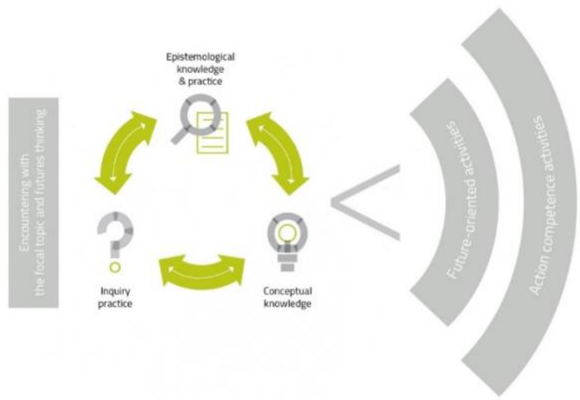
ACTIVITY 5:
INTRODUCTION TO THE MACHINE LEARNING APPROACH

Position in the module ***Epistemological Knowledge & Practice*** ***Conceptual Knowledge*** ***Inquiry Practice***	 The activity envisages an introduction to the machine learning approach to reasoning by stressing what form of reasoning is employed, and to what extent this differs from that adopted by imperative and logical-declarative approaches, in particular: ✓ what it means for a machine to learn to solve a problem or to perform a task; ✓ how an explicit knowledge base of the problem is not necessary, nor is it necessary to know the sequence of actions to be performed; ✓ the significance of the fact that the user's choices mainly consist in i) deciding the architecture of the machine learning system (e.g. feed forward neural network) and ii) building the database from which the machine will be asked to learn; ✓ what it means to take a decision within this approach; ✓ what it means that the machine learning approach is subsymbolic and bottom-up.

Goals	***conceptual***
	● to understand the difference between supervised and unsupervised learning: the former is the machine learning task of learning a function that maps an input to an output based on example input-labelled output pairs, while the latter is the machine learning task of inferring a function that describes the structure of unlabelled data which has not been classified or categorised;
	● to understand the concept of feature and, only for the supervised approach, of target value;
	● to understand the concept of hypothesis function and its mathematical formulation for two common examples (linear regression and binary/logistic classification);
	● to understand the concept of cost function and the procedure of minimisation to tune the parameters of the hypothesis function;
	● to understand that the problems that are more frequently addressed using neural networks are perceptual ones in which there is no clear requirement to describe in an algorithmic way the procedure that leads to the successful completion of a task (e.g. multiclass images classification);
	● to understand the model of a neuron in a basic example of neural network (e.g. feed-forward NN);
	● to understand qualitatively the steps for training a neural network, in particular:
	  ✓ the algorithm of forward-propagation of the input data through the layers of the network for the calculation of the hypothesis function;
	  ✓ the algorithm of error back-propagation for the minimisation of cost function and the assessment of the weights that characterize the connections between neurons;
	● to understand the difference between the three phases of training, validation and testing of

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the network;

to understand the basic definition of efficiency of a neural network system;
to understand that - as a consequence of its non-100% efficiency - the process of decision making of a machine learning system results in generating predictions of a probabilistic nature.

epistemological

to recognise that the type of intelligence displayed by neural networks (intelligence = learning from a database of examples) is different from those displayed by machines in the imperative (intelligence = executing a set of instructions to perform a task) and logical/declarative paradigms (intelligence = inferring from a knowledge base made up of facts and roles);
to recognise that a neural network can be interpreted as a complex system, since it displays some properties that are typical of these systems; in particular:

✓ the capacity to learn/to perform a task of a neural network is a bottom-up process comparable to an emergent property;
✓ the rules every single neuron (agent) of the network has to follow are very simple and specific;
✓ a small variation of a critical weight of the network can bring about a wide difference in the predicted output and this behaviour is comparable to a sort of butterfly effect;
✓ the weights of the network are assessed with a circular process of feed forward-propagation of the inputs and error back-propagation in which the output results modify the structure of the network itself;

to recognise that behind a machine learning approach there is a non-deterministic paradigm of prediction, since the results are probabilistic and subject to uncertainty;
to become aware that a machine learning approach is a subsymbolic approach: the result of the training and validation phases is a network constituted by weights (float numbers) that cannot be translated into a human-intelligible meaning directly linked to the given output of the system;
to become aware that a machine learning approach is a bottom-up approach (i.e., a collection of data together with a generic structure of the network and basic rules for the individual agents generate a probabilistic prediction);
to recognise that in this approach the role of the user consists in submitting to the network a wide, various and balanced dataset in order that the predictions not be distorted;
to compare this approach to those previously encountered (imperative and logical/declarative) in order to think about the different methods of learning and become aware about possible problem-solving strategies and forms of reasoning in different settings.

social/emotional

to become actively involved in discussion, to provide feedback on one's own personal approach to problem solving, learning and reasoning (in and out of school).

</td></tr>
<tr><td>Time required</td><td>1 hour</td></tr>
<tr><td>Materials</td><td>
<u>Slides for the dialogic lesson</u>

Samuel's definition of machine learning
Focus on the basics of supervised learning and, in particular, on the concepts of features, as characteristics used to describe the data
Schema of a generic supervised learning system: starting from the input dataset, through the learning algorithm, the result is a hypothesis function that should be a good predictor, robust also regarding new data
Examples of two common and very well-known hypothesis functions: linear regression and binary/logistic classification, both dependent on a set of theta parameters

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	• Focus on minimisation of the cost function as the procedure to choose the right thetas that make the hypothesis function robust • Focus on the necessity of more advanced structures (e.g. neural networks) to address high dimensionality problems (e.g. image classification) • Focus on a specific example of 4-classes image classification problem (pedestrian vs car vs motorcycle vs truck), underlining in particular: ✓ the structure of the database (features and target values); ✓ the task the network has to learn to perform (to automatically classify new unseen images into one of the 4 classes of the training dataset) • Focus on the model of the neuron as a computational unit that receives the inputs from its dendrites, makes calculations (activation function) and, through its axon, sends the results to other neurons • Focus on the structure of the network and on the process of forward-propagation for the computation of the output • Focus on the minimisation of the cost function to assess the weights of the network through the algorithm of error back-propagation • Focus on the validation and test phases that follow the training stage • Focus on a basic definition of efficiency of the network, as a measure of its reliability and of its capacity to generalise the performance of the task with new data, different from those in the training dataset • Summary of the crucial points of the lesson, underlining the differences between the approach of machine learning as opposed to imperative and logical/declarative approaches • Focus on the features that make a neural network comparable to a complex system
Teaching methods	***Dialogic lesson*** The teacher encourages each student to actively participate in the dialogic lesson and ensures that the whole class is engaged in the collective activity. In particular, it is highly recommended that the students participate in: • recognising the complex features of neural networks and making a comparison with complex systems already encountered in earlier sections of the module (e.g. flocks, roundabouts, cellular automata, flutes, …); • recognising the differences and similarities with the imperative and logical/declarative approaches.
Tips for teachers from previous classroom experiences	In our experience, almost all the students showed interest and were fascinated by the mathematical and computational aspects behind the machine learning approach with neural networks. Even though the final choice is up to the teacher and his/her didactical goals, we suggest that he/she does not go into too many details with the mathematical formalism but simply provides a basic outline of the computations the machine executes. The focus should especially be on the main conceptual points to foster epistemological awareness about this specific approach.
Additional resources	• Online course about machine learning with some mathematical details and practical examples. https://www.coursera.org/learn/machine-learning • A collection of TED Talks (and more) on the topic of Machine learning. https://www.ted.com/topics/machine+learning

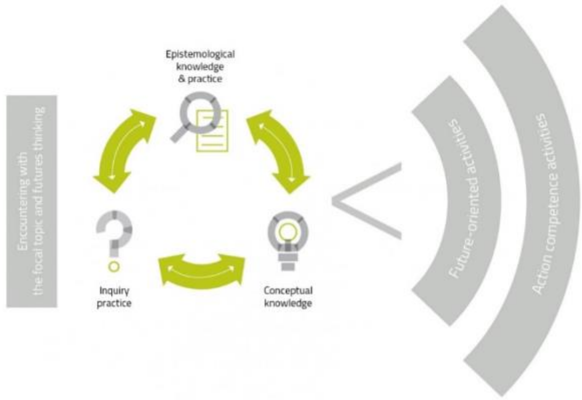
ACTIVITY 5b:

TIC-TAC-TOE & MACHINE LEARNING (MATLAB)

<table>
<tr>
<td>Position in the module

Epistemological Knowledge & Practice (EKP)

Conceptual Knowledge

Inquiry Practice</td>
<td>


The activity illustrates a concrete example of the Machine Learning approach used to teach Lucy to play (and win) tic-tac-toe. The language used to write the program is MATLAB.

The activity consists of presenting and commenting on an existing program, in order to flesh out its structure and the practices commonly used to build up a Neural Network. Then Lucy's ability to play tic-tac-toe is tested according to the number and variety of examples used to train the neural network. The ability is tested in a statistical manner, creating hundreds of automatic tic-tac-toe games between Lucy and other known algorithms (imperative, random).
</td>
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<tr>
<td>Goals</td>
<td>
conceptual

to retrace the basic steps of a machine learning approach to a decision problem such as the tic-tac-toe game - (1) to point out the neural network goal, (2) build up a database, (3) choose a network structure, (4) train the network and (5) test its efficacy;
to introduce some of the practices commonly used to build up a database of examples;
to introduce some of the practices commonly used to choose, train and test a simple neural network;
to understand that in order to test neural network efficacy, we have to use statistical methods, as opposed to the other two approaches;
to understand the role of the number and the variety of the data in making a good decision (and thus also the essence of BIG DATA);

epistemological

to comprehend that the person who instructs Lucy (whoever writes the program) may also not know anything about the strategies useful to win at tic-tac-toe, and that the only knowledge needed is that for building up a good dataset from which to learn;
to recognise that behind a machine learning approach there is a non-deterministic paradigm of prediction, since the results are probabilistic and subject to uncertainty;
to recognise that a machine learning approach is a sub-symbolic approach: the result of the training and validation phases is a network constituted by weights (float numbers) that cannot be translated into a human-intelligible meaning directly linked to the given output of the system;
to recognise that a machine learning approach is a bottom-up approach (i.e., a collection of data together with a generic structure of the network and basic rules for the individual agents all generate a probabilistic prediction);

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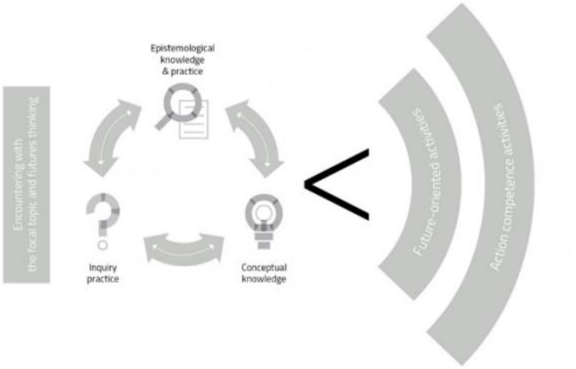
	• to better understand what typologies of problems are better solved with a Machine Learning approach (i.e.perceptive ones) and the limits of the other approaches. ***social/emotional*** • to become actively involved in discussion; • to develop meta-reflection about what it means to learn, and develop a deductive reasoning to solve a problem.
Time required	45 minutes

Materials	• Program expressly written in MATLAB to train and test a feedforward Neural Network to play tic-tac-toe.
	• Support slides.
	The conceptual steps of the lesson are:
	1. Construction of an **example dataset**: to gather a huge number of tic-tac-toe games that an imperative and a random algorithm can play automatically. The winner's moves are to be taken as target examples.
	2. choosing a **neural network structure**: a hidden uni-layer feedforward neural network is selected according to explicit criteria
	3. network **training and test** of Lucy's ability while
	    • increasing the **number of games** examples: Lucy wins most of the games when trained with more game examples, also when played by only random algorithms → digression about AI *creativity* and *sub-symbolic* approaches
	    • increasing the **variety of games** examples: when trained with games played only between imperative algorithms. Lucy does not know what to do against a random algorithm (overfitting).

Teaching methods	During the dialogic lesson the teacher encourages each student to actively participate and ensures that the whole class is engaged in the collective activity The students are expected neither to know any programming language nor to be able to code; it was made clear that computing skills are not required.
Tips for teachers from previous classroom experiences	The teacher should pay attention to the level of detail provided in the lesson, tackling open technical scenarios, practices and applications without becoming swamped by them. This seems to be crucial: • to maintain a clear image of the overall aim of the module • to actively engage also those students who are not really interested in programming details
Additional resources	• Videos of AI algorithms playing games: Breakout: https://www.youtube.com/watch?v=V1eYniJ0Rnk Snake: https://www.youtube.com/watch?v=zIkBYwdkuTk SuperMario: https://www.youtube.com/watch?v=qv6UVOQ0F44 about alphaGo: https://www.youtube.com/watch?v=8dMFJpEGNLQ • AI and real-life conversation: https://www.youtube.com/watch?v=lXUQ-DdSDoE • AI and design: https://www.youtube.com/watch?v=aR5N2Jl8k14

ACTIVITY 6:
PREDICT, HYPOTHESIZE AND IMAGINE THE FUTURES:
FROM PHYSICS TO FUTURES STUDIES

Position in the module *Bridge between science ideas and future*	 This activity is one of transition between the EKP/CK/IP part of the module and the section related to future-oriented practices. The transition is guided by the introduction of the science of complex systems as a new paradigm to think about the future, radically different from that of classical physics. During the lesson, it is pointed out that this new non-deterministic way of thinking about the future has also inspired a branch of social sciences, i.e. futures studies, which has named 4 different types of "P" futures: probable, plausible, possible and preferable.
Goals	***conceptual*** ● to recognise the conceptual assumptions behind a very common problem of classical mechanics, in particular: ✓ the principle of superposition of effects; ✓ the linearity of most laws; ✓ the irrelevance of the space scale since the same laws hold at all the space-time scales; ● to understand the definition of a complex system as a system made up of different individual elements (agents) that, interacting with each other according to non-linear relations, give the complex system some properties that classical systems do not have; ● to understand the main features of Schelling's model, in particular: ✓ the simple decision rule for the agents; ✓ the non-linearity of this rule; ✓ the emergent property of segregation as the result of the application of simple rules to single agents; ✓ the circularity between the agents and the aggregate state of the system: the agents, following their elementary rules, move creating a global property; the global property determines new local conditions for the individuals; ● to understand the main features of the predator-prey Lotka-Volterra model, in particular: ✓ the aggregate description via non-linear differential equations; ✓ the alternative agent-based description via simple non-linear rules each agent has to obey; ✓ the circularity between causes and effects; ● to understand the concept of feedback as an element of the cause-effect relation, interpreted as a circular chain in which the last effect of the chain modifies the first cause from which the loop originated, either amplifying (positive feedback) or softening it (negative feedback); ● to understand the main features of the Lorenz model, in particular: ✓ the non-linearity of the differential equations that describe the convection of the fluid; ✓ the sensitive dependence of the model on initial conditions, as experienced by Lorenz,

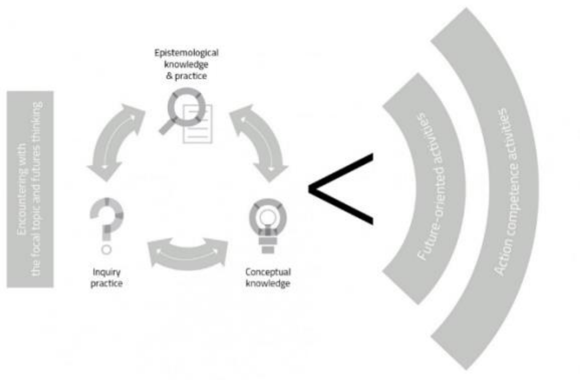
	which leads to deterministic chaos; ✓ the concept of attractor as a butterfly-shaped object in which the trajectories in the phase space are collected; ● to understand the difference between prediction, as a univocal result of the application of a model, and projection, as a range of possibilities; ● to understand the graphical representation of the futures cone and the difference between the 4 "P" futures (probable, plausible, possible and preferable) in terms of trigger elements, type of thought and techniques of construction; ● to understand the difference between the disciplines of forecast, foresight and anticipation; ● to understand the concept of scenario; ● to understand the concept of backcasting as the process carried out after having defined the desirable future, retracing the temporal path to identify policies, programs, actions that lead from the future to the present; ● to understand the difference between drivers and values as guiding principles toward the individuation of a desired scenario. ***epistemological*** ● to recognise that in classical physics: ✓ the future is deterministically and univocally predictable, starting from initial conditions; ✓ the uncertainty of prediction is as small as the accuracy in the measurement of initial conditions is high; ✓ the system can be decomposed as sum of its minimal elements and the total effect is the sum of the effects on its minimal components; ✓ a change of scale from inside-the-system (internal eye) to outside-the-system (external eye) is not necessary to understand what is happening, since the same laws hold for the agents and the system; ● to recognise that science, during its history, has developed other alternative ways to think about the future and to "predict" it; ● to become acquainted with the procedure of explanation as individuation of a plausible, not univocal, cause for the final result of the evolution of a system; ● to recognise that the concept of emergent property leads to a crisis of reductionism, since the system cannot be decomposed without making it lose the properties that characterize only the aggregate situation; ● to recognise that in complex systems the linear causality is not appropriate for interpreting what happens, but it is necessary to view causality in a circular way, using also the concept of feedback; ● to recognise that the high sensitivity to initial conditions and the deterministic chaos which characterise complex systems lead to a new meaning for the term "prediction": the future cannot be "predicted" in a traditional sense since we cannot wield exact control on the measurement of initial conditions. The predictions are replaced by projections; ● to go beyond the apparent oxymoron between determinism and chaos, recognising that these are features of complex systems, absent in classical systems; ● to recognise the difference between modelling via an aggregate description and via the specification of rules for the agents; ● to understand that there are many 'futures', not just one; ● to understand that behind the concept of scenario there is an individuation of key factors in the present that will probably orient future developments; ● to recognise that the process of backcasting is not a deterministic operation because there could be multiple and different causes for a given output; ● to recognise that at the basis of the disciplines of forecast and foresight there are, respectively, two important scientific practices: trend extrapolation and simulation. ***social/emotional*** ● to understand that the uncertainty that characterises complex systems can be interpreted not

	only in a negative way (impossibility of prediction) but also in a productive one (uncertainty that opens up a range of possibilities); • to enrich the perception of the future with the dimension of imagination and choice provided by the preferable future; • to unveil the main assumptions of classical physics studied at school so as to encourage more engagement with the science discourse, through the lens of futures issues.
Materials	***Slides for the dialogic lesson*** • Introduction about the conception of time and future in classical physics • Focus on a simple problem of classical mechanics, underlining the assumptions behind it (e.g. superposition of effects, linearity of relations, reductionism, …) • Focus on the concepts of determinism, uncertainty, system decomposition and space-time scales in classical physics • Introduction to the new ways of thinking about time as offered by complex systems • Definition of complex system • Focus on the segregated city of New York in 2012 and some possible explanations for this phenomenon (politics, self-segregation, emergent property) • Focus on Schelling's model (emergent property and non-linear description) • Parenthesis about linguistics to explain non-reductionism • Focus on the predator-prey model (aggregate and agent-based descriptions, non-linearity, circularity between causes and effects) • Focus on the concept of feedback • Focus on Lorenz' model (non-linearity of the equations; butterfly effect, attractor, deterministic chaos) • Introduction to futures studies and the disciplines of forecast, foresight and anticipation • Focus on the futures cone and the 4 "P" futures • Focus on the concept of scenario • Focus on the concept of backcasting • Summary of the differences between the 4 "P" futures in terms of trigger elements, type of thought and techniques of construction
Teaching methods	The teacher encourages each student to actively participate in the dialogic lesson and ensures that the whole class is engaged in the collective activity. In particular, it is highly recommended that the students participate in: • finding examples of complex properties already encountered in earlier sections of the module (e.g. flocks, roundabouts, cellular automata, flutes, …); • recognising the main difference among the 4 types of futures.
Tips for teachers from previous classroom experiences	In our experience, almost all the students showed interest and were fascinated by the new features of complex systems. To foster students' engagement with the lecture, it would be better to enrich the lesson with group activities to explore the additional resources suggested below, so that they can experience some didactical simulations of complex systems in order to reach a better understanding and a stronger grasp of the concepts taught.

Time required	One hour and a half
Additional resources	• interactive simulation of Schelling's model: http://ncase.me/polygons/ • a simpler simulation of the Schelling's model: http://nifty.stanford.edu/2014/mccown-schelling-model-segregation/ • interactive aggregate simulation of the Lotka-Volterra model: http://www.phschool.com/atschool/phbio/active_art/predator_prey_simulation/ • interactive agent-based simulation of the Lotka-Volterra model: https://www.eduweb.com/portfolio/studyworks/predators8a.html • Ted-Ed video lesson about the concept of feedback: https://ed.ted.com/lessons/feedback-loops-how-nature-gets-its-rhythms-anje-margriet-neutel

ACTIVITY 7:
THE TOWN OF ADA (PART 1):
ANALYSIS OF A COMPLEX CITIZENSHIP CONTEXT OF URBAN PLANNING

Which social, political, economic and ethical implications can a decision on Artificial Intelligence (AI) have? Which stakeholders, values, scientific, technological and social issues are involved in a decision concerning AI?

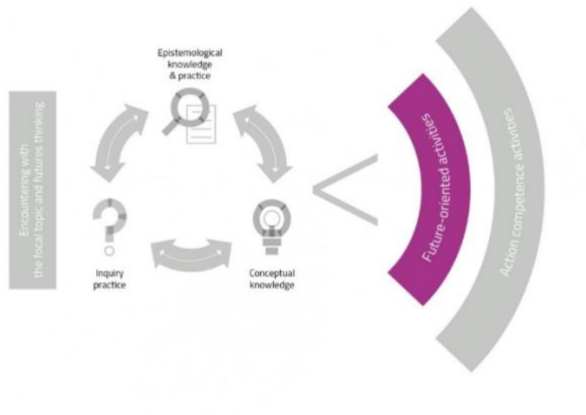
<table>
<tr><td>Position in the module</td><td>
</td></tr>
<tr><td>Bridge between science ideas and future</td><td>The activity connects the scientific theme (AI) with the issue of the future. The activity opens up a series of team-work tasks on "the city of Ada", aimed to help students to reflect critically on the social, political, ethical, and economic implications of a decision concerning AI, as well as on the values, interests implied in any citizenship decision or plan.
The activity represents a bridge between scientific ideas - developed in the previous activities - and future-oriented practices because:
● the concepts introduced in the previous activities and related to complex reasoning in science are turned into skills to analyse a problem of urban planning in a context – the city of Ada - characterised by inner complex dynamics;
● epistemic practices (schematising, arguing, explaining, posing questions, formulating hypotheses, triggering peer-to-peer interaction….) are turned into skills to analyse in depth a complex context in the present, and to explore possible choices and their future implications.</td></tr>
<tr><td>Goals</td><td>conceptual
● to turn typical concepts of complex reasoning (linear or circular causality, feedback…) into skills to analyse a citizenship context where complex dynamics are involved;
● to reflect critically on the concept of multidimensionality and turn it into skills to recognise the different dimensions (political, social, economic, scientific, ethical…) involved in a complex citizenship context;
● to turn an in-depth analysis of a citizenship context into skills to imagine possible future implications of a decision.
epistemological
● to recognise modelling and schematisation as important processes for isolating and analysing the different aspects of a complex context;
● to recognise arguing, explaining, posing questions, formulating hypotheses as important epistemic practices, borrowed from science, which can be used to analyse any complex context;
● to recognise the concept of "dimension" (political, social, economic, scientific, ethical, environmental, professional ...) as important for revealing the relationships among the</td></tr>
</table>

	different components of a complex context and among the stakeholders. ***social/emotional*** • to become involved personally in group or collective discussion; • to become aware of the values implied in specific choices and to recognise the choices that take into account specific values; • to learn to share different points of view; • to learn to mediate between different points of view and reach consensus.
Materials	***The story:*** THE TOWN OF ADA The main material consists of a document where the story of Ada is described. The story refers to a small, growing city, Ada. Ada is enjoying an extraordinary season in terms of opportunities for future development and the city administration has to make decisions and form a strategy. To make clearer the context in which important decisions must be made for the future of Ada, a detailed description of the city is given: its urban structure, the people who live there, the companies and the activities that operate there…. The most important company is "Babbage", which produces processors that could be used for AI developments. The developments of AI can provide new impetus to both the company and the city so Babbage makes some proposals to city administration; this pushes the Mayor and citizens to make decisions that affect both private and collective interests. ***Worksheet*** The worksheet includes the following steps: 1. read the description of the town of Ada (social, technological, urban, ...), analyse it and find a way to represent it in a pictorial, schematic way. 2. recognise ● the stakeholders involved in any possible decision; ● the needs and interests of the different stakeholders; ● the interactions between the different stakeholders. 3. make a decision: if you were the Mayor of Ada, would you accept Babbage's proposals? Why, or why not?
Teaching methods	***Teamwork*** The groups are made up of 4 / 5 students and are formed spontaneously; the only constraint is a similar number of males and females. The teacher encourages each member of the group to take part in the discussion and support the exchange of ideas, helping to orient the discussion, in the event it diverges or becomes stuck. The students of each group have to: ● read carefully the story "the town of Ada"; ● discuss with each other the analysis of the town of Ada and reach an agreement about the decision; ● report the group's response about the decision on the sheet.
Tips for teachers from previous classroom experiences	It is recommended to use a drawing, a map or some other imagery to conduct an in-depth analysis and to build a synthetic but articulated image of the city. It is recommended to bring out the structure of the relations between the different components involved and the relations between the different stakeholders involved in the decision.

Time required	Reading the text and groups discussion: 45 minutes Sharing of the workgroup results: 5 minutes per group
Additional resources	• To gain insight into the role of the perspective of complexity for urban planning. *What can complexity theory tell us about urban planning?*

ACTIVITY 8:
THE TOWN OF ADA (PART 2):
POSSIBLE FUTURE SCENARIOS

Which values, or scientific, technological, and social issues are involved in each of them?

Position in the module ***Future-oriented activities***	 The activity is focused on the concept of *future scenarios* and guides the students to reflect about events that may have caused a possible and/or a *desirable scenario* and which values are involved.
Goals	***conceptual*** ● to consolidate concepts like *projection, space of possibilities, scenarios* (already introduced during the complex systems activities) and turn them into skills for thinking of a *plurality of futures;* ● to turn the concept of *scenarios* into skills for thinking about *different ways* to achieve *possible futures;* ● to consolidate the concept that different future scenarios are *not values-neutral*; ● to turn the concept that "the different future scenarios are not values-neutral" into skills for thinking about one's own *desirable future*. ***epistemological*** ● to recognise that the linear model of causal explanation and the deterministic prediction somehow do not work in complex settings; ● to recognise that accurate predictions are rarely possible and, usually, not necessary; ● to move from the idea of a unique future to the idea of plurality of futures (so that 'scenario' becomes a keyword). ***social/emotional*** ● to recognise that it is socially, economically and personally relevant to adopt a way of thinking in terms of "possibilities" (as opposed to "necessity") and to explore different ways to realize possible futures; ● to recognise that the different possible decisions are not values-neutral; ● to become actively involved in the exploration of the dimensions (social, economic, personal…) that are involved in a context; ● to become actively involved in the exploration of values that influence, in a complex context, any decision; ● to think about personal objectives, wishes, aspirations, values.

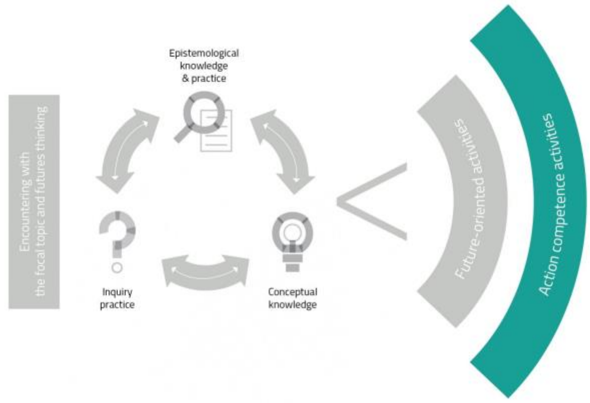
Materials	**The story** The main material consists of a document entitled "The Town ADA at 2040: three possible future scenarios". The document includes three different possible evolutions for Ada. The first one is the '*hyper technological scenario'*, in which the citizens of Ada entrusted Deep Thinking (AI) to administer the town and to organize the life of everyone. The last one is the '*rural scenario'*, in which citizens decided to bid on a return to a natural life, good food, good relationships, handicraft, culture. Innovation is considered cause of isolation and irresponsibility. Between the two extremes there is the '*balanced but also creative and plurality scenario*', in which the quantity and variety of activities that co-exist allow the citizens to keep together tradition, innovation, cultural differences and social inclusion. **Worksheet** The worksheet includes the following steps: 1. analyse three different possible future scenarios for Ada, identifying both interesting/positive and worrying/negatives aspects (economic, social, cultural…) in each of them (teamwork); 2. choose the preferred scenario; explain the reasons for own personal choice (individual work); 3. share the reasons for choosing the preferred scenario (and, if appropriate, the negative aspects) and identify at least two events that may have caused the emergence of the preferred scenario and which values are expressed (team work).
Teaching methods	**Teamwork** The students are encouraged to talk freely about the analysis of *scenarios* (the groups are spontaneously formed and, if possible, they should be the same as in the ADA1 activity). **Individual work** After the group discussion, the students are invited to answer individually about the choice of preferable scenario. This activity is assigned as a homework task and the answers are sent by e-mail. The teacher reads the answers and forms new groups (four / five students) based on the chosen scenarios (similar world-views and values). **Teamwork** The students are encouraged to share the reasons for their preferred scenario and, if appropriate, what they do not like about it; they are moreover requested to discuss the events that may have caused that scenario and which values are expressed (the groups are formed by the teacher).
Request	Each (spontaneous) group has to: ● read carefully the three possible future scenarios for Ada; ● recognise different aspects in each scenario. Each student has to: ● choose and explain their preferred scenario; ● report their response in the form she/he prefers (scheme, table, map, narration..) and send it by e-mail to the teacher. Each group (formed by the teacher) has to: ● share the personal analysis; ● identify at least two events that may have caused the emergence of the preferred scenario; ● identify the values expressed in the new structure of the city.

Time required	Group discussion (spontaneous group): 30 minutes Homework: the time requirement is personal. We estimate 30 minutes Group discussion (formed by the teacher): 45 minutes
Additional resources	• https://en.wikipedia.org/wiki/Scenario_analysis

ACTIVITY 9:
THE TOWN OF ADA (PART 3):
DESIRABLE FUTURE, BACK-CASTING AND ACTION PLANNING

Which actions and action competence can contribute to achieving the desirable future?

<table>
<tr>
<td>***Position in the module***

Action competence activities</td>
<td>

Through this activity, the students are encouraged to imagine the town where they wish to live or visit in 2040, and to think about their roles/professions there.
The activity is focused on the concept of *desirable future* and, through action competence strategies, the students are guided to play with *forecasting* and *back-casting* activities, and to plan actions that can contribute to achieving the desirable future. During the activities the students are encouraged to imagine possible future careers and unleash their creativity.</td>
</tr>
<tr>
<td>***Goals***</td>
<td>***conceptual/epistemological***
● to consolidate the idea that an individual – in order to be able to choose among alternative futures – has to be exposed to the sense of *alternative futures*;
● to consolidate the concept of *multi-dimensionality* and turn it into skills to plan actions;
● to consolidate the concept of *agent* in a complex system and turn it into a skill to plan actions;
● to consolidate the concept of *complex system* (and its characteristic concepts of *circular causality, feedback, non-linearity*…) and turn it into skills to analyse the effects of an action by implementing local/global strategies of thinking;
● to become acquainted with the concepts of *back-casting* and *forecasting* and turn them into skills to activate back-and-forth dynamics between present and future.
social/emotional
● to recognise that desirable futures are mainly emotional and ethical rather than cognitive;
● to recognise that, when you think in terms of desirable futures, you have to assess your values and desires, identities, competences and different cultural points of view;
● to recognise, in a discussion, what is possible/valuable to negotiate (since there are meta-criteria that allow different positions to be revised, re-conceptualized or differently situated in a global shared view) and what is not possible to negotiate (since it refers to values conceived as irreducible for a person or culture);
● to become acquainted with the idea that each individual can act as agent in a complex society and, hence, can play an active and responsible role in creating one's own future;
● to take an active and personal role in the interaction with society (within the complex view</td>
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</table>

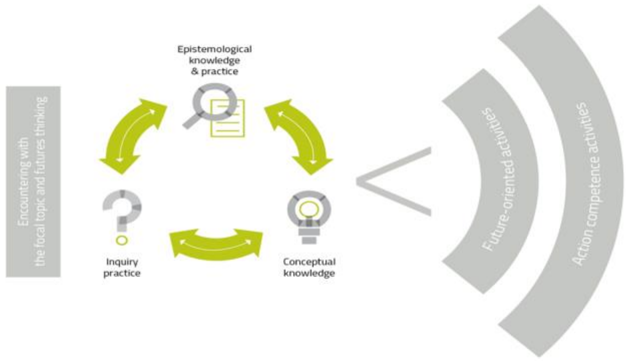
	of the interaction between individuals and society); ● to learn to cope rationally, emotionally, creatively and responsively with their future; ● to widen the imagination about possible future STEM careers.
Materials	**Worksheet** The worksheet includes the following steps: ***1. imagine the "desirable scenario"*** ● to find a meaningful and original slogan that characterizes Ada as the ideal town to live in or visit in 2040; ● to arrange a brief description of this ideal town. ***2. plan actions – go forward and backward in time*** ● *move forward to the future*: identify a problem that you now think is a significant problem and that, in your desirable town in 2040, has been solved; ● *come back to the present*: find an original idea (a leverage point) to solve the problem and plan the actions that you can undertake in the present time in order to solve the problem in 2040.
Teaching methods	The groups (four / five students) were formed by the teachers (in the previous activity ADA2) on the base of similar worldviews and values. The teacher implements "action competence strategies". The teacher encourages each member of the group to take part in the discussion and support the exchange of ideas, helping to orient the discussion if it diverges or the group becomes stuck. In particular, the teacher suggests techniques to widen the imagination, explode/explore the ideas.
Request	For the *first step* each group has: ● to find a meaningful and original slogan that characterises Ada as the ideal town to live in or visit in 2040; ● to present a 3-minute overview of, the town of ADA, highlighting the main features that make it a desirable town. For the *second step* each group has: ● to identify a problem that, in their ideal town of 2040, has been solved; ● to find an original idea (a leverage point) that in 2040 has contributed to solving the problem; ● to plan actions that can achieve the idea and contribute to solving the problem. In designing actions, students have to describe: ✓ who they are and what position they have when they take action (political decision maker, private citizen, association, company, business, bank, school principal, …); ✓ what they aim to do; ✓ why they believe that these actions aid the solution of the problem. ● to present their *success story* in the form of ***back-casting activity***: the problem in 2040 is solved, tells the story of how actions have been planned to solve it (a narrative of the past from the perspective of 2040). Each group is free to choose the mode of presentation that it prefers. To help students to identify the original idea (second point of step 2), they are asked to ✓ write the problem on a poster (as a title); ✓ write, at least, 5 ideas per student on 5 post-it notes (one idea per post-it) in a few

	minutes (the ideas must be spontaneous); ✓ stick every post-it on the poster and attempt to classify them into "categories"; ✓ vote for the most and least interesting ideas; ✓ try to analyse both ideas (the most interesting and the most boring) by exploring them in the different dimensions (social, political, …); ✓ choose one of the two ideas (sometimes the idea that, at first sight, appears less interesting, after the analysis, becomes the best).
Time required	*The first step (about 1 hour)* Group discussion: 45 mins. Sharing the brief description of the "desirable scenario": 3 minutes per group *The second step (about 6 hours, possibly at home)* Group discussion and preparation of the presentation (from 4 to 6 hours - this task can be given partially as homework) Presentation sharing: 45 mins per group
Additional resources	• https://en.wikipedia.org/wiki/Backcasting

ALTERNATIVE ACTIVITY 3-4-5:
TIC-TAC-TOE AND IMPERATIVE & MACHINE LEARNING APPROACHES

<table>
<tr>
<td>Position in the module

Conceptual knowledge

Epistemological knowledge & practice</td>
<td>


This activity combines two of the three original tic-tac-toe activities focusing on the technicalities of AI, and goes through their most essential parts. The activity also serves as a summary of the previous introductory and overview activities. Compared to the three original activities, for example, the complex system aspect of the activities has decreased in importance, the main goals now being:

✓ to get to know the “traditional” imperative approach in order to compare it with the neural network approach
✓ to understand that neural networks learn from existing examples
✓ to understand that we achieve the best results by training a neural network with a wide, various and balanced data set

The activity starts with an introduction to the imperative approach. Students learn the basic idea of this approach, and see how it is not sensible to use it in solving very complex problems. The machine learning approach offers one solution to tackling these kinds of situations.
Students are shown how a sample of example games is generated, how a neural network is trained, and how differently-trained AIs play against one another. The results of the games are analysed and discussed.
</td>
</tr>
<tr>
<td>Goals</td>
<td>
conceptual

to know that there are different approaches to teaching a machine how “to reason” and solve a problem
to know the qualitative difference between imperative and machine learning approaches
to understand qualitatively the steps for training a neural network
to understand the need for wide, various and balanced datasets, and creativity in the context of neural networks

epistemological

to recognise that behind an imperative approach lies a linear causality structure and a deterministic paradigm of prediction
to compare the different approaches (neural network and imperative)
to think about the different methods of learning
to become aware about possible problem-solving strategies and forms of reasoning in

</td>
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	different settings • to realize the potential of neural networks in practice ***social/emotional*** • to widen the imagination about problem solving methods and problems that can be solved • to enlarge the imagination about possible future STEM careers in computer / data science • to arouse students' curiosity and interest in neural networks and programming
Time required	1 hour
Materials	***Slides*** The lesson and slides consist of four parts: Ways to teach an AI to play; Imperative approach; Machine learning approach; and How to train your AI. ***Program*** Program written in MATLAB to train and test a feedforward neural network to play tic-tac-toe. **N.B.:** to be able to run the program, MATLAB must be installed onto your computer. Running the program also requires some extra deep learning tools.
Teaching methods	***Interactive lecture*** In the Imperative approach section, students are qualitatively introduced to the imperative approach. We did not show them the program, but merely discussed the basic principles of this approach. The main goal of this part is to show students how it is not sensible to use the imperative approach in solving very complex problems. In the Machine learning approach section, students are qualitatively introduced to the machine learning approach. In this part, we chose not to introduce any technical details of neural networks, and only discussed the approach at a very basic level. The How to train your AI section consists of the steps of training a neural network to play tic-tac-toe. Here we concentrated on the first and last steps (collecting a data set and testing the AI) only. Collecting the data set was demonstrated using an on-line tic-tac-toe match: • Play a round with https://playtictactoe.org/ • Draw all the board configurations on the blackboard. • Explain how the data set is built by repeating the previous steps. We chose to run the program just once in the classroom and then simply look at and discuss previous run results displayed in tables. In going through the tables, students got to take part in guessing the results and trying to explain them.
Tips for teachers from previous classroom experiences	Running and becoming used to the program took some time; in particular, analysing the results of the games required some expertise. Take your time to go through some additional materials and study the topic before teaching (if you are not expert in the topic). Our solution of collecting the data into tables was not optimal as going through them was apparently quite difficult for students to follow. If the tables are used, they should be gone through slowly, and the teacher should somehow try to motivate students to participate. In tables, though, it was easy to compare the results of neural networks trained with different data sets.

Additional resources	• MATLAB: https://www.mathworks.com/ • Machine learning with MATLAB: https://www.mathworks.com/solutions/machine-learning.html (and the videos therein) • Deep learning with MATLAB: https://www.mathworks.com/solutions/deep-learning.html (and the videos therein)

ANNEX:
Notes on the module implementation in Finland, 15.1.-19.3.2019

<table>
<tr><td>Overview</td><td>The AI module was implemented at Helsinki Normal Lyceum, Finland, in spring 2019, as an extra-curricular course outside school hours. Altogether there were seven classes, amounting to 16 hours of teaching.
The course was taught by two teachers of Normal Lyceum. Also, two experts of AI (a computer scientist and a cognitive scientist) were invited to give lectures. The teachers received organisational help from an I SEE employee, and an I SEE researcher implemented the activities that led to the students' final projects of the course.
In return for completing the course, students were promised a school course or two credit points in certain study programs of UH. Students were required to attend the lessons (or compensate for their absence with exercises), complete assigned homework, and prepare and present a final project in a group.
Nine students completed the course.</td></tr>
<tr><td>Activities</td><td>The main activities implemented on the course in chronological order were:
General introduction to the course and AI
ACTIVITY 2: AI everywhere
Two expert lectures
Tic-tac-toe (ACTIVITIES 3 & 5, modified)
The essential parts of the tic-tac-toe activities that had not been covered in the previous classes. Due to time restrictions, the lesson concentrated on the imperative and machine learning approaches.
Modified ADA activity (ACTIVITIES 6 & 7, slightly modified as described below)
Reading and discussion of the three ADA scenarios.
Problem analysis (ACTIVITY 6, slightly modified as described below)
Analysing and mapping the societal problems students had identified in small groups. We adapted activity 6 by replacing the context of the city of ADA with a wider context of students' own choice.
Lesson on future studies
Scenario building and backcasting (ACTIVITIES 7 & 8, slightly modified as described below)
We adapted activities 7 and 8 to student-chosen societal contexts and problems instead of the context of the ADA city.
Presentation of the final projects.
The student groups presented their final projects to the class.</td></tr>
<tr><td>Notes on slight changes (not substantial) to some activities</td><td>While we needed to re-design the tic-tac-toe activity to fit in with the context constraints, some activities were re-adapted mainly for cultural reasons. Unlike the Italian students, we thought that their Finnish peers did not find the context of a city particularly stimulating. Thus, we modified the activities about ADA so as to leave them free to explore alternative scenarios and desirable futures more freely and, in particular, by referring to real-life global problems. We made this adaptation of the activity since we thought that discussing real-life global problems meets Finnish students' interests better, and frames students' group work in future-oriented activities more effectively in our case.</td></tr>
</table>

	Below, the changes are described and commented activity per activity. **ACTIVITY 7:** ADA (part 1) - analysis of a complex citizenship context of urban planning We combined the *ADA* activities 7 and 8. Students were asked to read the story of ADA (from activity 6) and then the three scenarios (from activity 8). In small groups, they were asked then to analyse positive, worrying, and negative aspects in each scenario from economic, cultural and personal points of view. They were also asked to individually state which scenario they preferred. The scenarios were discussed in class and students voted for the best scenario. When analysing and mapping societal problems, we adapted activity 7 by replacing the context of the city of ADA with a wider context of students' own choice. Yet, the core of the activity remained the same: students identified stakeholders, recognised the needs and interests of the different stakeholders and mapped their interactions. Students learned to think about their problem not in isolation but as a part of a complex system. They also learned to identify stakeholders and leverage points to change the system. When running the activity, we also adopted some materials from "Mapping the Problem and Systems Thinking" (from the QC module). Students were very engaged in the activity and produced excellent mind maps of their problems embedded in complex societal systems. Problems the groups chose included climate change, pollution of the oceans (plastics, microplastics) and antibiotic resistance. **ACTIVITY 8:** ADA (PART 2) - THE TOWN OF ADA: POSSIBLE FUTURE SCENARIOS As in the stakeholder analysis (see *Introduction to Futures Studies & Problem analysis* above), here we decided to try working with student-chosen societal contexts and problems instead of the context of the ADA city. Again, we thought this choice would better meet our students' preferences. In the activity, students developed and discussed a variety of scenarios on how the problem they chose (as well as the system in which it is embedded) will develop by 2040. Students were guided to employ three fundamentally different ways of thinking about future: following the trends (baseline scenario), questioning assumptions and speculating (alternative scenarios) and visioning (desirable scenario). Here we also used some of the material from the "Scenarios" activity (QC module). **ACTIVITY 9:** ADA (PART 3) - DESIRABLE FUTURE, BACK-CASTING AND ACTION PLANNING Finally, students were asked to take their desirable scenario and use the "backcasting" method to come up with a timeline and empowering "success story" on how they, looking back in 2040, were part of the solution to the problem they focused on. Students worked intensely with their scenarios and seemed able to switch between the different thinking methods and approaches to future. After this activity, students presented their future scenarios, i.e. final projects, in the groups. The presentations were, overall, excellent. It was clear that some students really became engrossed in the exercise. Due to the scheduling challenges of the course, the teachers were worried how well students could understand the main idea of this final project activity and how well they could take the whole course into account in this task. The presentations showed that their worries were unnecessary. We were very impressed by the high quality of students' presentations. The scenarios they presented were creative and empowering. Students were able to tell their stories in the past tense and followed the "backcasting" idea very well. Presentations were followed by several questions from other students and a lively discussion.
General comments	• We had to schedule the course to fit into a shorter time-scale, and therefore had to leave some lessons and activities out, and combine other activities. Modifying and

	combining the activities however worked out quite well. • Due to the scheduling challenges we were worried how well students could understand the main idea of the final project activity and how well they could take the whole course into account in this task. The final presentations showed that these worries were unnecessary. • The timing of the lessons (Tuesday evenings from 4 pm to 6 pm) was not optimal, since we had to skip some Tuesdays due to exam sessions or vacations. Meeting only once a week over a long period of time tends to fragment the explored themes, and the students had to reorient themselves every time the lessons re-started. Also, many of the students were tired in the evenings during the lessons. A few more intensive days or daytime schedule for the course would have been preferable. • Several students unfortunately had to drop out before the final stages of the course, due to reasons not related to the content of the course.

The Finnish path