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AI Curriculum for European High Schools: An Embedded Intelligence Approach

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Abstract
This paper presents a proposal of specific curriculum in Artificial Intelligence (AI) for high school students, which has been organized as a two-year subject. The curriculum was designed based on two premises. The first one is that, although the proposal is targeted to scientific programmes, the involved students and teachers do not have any previous knowledge about AI. Accordingly, the teaching units have been designed with the aim of supporting teachers in a new discipline for them and, in addition, providing an introductory level to students. The main didactical objective is to establish the fundamentals of AI from a practical perspective, learning technical concepts by using them to solve specific problems. The approach that has been followed in the teaching units is focused on developing embedded intelligence solutions, that is, programming real-world devices which interact with real environments. To this end, and to address a second fundamental premise of low investment capability at schools, it has been decided to use Smartphones as the central technological element to implement such embedded intelligence at classes. This curriculum has been developed within the Erasmus + project entitled "AI + : Developing an Artificial Intelligence Curriculum adapted to European High School". The project was carried out by a team of AI experts and high school teachers who created the teaching units, and a group of students that tested them for three years, providing feedback to make the curriculum feasible for its introduction in schools in the short-term. The main results obtained from its implementation within the project scope are presented and discussed here, with the aim of contributing to the AIEd community progress by means of a practical pilot experience. Although the curriculum has been designed and tested at European level, it has been created with a general perspective of AI education, so it can be applied worldwide.

Keywords Artificial intelligence education · Digital education · Curriculum design · STEM education

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Introduction

The relevance of Artificial Intelligence (AI) for education goes far beyond training AI engineers, which is itself essential, to include all school-aged young people (Szczepański, 2019; Ernst et al., 2019). There are two key needs in this scope: to prepare all young citizens better understand how AI works for living in a world increasingly impacted by it, and to train more of them for studying AI in higher education. These two aspects are highlighted in recent academic literature (Luckin et al., 2019) as well as the latest draft report published by UNICEF on Policy Guidance on AI for children (Dignum et al., 2021) which emphasises that children's AI literacy and participation are being considered among their fundamental rights. In the particular case of Europe, the EU's Digital Education Action Plan 2021- 2027 (EC, 2021) proposes a long-term plan in digital skill training, but it puts a special emphasis on developing formal plans for AI education at pre-university levels, which affect compulsory schooling, and where adaptations of existing university resources are not enough.

Consequently, there is a global need for creating formal curricula in the scope of AI at pre-university education. This is a challenging goal that must be driven by policy makers, and some remarkable initiatives have already started, as it will be described in the next section. But, at the same time, education and AI researchers must contribute to this goal by developing and testing specific curriculum proposals, so the global education community can take advantage from their experience. This is where the current work comes in by presenting the AI + educational project (AI+, 2022a).

AI + is an Erasmus + project coordinated from the University of Coruña (UDC), with the aim of *developing an Artificial Intelligence curriculum adapted to high school education in Europe*. It has been carried out since 2019 by a partnership of six high schools from five different countries around Europe (Lithuania, Finland, Slovenia, Italy, and Spain). The curriculum development is based on the integration of knowledge and experience of AI experts from the University, both as researchers in AI and as professors for AI-related subjects, and high school teachers. This way, the teaching units (TU) that make up the curriculum are not simple adaptations of university resources, but completely original ones designed in cooperation with teachers. The TUs have been tested by the groups of students at the partner schools to obtain a reliable and feasible curriculum that can be introduced in the formal teaching plans of European schools starting in 2022/23.

The current paper is devoted to the presentation of the main features of this curriculum developed within the AI + project, as well as the main application results obtained with students and teachers. Specifically, the following aspects will be described: (1) the AI topics selected to construct the curriculum at this educational level, (2) the teaching methodologies that have been used, (3) the temporal organization of the curriculum, (4) the obtained teacher's feedback and how it has been integrated, and (5) the main application results obtained the scope of the project that support the curriculum design.

Similar Approaches

Introducing AI in pre-university education has been faced from different perspectives. The most general and challenging one is that of developing a complete AI literacy for future generations. Literacy has been considered as the ability to read and write, but here it refers to digital literacy, more specifically "AI literacy is the set of competencies that enables individuals to critically evaluate AI technologies; communicate and collaborate effectively with AI; and use AI as a tool online, at home, and in the workplace" (Long & Magerko, 2020, p. 2). In this scope, policy makers, global education institutions, and researchers in education have been working from a global and general perspective, providing guidelines applicable to any educational system (Vuorikari et al., 2022; Ng et al., 2021).

In a lower level, we can find curriculum development initiatives. The main difference is that these approaches are focused on AI training at particular education levels (Yang, 2022; Lee et al., 2021; Chiu et al., 2022), assuming that they will be part of a global AI literacy (digital education framework). In this case, it is complicated to find homogeneous approaches that can be introduced worldwide, due to the organization differences that exist in the pre-university educational systems. One of the most remarkable initiatives in this line is the UNESCO report about K-12 AI curricula (UNESCO, 2022, p. 6), which aims "to guide the future planning of enabling policies, the design of national curricula or institutional study programmes, and implementation strategies for AI competency development".

Secondary school (ages 15–18) has been one of the most active target levels in this scope, mainly because these students have digital and mathematical skills adequate for AI training, so short-term results can be obtained. In this level, we can find official initiatives from education administrations that must be highlighted. This is the case of China, where they have been teaching AI subjects in middle and high school since 2019 (Knox, 2020); South Korea, where they have approved starting with AI subjects in high schools in 2021 (Soohwan et al., 2020); India, which is introducing AI in 200 secondary schools in a partnership with IBM (CBSE, 2022); or Australia, which has funded the CSER K-12 Digital Technologies Education program (CSER, 2022). Most of these approaches have been mainly developed by computer scientists and experts in AI, adapting to secondary school the contents of the AI courses and classical books like (Russell & Norvig, 2021), used at university degrees. Their main drawback is that secondary school teachers and educators are key for a feasible AI curriculum definition (Schiff, 2021; Miao et al., 2021).

The most remarkable approach in this line is the AI4K12 initiative from the USA (AI4K12, 2022). It has three main objectives: (1) develop national guidelines for AI education for K-12, (2) develop an online, curated resource directory to facilitate AI instruction, and (3) create a community of resource and tool developers focused on AI for K-12 audience. This initiative encompasses experts from different fields in computer science and education worldwide, with the aim of establishing a solid background towards AI teaching in pre-university education. From the work of these experts, future formal curricula will be developed with a solid pedagogical and technical background.

The curriculum presented in this paper follows the same core principles as the AI4K12 initiative, although it is not targeted to general secondary school, but to a more specific type of student and teacher. It was decided to focus on secondary school (student age range 15 to 18) with a scientific speciality in order to simplify the curriculum development, mainly due to their background in mathematics and programming (logics). The main educational contribution of this work is the development of a set of structured teaching units (TU) to introduce high school students in the fundamentals of AI in a two-year subject, without requiring any previous knowledge of this topic. The TUs have been tested during three years with a heterogeneous group of 30 students (on average), and with the contribution of 12 high school teachers, to make them feasible to be used in the short-term. Even in a constrained scope, this type of operational educational initiative contributes to the future development of AI education from a less theoretical but practical perspective. The TUs are open at the results page of the AI + project (AI+, 2022b) so all the education community can use them.

When developing a curriculum for any new subject, some key aspects must be addressed: (1) the didactic objectives (concepts and skills that will be learned); (2) the teaching methodology; (3) the specific topics that make up the syllabus (4) the curriculum organization. They are described in the following sections.

Didactic Objectives and Methodology

It must be first established if we aim that the students "learn for AI", preparing them to understand what it means to live in a world increasingly surrounded and shaped by AI, or "learn about AI", focusing on AI methods and techniques that require specific mathematical and programming skills (Holmes et al., 2019). The first approach is targeted towards using AI-based tools and analyzing the consequences, so a less technical background is required, and a wider audience can be reached. The second is targeted towards understanding how AI systems work from inside, by programming them, acting as engineers.

The curriculum presented here follows the second approach, with the premise that knowing with more detail how to implement an AI system will provide a deeper learning and understanding of what AI is and what it is not. Consequently, the basic student work will be focused on programming simple AI systems. The starting premise is that students have a background knowledge of mathematics (secondary school level), and they also have some fundamental experience in programming. This is a very relevant pre-requisite for this curriculum, and in the case that students do not have such basic training, a specific course is proposed to be carried out before starting with the TUs. However, the objective is not to acquire a deep knowledge in AI techniques and methods, which would be feasible at this level, but to understand the working principles of AI based systems by developing them, not only by using them.

The AI teaching perspective followed in this work is mainly practical, based on programming AI systems running on real-world devices and solving specific problems with them, what is known in the field as embedded intelligence (Alippi, 2014).

This perspective of AI fits with the recommendations of the European Commission (EC, 2018) for the future digital education plans, focused on “specific AI”, instead a more theoretical and general perspective. It requires relying on some specific hardware elements to implement the teaching material at class. To this end, a key premise in the project is that of using standard Smartphones as the central technological element for all educational material to be developed. Current smartphones have the technological level required for AI teaching in terms of sensors, actuators, computing power and communications; and they will have it in the future because they are continuously being updated.

The TUs have been designed based on two operational premises, with the aim of make them feasible for schools. Firstly, it is considered that students and teachers do not have any previous background in AI. Hence, the TUs will address only fundamental AI methods, avoiding trending topics and popular issues that are not formally established. Moreover, they will be designed for the teacher, to support them in this new discipline, including simple theoretical material, clear recommendations, solved exercises, and others. Secondly, it is also considered that schools are very limited in terms of technical equipment for teaching AI, and they can manage a short budget. This requirement is faced by recommending using the student’s Smartphone to perform the TUs practical work, because a large majority of high school students have their own one. This significantly reduces the cost of introducing this subject at in regions with low economic capacity. It obviously opens the discussion of allowing students to have their Smartphone at class. Our approach here is that it is basic to make them responsible of a proper use for learning, and it is also important for their digital education to realize the technical capabilities of these devices they use every day.

Regarding the teaching methodology, the present curriculum follows a STEM approach, since it requires knowledge from different disciplines to solve the practical cases, mainly mathematics, logics, and physics. Each TU presents a challenge or project that must be faced by students through a cooperative project-based learning (cPBL) approach (Kokotsaki et al., 2016), where students are organized in teams, and they perform the six typical steps of an engineering project: (1) problem definition (specifications), (2) planning (tasks and subtasks), (3) schedule (time organization), (4) implementation (progress monitoring), (5) validation (solution assessment), and (6) evaluation (presentation of results). This methodology is based on a pro-active learning where the theoretical concepts are briefly introduced by the teacher as they are required to solve a practical task (learning by doing), and it is up to the students to consult the bibliography or ask the teacher at group level if they require further knowledge. cPBL has provided successful results in previous studies as a proper methodology to engage students in STEM subjects like AI (Beier et al., 2019; Wan et al., 2022).

The review study of AI literacy developed in (Ng et al., 2021), concludes that the most used pedagogical approaches in secondary/high school level have been collaborative learning, inquiry-based learning, project-based learning, and constructionism. Consequently, following such cooperative PBL approach seems adequate in this scope as an initial approach. Moreover, it has shown successful results in STEM education (Capraro et al., 2014). It is also adequate for the specific AI approach commented above, where the main didactic goal is to solve problems with AI systems.

Artificial Intelligence Topics for High School Students

Defining the set of AI topics that make up the syllabus that will compose the curriculum is a key aspect. AI covers a wide scope, and the choice must be rigorously justified. In this proposal, 8 main AI topics have been included in the syllabus. Before describing them, and why they have been selected, it must be pointed out that the curriculum presented here is based on the concept of *intelligent agent*, illustrated in the diagram of Fig. 1, which is explained to students in the introductory TU. In this approach, an AI system is composed by an agent that is situated in an environment (real or virtual) where it operates. The agent is continuously interacting with its environment in a cycle that is represented in Fig. 1 through the curved arrows. Using the information obtained from its sensors in the *Sensing* stage, the agent selects the most appropriate action (or actions) it should carry out to fulfill its goals.

Fig. 1 Basic components of an AI ecosystem

Such action is executed in the environment in an *Actuation* stage, which modifies the environment. Consequently, new sensing values can be obtained in the Sensing stage that contain the changes derived from the executed action. The intelligent agent may use this information to infer the relation between the applied action and the contribution to the goal achievement. This cycle continues over time, and the *agent* can learn from its experience in order to improve the action selection process.

This concept of situated agent is the formal representation of the embedded intelligence approach established above for this curriculum. It is also the AI approach followed by the most popular text books in the field like (Neapolitan & Jiang, 2018) or (Russell & Norvig, 2021), as it can be read in the overview section of its last edition. Classical perspectives to education in AI where mainly focused on high level processes that take place inside the agent, like knowledge representation, reasoning, or learning, assuming that the sensing and acting stages work properly. The experience in fields related to applied AI, like robotics (Murphy, 2019) or ambient intelligence (Gams et al., 2019), has shown that the considerations about real world sensors and actuators must be included as a nuclear part of the AI literacy, because they can induce restrictions to the higher level components.

To properly explain students what processes run inside the agent, and how intelligent capacities are provided, the diagram shown in Fig. 2 is presented to them in the introductory TU. It is a schematic of the main operational processes that make up an intelligent agent, taken from classical text books (Russell & Norvig, 2021; Murphy, 2019) and adapted by the authors of the current work based on their experience in applied AI (Bellas et al., 2010; Duro et al., 2019).

Five internal processes or operational blocks, linked to Sensing and Acting, have been considered:

1. *Motivation*: the agent must have some type of motivation to operate, that is, the system must fulfill some goal. The motivation can be imposed by the designer,

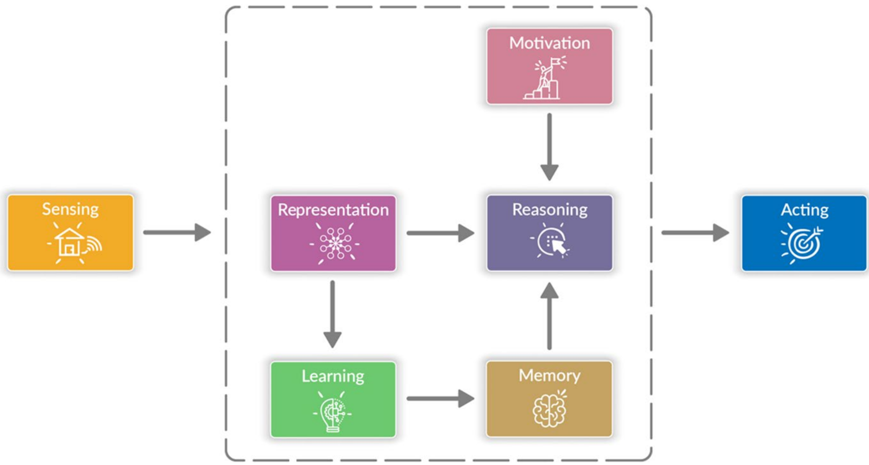

Fig. 2 Main processes in an intelligent agent from an operational perspective

or it can be learnt by the system, which implies a higher level of intelligence, as explained in the Artificial General Intelligence (Goertzel, 2016) or cognitive agent (Baldassarre & Mirolli, 2013) bibliography.
2. *Representation*: the information coming from the sensors must be stored in the computational system under some type of representation, which is very important in order to simplify the remaining processes (reasoning and learning mainly).
3. *Learning*: every intelligent system must learn from experience. This feature is very relevant, because it provides the capability of adapting to new situations, and consequently, being really autonomous.
4. *Reasoning*: the agent must select the action to be applied in the environment following some type of decision process, from a very simple reactive decision, to a very complex one, using internal models, planning, optimization, etc.
5. *Memory*: it is mandatory that an AI system has different types of memory elements to store the models that are learnt, the representations, and other important data that could be useful in the future to avoid re-learning.

Each of the processes that are displayed in Fig. 2 must be present in the implementation of an intelligent agent, although their complexity level can go from very simple to very complex, leading to a more or less autonomous response. According to this approach of situated intelligent agent, with the main blocks displayed at Fig. 2, the AI topics that should be introduced to students can be now properly defined.

The Eight AI Topics

The curriculum presented in this work proposes the following 8 AI topics to be addressed in the TUs:

1. *Perception*: The first topic is focused on the information the agent can obtain from its sensors. It is very important that students distinguish between perception and sensing. While sensing, in this scope, refers to the process of measuring data with a sensor and store it in digital form, perception is the extraction of meaning from such stored data. In this topic, teaching will be focused on the fundamentals of sensors and perception processes more widely used in AI, mainly computer vision, sound and speech recognition, and tactile interaction.
2. *Actuation*: an actuator is a component of a machine that is responsible for moving and controlling a mechanism or system, like a motor. In simple terms, it is a "mover". Actuators are very common in AI systems that must operate in the real world, because they have to deal with electro-mechanical components to performs actions. In the scope of AI, a more general concept of actuator must be considered, not only motors. Students must understand that, in AI, an actuator is every component capable of performing an action, like speakers and LCD screens, which can be used to perform a communicative action.
3. *Representation*: the information that is internally used by the computational system that supports AI can be stored in different ways. This representation is very

important in order to simplify the remaining processes that are carried out, like learning and reasoning. Students will learn the basics of representation, and how the raw sensorial information can be processed to be properly managed by the computational system. This topic implies learning the conceptual differences between symbolic and sub-symbolic representation, and implementing some simple approaches like graphs, trees, or 2D grids.

4. *Reasoning*: the process of selecting the action that must be applied to fulfill the system goals can be simple, a reaction or rule that selects the action from the perception, or it can be more complex, implying a search process over models and representations. That is, prospection and evaluation. In this educational level, only simple reasoning techniques will be introduced in the scope of problem solving in computer science, like graph search, decision trees, or simple rules.
5. *Learning*: the topic of machine learning is fundamental in this curriculum. Students will learn the basics of supervised, unsupervised and reinforcement learning from a practical perspective. They will implement simple programs that perform data preparation, model training, model testing, and model application in a real problem.
6. *Artificial Collective Intelligence*: future AI systems will be interconnected creating a collective intelligence network. The fields of Ambient Intelligence (AmI) and Internet of Things (IoT) encompass this AI approach. On them, distributed sensors and actuators are situated in open/closed environments and through a coordinated communication, they are able of performing different tasks. Smart home, smart industry, and smart city are very relevant application areas that students must know. In the curriculum, these topics will be addressed from the perspective of multi-agent systems (Weiss, 2016).
7. *Motivation*: this is an open topic in AI, related with Artificial General Intelligence, but students should understand how a motivated AI system will work, and how it can be controlled by the human. As a consequence, in this topic, we will address aspects like learning by demonstration, learning by imitation, or intrinsic motivation from an introductory perspective. As it is complicated to work in practical aspects of motivation at this education level, it will be trained in a more unplugged fashion, promoting reflection and discussion about its ethical consequences.
8. *Sustainability, ethics, and legal aspects of AI (SEL):* the impact of introducing AI at many social levels will bring up new benefits and drawbacks that must be faced, and students must be aware of them (Holmes et al., 2021). The ethical aspects and the legal issues behind AI will be trained in this topic. Moreover, the sustainability and carbon footprint associated to AI technologies must be discussed too.

Figure 3 diagram displays a diagram of a global AI ecosystem where the 8 topics established above are present and interconnected. *Sustainability, ethics, and legal aspects of AI* surround the ecosystem representing its impact over society, that is, the real world outside it. Inside the blue square, each semi-sphere represents one intelligent agent, and the arrows correspond to the communications between them, which lead to a network of agents (multi-agent system), a topic that will be trained in the specific *Artificial collective intelligence* TUs of the curriculum. Each single agent

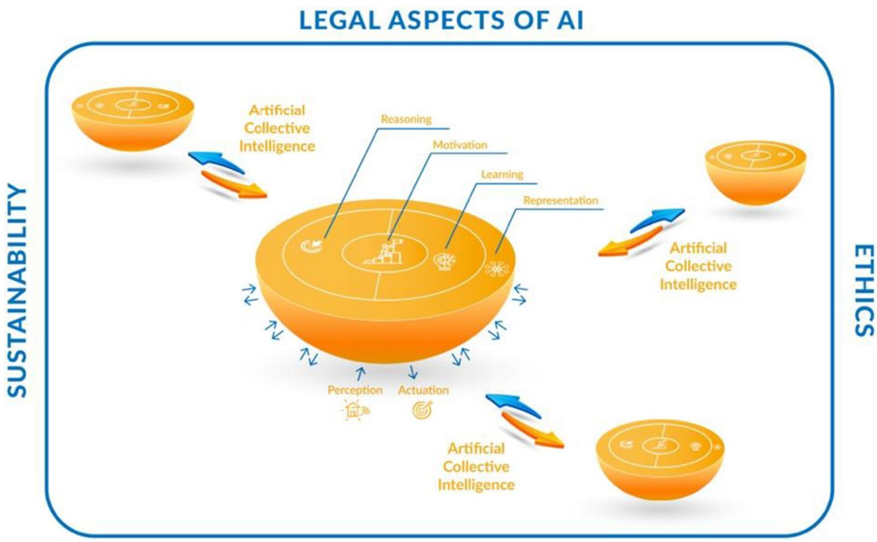

Fig. 3 Topics included in the curriculum represented as an AI ecosystem

in the diagram takes information from the environment (*perception*) and performs actions on it (*actuation*). Inside it, a layered structure has been used, being the most external one the *representation* layer, which is directly connected to perception and actuation. Next, the *learning* and *reasoning* layers are at the same level, because both use the representation to create models, and they can co-exist (using learned models for reasoning) or work independently. Finally, in the core of the agent, the *motivation* layer has been included, representing that it controls the overall operation towards an objective.

It can be observed that all the blocks displayed in Fig. 2 are topics that students will study in the curriculum, except that of *memory*. It is a key element in an AI system that aims to be fully autonomous, because it supports open-ended learning, operating as a core element that manages the acquired knowledge over time (Becerra et al., 2021). But a proper implementation of a memory system is out of the scope of this education level. It would imply dealing with topics like short-term memory, long-term memory, information storage and retrieval, context detection, and others. Anyway, students will use simple memory elements to store information (obtained from the environment or from other systems) and models (used in representation, reasoning and learning) in most of the TUs.

As commented in the introduction, the most relevant initiative for the development of formal AI curricula for secondary school is that of AI4K12 (2022). They propose 5 AI topics as the core knowledge students must gain at this level: perception, representation & reasoning, learning, natural interaction, and societal impact. The results obtained in this initiative have been taken as reference by global institutions like UNESCO (2022). This selection of topics was taken as an inspiration for the AI + curriculum too, with some variations. Perception and natural interaction are considered in the current proposal in the topics of perception and actuation, with a more general perspective than just dealing with humans. Representation and reasoning have been maintained in the current curriculum too, although as independent topics. It is clear the dependence between them, but as representation affects to other processes, like learning, it was decided to keep them separated. Learning and societal impact are key topics, and they are covered both in AI + and AI4K12. Finally, the AI + curriculum includes two topics not considered in AI4K12, namely, artificial collective intelligence and motivation. They are strongly related to the future impact of AI, so they can be easily incorporated in discussion and reflection sessions.

Apart from AIK12, after reviewing those formal curricula proposals that provide open information about their syllabus, it can be concluded that the specific AI topics they cover are heterogeneous, and they do not approach AI education in such a general way. This is a consequence of the different educational systems, specializations, and didactic objectives of each area or country. Generally speaking, we can find three main approaches: the first one is mainly targeted towards machine learning and data science (CBSE, 2022; Lee et al., 2021), the second one is focused on AI-based technologies and applications (computer vision, natural language processing, human–machine interaction) and their ethical implications (Miao et al., 2021; Vuorikari et al., 2022), and the third highlights those topics typical from robotics (Chiu et al., 2022; Knox, 2020), because these devices are used at class. If we move to education companies and private initiatives like (AI4ALL, 2022; ReadyAI, 2022; ISTE, 2022; Ericcsson, 2022; CODE, 2022), we can find a wider scope in AI topics, as these approaches follow more general education levels towards AI teaching.

Summarizing, the 8 topics proposed in this work cover the main processes involved in the operation of an intelligent agent, and they are very similar to those selected in the most relevant initiatives in the field.

Curriculum Organization

The previous 8 topics will be trained with students organized in 5 levels of incremental complexity (see Fig. 4). The first one, focused in establishing the AI scope explained before, will imply web search and investigation, with the aim of showing students real applications in this field. From the second level to the last one, which make the core of the curriculum workload, real problems belonging to three AI application fields will be addressed by the students in the TUs: intelligent smartphone apps, autonomous robotics, and Internet of Things (Ambient Intelligence). Although many other application areas could have been selected, these are very representative of current embedded intelligence domains, and all of them can be developed at schools using a Smartphone. Figure 4 displays, in the right part, an arrow representing that SEL topic will be included in the 5th levels by means of different discussion and reflection activities.

In the three main application fields, students will have to implement programs to solve specific problems. To develop intelligent smartphone apps, it has been decided to use the MIT App Inventor environment, and the available modules for AI (App Inventor, 2022). Regarding autonomous robotics, smartphone-based

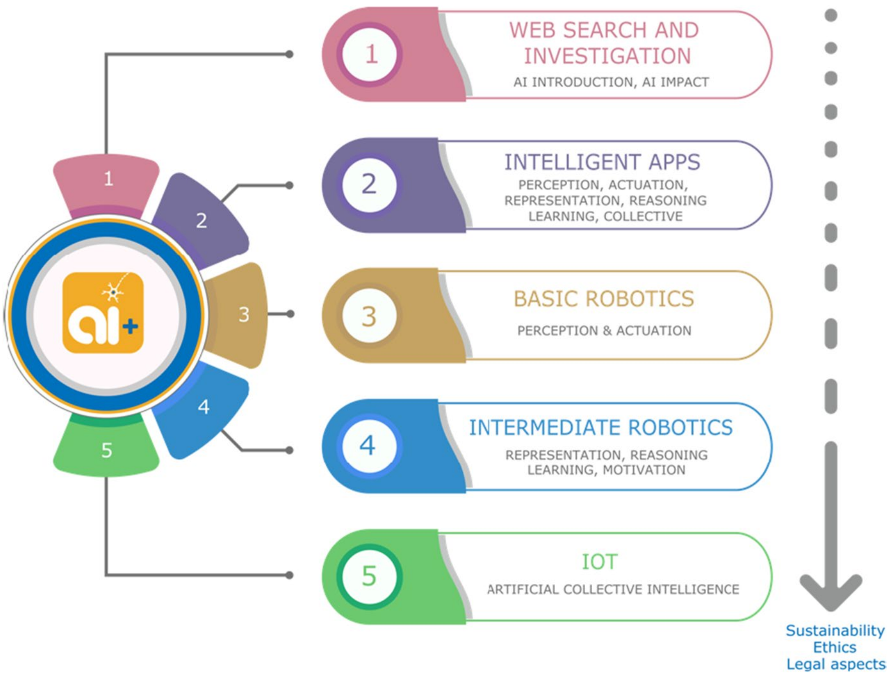

Fig. 4 Curriculum organization in terms of the application fields

robot Robobo (2022) will be used. Due to the technological capabilities of this platform students will train their skills on most of the AI topics explained above, both in real and simulated cases (Bellas et al., 2017; Llamas et al., 2020). Finally, for the IoT field, the Home Assistant framework (Home, 2022) will be used, which supports android libraries too.

Figure 5 shows a table with the timeline of the proposed curriculum. It covers two academic courses, each of them lasting 32 weeks, with 2 h of teaching per week associated to this subject. The curriculum has been divided into 17 TUs, implying a variable number of classroom hours. As it can be observed in the figure, for the first year, there is an initial set of 6 TUs where the 8 AI topics, but motivation, are covered in an introductory fashion. TU1 is focused on providing students with an overview to real applications of AI, in which they have to perform an oral presentation with details about one of them. From TU2 to TU5, students implement smartphone apps through App Inventor that are tested in the real world (Guerreiro-Santalla et al., 2021, 2022). To properly carry out these TUs, we have included an App Inventor Tutorial before TU2 to train students in the basics of this tool. TU6 provides an introductory view of the social impact of AI. It is implemented through a web search and investigation task, in which students must create an infographic using the Genial.ly web tool. From TU7 to TU9 students go deep in intelligent robotics using the Robobo robot with Scratch. All of them had previous experience in this programming language, which allowed to focus more on AI concepts. Finally, TU10 implied another web search and

Year	Level	Unit	Topics	Tool	Hours	Weeks	Project
FIRST YEAR	Intelligent Smartphone Apps	1	AI Introduction	Google Slides	4	2	Web search real AI application
			App Inventor tutorial	App Inventor	**8**	**4**	-
		2	Perception and Actuation		6	3	The School Path Guide I
		3	Representation and reasoning		8	4	The School Path Guide II
		4	Learning		8	4	Capture it I
		5	Collective Intelligence		4	2	Capture it II
		6	Sustainability, ethics and legal aspects	Genial.ly	4	2	Myths & Truths
				Total	**42**	**21**	
	Basic Robotics	7	Perception and Actuation (IR-motors-encoders)	Robobo & Scratch	6	3	Open-ended movement
		8	Perception and Actuation (orientation-camera)		6	3	Color search and collect
		9	Natural interaction (screen, speaker)		8	4	Robobo pet
		10	Human-robot interaction (Impact of AI)	Podcast	2	1	AI tutoring systems
				Total	**22**	**11**	
	TOTAL				**64**	**32**	
SECOND YEAR	Intermediate Robotics		**Python fundamentals**	Robobo & Python	**10**	**5**	-
		11	Transition from Scratch to Python		8	4	TU7 & TU8
		12	Advanced perception & machine learning		8	4	Recycling
		13	Reinforcement Learning		8	4	Coverage with Q-learning
		14	Representation & Reasoning		10	5	Path Planning
		15	Motivation (Impact of AI)	Canva	4	2	Artficial General Intelligence
				Total	**48**	**24**	
	Smart Environments		**Home Assistant Tutorial**	Home Assistant	4	2	-
		16	Ambient Intelligence	Home Assistant & Python	8	4	Classroom automation
		17	Smart Environments (Impact of AI)	Thinglink	4	2	Sustainable Development Goals
				Total	**16**	**8**	
	TOTAL				**64**	**32**	

Fig. 5 Timeline of the AI curriculum

investigation task related with the ethics behind human–robot interaction and AI tutoring systems.

The second year is more technical than the previous one, and it implies students to solve more challenging projects using Python language. To smooth the transition from Scratch to Python, a specific introductory TU has been included (TU11), which faces the same project as TU8 but with the new language. As tested in the workshops carried out with students in the project, this is enough for those with high skills in programming, or with previous experience in text-based programming. But for the majority, it is recommendable to carry out a specific training in Python fundamentals, as the one proposed in Fig. 5 before TU11 with a minimum of 10 class hours. However, it must be pointed out that this is not a programming curriculum, and the TUs include programming templates and external libraries that simplify the solution achievement. TU12, TU13 and TU14 continue to focus on autonomous robotics, and go deeper in very relevant AI methods like reinforcement learning, planning, and object recognition with deep learning. TU15 is, again, a web search and investigation task related with the field of Artificial General Intelligence, and intrinsically motivated systems. Finally, the two last TUs are focused on Artificial Collective Intelligence. On TU16 students create simple python scripts through Home Assistant and a specific library developed in the AI+scope. The challenge is to automate a classroom management system using CO2 level and ambient light sensors, together with a fan, a speaker and lights as actuators. The Robobo robot was also included to create a richer collective AI system. Finally, in TU17 students must investigate the UN's sustainable development goals to create an interactive visual tour with Thinglink showing the potentially of AI to deal with such goals.

As it can be observed in Fig. 5, the 8 established topics are not covered with the same depth. In this sense, perception, actuation, machine learning, and SEL have been considered the most relevant topics at this education level, and they have a higher associated workload. All the TUs have been tested in the realm of the AI + project and they can be downloaded at (AI+, 2022b). On them, the specific challenges are described, and materials for teachers and students are available.

Teaching Unit Organization

All the TUs include a pdf file that represents a teacher guide, and a second one that represents student's activities. There is a TU0 that has been created only for teachers where the curriculum organization is detailed, including methodological aspects (AI+, 2022b). Apart from this TU0, in all the remaining ones, the teacher guide is composed by the following sections:

1. *Introduction*: where an overview of the topic to address in the TU is provided to engage students, including a brief description of the challenge scope and its real applicability.
2. *Context*: where the prior knowledge required by the students in order to properly follow the TU is established.
3. *Learning objectives*: where the pedagogical goals of the TU are formalized, organized into specific (those related to AI) and transversal (those related to other subjects or skills) concepts.
4. *Contents*: where the specific AI concepts to be studied are specified.
5. *Temporary organization*: each TU is organized into activities, which finish with a deliverable that must be evaluated by the teacher. Each activity is organized as a set of tasks, which are milestones that must be followed to reach the final objective. This temporal organization of the challenge into tasks is provided to the teachers, although the recommendation is that the students generate it by themselves, as time management it is a key competence in the PBL approach.
6. *Necessary resources*: the hardware and software elements required to complete the TU are detailed.
7. *Bibliography:* the general bibliography covering the TU contents is provided, together with links to multimedia material.
8. *Groups:* a feasible distribution of students into groups is proposed considering the challenge to be carried out in the TU. In this sense, TU0 provides a description of possible roles to be considered (Time Manager, Programmer and Hardware Manager).
9. *Challenge / Project:* this section is the core part of each TU. It contains a description of the challenge (project specifications are provided in the text and clarified by means of a video with the expected functioning of the solution), the theoretical concepts to be introduced by the teachers, the work to be carried out by the students, the description of a possible solution, and the proposal of how to evaluate each task. It must be pointed out again that the TUs have been designed for the teacher, so they are responsible for reading, testing and adapt-

ing the contents to their specific group of students. However, although they are free to adapt the TU, some relevant aspects must be preserved: the project specifications (how the solution must work), the teaching methodology (learning by doing), and the specific learning objectives. A possible solution to the challenge is explained in this section to help the teacher, but it is not intended to be provided directly to the students. The degree of guidance that each teacher decides to use with the group is out of the scope of this work.

10. *Evaluation:* a proposal of specific values for the rubrics is provided, as well as an example of the final questionnaire to be filled by the students.
11. *Complementary activities:* thinking of students that are able to finish the challenge early, a set of complementary activities are included at the end of the TU. They are improvements to the challenge with varying complexity that the teachers can propose.
12. *Annex:* the annexes contain technical details regarding the solution program, or other specific aspects covered in the TU, but considered as additional.

All the details of these sections are available at (AI+, 2022b), but for the sake of clarity, Table 1 shows the learning objectives of the first year TUs. It can be observed that most of the specific items are completely new for this education level, but transversal ones should not, so with the TU completion they will be reinforced.

Evaluation

Although evaluation is open to the teachers' criterion, in the AI + project, a specific proposal for the evaluation of the TUs has been created. It has been designed following general recommendations in STEM bibliography (Capraro & Corlu, 2013), and integrating the feedback provided by the teachers involved in the project.

To evaluate the TU comprehension by the students, two main aspects should be considered:

1. *The correct functioning of the program:* the TUs rely on a challenge/problem that must be solved in the real world. Therefore, students may focus their efforts on the reliability of the program they develop, which must verify the TU requirements.
2. *The understanding of the AI concepts of the TU*: apart from achieving a reliable solution to the challenge, students must learn the underlying AI concepts, so that they can extrapolate them to other problems. In this sense, every TU deals with the fundamentals of a given topic, so the concepts to be evaluated are very specific.

To achieve a proper evaluation of these aspects, three main methodologies are proposed:

1. *Final test of the program:* at the end of the TU, each group must show the operation of the program in the real world. The teacher must perform a program check,

Table 1 Learning objectives of the TUs corresponding to the first year in the proposed curriculum

	Specific	Transversal
TU1	• Fundamentals of perception, actuation, representation, reasoning, learning, motivation, collective intelligence, ethics, legal aspects, and sustainability in AI • Embedded intelligence • Real applications of intelligent agents	• Web search and investigation • Synthesizing skills • Group discussion and reflection • Oral presentation
TU2	• QR code sensing • Speech production • Speech recognition • Human–machine interface • Gyroscope and magnetometer sensors	• Computational thinking: variables, conditionals, loops, events and functions • Euler angles: roll, pitch, yaw
TU3	• Digital image representation • Topological and metric mapping • Simple graphs • Rule-based reasoning • Probabilistic reasoning	• Computational thinking: variables, conditionals, loops, events, lists and functions • 2D maps • Time measurement • Empirical probability
TU4	• Data preparation • Supervised learning • Artificial Neural Networks • Image classification • Model validation	• Computational thinking: variables, conditionals, loops, events, lists and functions • Digital image processing • Numerical vs categorical variables • Probability
TU5	• Centralized vs distributed networks • Cloud database • Speech production	• Computational thinking: variables, conditionals, loops, events, lists and functions • Time measurement • User experience in videogames
TU6	• Ethical issues of AI: impact of jobs, data privacy, gender bias, population control • Legal aspects of AI • Sustainability of AI: benefits and drawbacks	• Web search and investigation • Synthesizing skills • Group discussion and reflection • Improve their ability to empathize (thinking about the consequences of actions in others)

Table 1 (continued)

	Specific	Transversal
TU7	• Infrared sensing • Motor control fundamentals • Blocking and non-blocking operation • Open-ended movement • Reality gap (simulation vs real robot)	• Computational thinking: conditionals, loops, variables, and functions • Time measurement • Angles
TU8	• Image segmentation • Sensing vs perception • Color blob and blob area • Image representation (coordinates) • Scene illumination • Robustness in robotics • Motion sensors	• Computational thinking: conditionals, loops, variables, and functions • Time measurement • Distance measurement • Angle measurement • Cartesian coordinates • Basic geometry: areas
TU9	• Human–robot interaction • Speech production • Emotion production • Tactile sensing: tap and fling	• Computational thinking: conditionals, loops, variables, and functions • Cartesian coordinates • Angle measurement • Parallel execution

reviewing if all the expected features of the program have been achieved, and if it solves the problem reliably. In every TU of this curriculum, there is a section devoted to evaluation, with specific features that must be controlled. In addition, the students must submit the programming code of their solution, so that the teacher can execute it, if required. As this is not a programming curriculum, the evaluation emphasis will not be on the code quality, but in its operation.

2. *Final test of theoretical concepts*: at the end of each TU, the students must fill a short survey in class that will focus on the main AI concepts addressed during it. This survey will be included in the evaluation section of every TU.
3. *Ongoing work during the TU:* apart from the final result of the TU, it is important to evaluate the "path" followed by the students during the TU completion. This is in accordance with the cPBL methodology we propose, because it is important to evaluate the participation of each student in the completion of the challenge. To this end, individual rubrics that the teacher must fill every week are proposed. They are specified in each TU, but in general terms, the main aspects to consider are those shown in the table of Fig. 6. It is a holistic rubric that does not focus on the specific AI challenge, but on the overall skills of the learners (Moskal, 2000). The task is considered as a whole in which individual deficiencies do not affect the overall quality of the activity (Huang & Jong, 2020).

Level (score) / Aspects to be evaluated	**Expert** (6 points)	**Competent** (4 points)	**Partially competent** (2 points)	**Not yet competent** (0 points)
Adequate selection of information	Seeks information for before asking the teacher. Rarely needs external help.	Seeks information for before asking the teacher but often needs external help.	Rarely seeks information for before asking the teacher.	Never seeks information autonomously. Always asks the teacher directly.
Time management	Manages the time very well and can help the rest of the classmates when finishes before the time.	Manages the time well although usually finishes right on time.	Does not manage time very well and sometimes finishes after the deadline.	Does not manage time very well and hardly ever finishes on time.
Design and construction of the solution	Always understands what he/she needs to be done and implements possible and effective solutions.	Usually understands what he/she must do and is able to implement possible and effective solutions most of the time.	Often do not understand what they must do and/or is often unable to implement possible and effective solutions.	Is hardly ever able to implement effective and possible solutions for the resolution of tasks.
Creativity	Develops very creative project. Following the instructions provided has been able to make an original product that stands out from the rest of the groups.	Develops creative projects although some of the ideas could have been better developed.	Develops projects which fits the proposal, with some creative element but could have taken more out of it.	Has limited him/herself to following the instructions. Unoriginal project.
Teamwork	Dialogues with group colleagues. Knows how to defend his/her position and accepts other proposals. Knows how to reach group agreements.	Dialogues with colleagues. Knows how to defend his/her position and although accepts other proposals. Does not always reach group agreements.	Dialogues with their colleagues but do not always know how to defend his/her position or accept other proposals. Does not usually reach group agreements.	Little dialogue with colleagues. Does not know how to defend his/her position or does not accept other proposals. Does not usually reach group agreements.

Fig. 6 Individual rubrics proposed to evaluate the ongoing work of the students

As the students advance in the curriculum, the TUs become richer and longer, implying a larger number of activities. From the PBL perspective, they are suitable for developing a final dissemination work by the students where they formalize the steps followed to achieve the goal, the problems encountered, and the solutions provided. It is recommended that teachers propose different activities in different groups of students. For instance, one group could perform an oral presentation, another could make a video, create a podcast, a blog entry, and so on.

Summarizing, each TU contains a proposal for teachers about its specific evaluation. It is based on 5 items, and the following percentages in the final assessment were agreed:

- The program is functioning correctly (at the end of the TU) – around 50%
- The submission of the programming code (at the end of the TU) – evaluated in the previous item
- The filling of a survey with theoretical contents (at the end of the TU) – around 20%
- The filling of individual rubrics (every week) – around 30%
- Optional: a dissemination work (at the end of the TU)

Teacher's Feedback

What makes the current curriculum proposal feasible to be implemented in high schools in the short-term is the integrated work of AI experts and secondary school teachers during the three years of its duration. Teachers in the six partner schools have been filling out a feedback form (shown in Fig. 7) as they implemented the TUs with their students. These forms were analyzed by the UDC team to homogenize the comments and an online group meeting was later carried out to agree the final changes and improvements to be performed to the TU.

Figure 7 contains the form received from one of the partner schools in TU2. It has been included as an example of the type of comment received. The remaining ones are available at https://cutt.ly/wD01JLp, where it can be observed the heterogeneity of feedback, and how different teachers rely on different aspects.

Following this process, the following changes have been made to the first version of the TUs:

- *Context*: the background knowledge regarding programming was adjusted in order to include only block-based programming, removing text-based programming, which will be introduced in robotics TUs in a progressive manner.
- *Contents*: specific tutorials about App Inventor were included in the TUs as requested by the teachers, together with a timeline to include them in the curriculum.
- *Temporary organization*: the feedback provided in this aspect was very heterogeneous, depending on the student's previous skills on programming and age. However, in general, the duration of the TUs has been increased by 50% with respect to the original one proposed by the UDC team. This information,

TEACHING UNIT 2 – ACTUATION AND PERCEPTION	
Please, enter any comment you have on the general sections in order to improve them	
Introduction	Not bad. We think that the goal of unity is achieved.
Context	As expressed at this point, prior knowledge of programming in App Inventor is necessary.
Learning objectives	At the Spanish level we would add greater oral and written comprehension of English.
Contents	We find it an affordable task, even though activity 2 was somewhat guided for most of the group. It can influence the current situation.
Temporary organization	Activity 1. Task 1 and Task 2, time planning is enough because they have previously done a similar exercise. Activity 2. Task 1, 2 and 3. We think that this activity requires a little more time, perhaps a session for adults. From the programming of the compass it seems to us something insufficient, especially because they need to first acquire technical concepts that they do not know and the programming must be something guided by the teaching staff, not totally autonomous.
Necessary resources	Most of our students have the required resources.
Bibliography	The bibliography that appears in point 7 is very useful because it does not enter into very technical data, but are videos of general concepts easy to understand by the students. However, the more technical videos on the operation of the gyroscope and magnetometer of the ***Activity 2 – Task 1*** are complex to understand, since concepts such as vectors, angular velocity, Coriolis effect, Hall effect, etc., do not yet know them. In this case, we have provided them with another not so technical but that make clear the work of each of these sensors without getting into very complex physical concepts for them that are not seen in this educational stage. (https://www.youtube.com/watch?v=vRrCuW3mSBA) Regarding the videos of the ***Activity 2 – Task 2*** are affordable for them, although we think they do not stop to watch them.
Group organization	Although this TU2 has been carried out individually and with online training (videoconference to solve doubts and guide them), this organization in pairs (in case of face-to-face sessions) seems perfect, with alternation of roles in each work session.
Challenge (Adequacy to topic, Motivating for students, others)	They found the challenge interesting and even useful to use in their schools. They accepted the challenge of carrying out the TU2 online without any problem. They understood the objective of it and, in this case, they understood much better the concept of perception and performance in an AI System. During this TU2 and, despite being done online, we found the students who voluntarily carried out the activity, quite motivated. Anyway, they are already tired with the workload of the school and do not ask the doubts. This negatively influenced the group's participation.

ACTIVITY 1	
Correct duration?	☒Yes ☐No, it's necessary
Theoretical information provided	☒Enough ☐Not enough, I need
Proposed task and solution (objective clarity, difficulty, others)	At the teaching level, it is easy to follow and there is no undefined step, which, when it comes to making the unit for its understanding, greatly facilitates the work of the teaching staff. At the aesthetic level and resources offered, it also seems very complete, although there are certain physical concepts that students are not able to assimilate. At the level of lighting, this activity 1 should not have difficulty under normal conditions. The resolution is clear and very guided from the template which, by the way, is very useful to them. In addition, they already did a similar previous activity and that helped them in the resolution.
ACTIVITY 2	
Correct duration?	☐Yes ☒No, it's necessary 2 extra hours
Theoretical information provided	☒Enough ☐Not enough, I need
Proposed task and solution (objective clarity, difficulty, others)	At the faculty level, we found this activity equally easy to follow. It is very well explained and there is no doubtful step left or without information. At the student level, we believe that the most complex part was task1, compass programming, because although they understand the general physical concept, translating that to programming in App Inventor cost them work. Most of the students needed guidance from the teachers to do it, although there were also students (1 student and 1 student) who were totally autonomous and another student almost autonomous. We think that most of the students do not stop to investigate and are already tired at this point of the course. We believe that this TU2 would have been easier in person and we even thought that it would have been completed autonomously by a greater number of alumn@s.
Please, enter any comment you have on the general sections in order to improve them	
Evaluation	Due to the current situation of the centers, this part was not raised to the students, we will only pass the Kahoot, although being proposed voluntarily, not all the students participated.
Complementary activities	Not solved due to lack of time. In any case, to carry them out, they would require another session to majors.
Annexes	The extra information it contains is appreciated. They complete the unit and facilitate the work of the teaching staff.

Fig. 7 Example of teachers' feedback form for TU2

obtained from the real application of the TU with students, is very relevant to create a reliable subject that can be taught in two academic years.

- *Necessary resources*: all the feedback in this aspect was very positive, and the use of the student's smartphone during classes did not imply any problem.
- *Bibliography*: classical AI books and texts were found to be too complex for secondary school teachers. Until now, few books, tutorials or specific courses adapted to this level have been published, so most of the references were extracted from websites, videos and other digital publications. This selection was criticized by some teachers because these references could change in time or become outdated soon. As a consequence, the bibliography is in a continuous update and improvement process in order to avoid such problems.
- *Challenge*: the teacher's feedback in this core section of the TUs implied a main improvement, apart from specific aspects of the technical solution proposed by the UDC team. Namely, two levels of student's guidance have been included: a higher one, where more information is provided to complete the challenge, and a lower one, where more room is given to their creativity.
- *Evaluation:* the main improvement in this aspect has been that of reducing the complexity of the rubrics, which originally included several items to be monitored by teachers during the completion of the challenge.

Application Results

During the three years of the AI+project development, five special training activities were carried out, involving all the students enrolled in the project working together on the same TU. An average number of 30 students from the 6 partner schools attended them. These activities were implemented as practical workshops with a duration between 6 and 12 h, divided in 2–3 sessions. They were leaded by the UDC team who developed them following the previously presented teaching methodology. Due to the pandemic, two were held in online fashion, while the other three were in person, but in all of them, the working groups were heterogeneous, mixing students of different nationalities.

Figure 8 shows the students' answers to some technical questionnaires carried out in these training activities. Each of them was composed by 10 questions of different typology. Due to space restrictions, only two of them have been included for each activity, but they are representative of the remaining. It must be pointed out that the students did not have any previous knowledge about the topics covered in the workshops, and the answers were obtained in the last session. The first two questions correspond to machine learning (TU4), the second pair to ethics (TU6), the third one to natural interaction (TU9), the fourth to computer vision and robotics with Python (TU10), and the last two, to reinforcement learning (TU11). A general analysis of the answers shows that most of the 30 students understood the technical issues behind each topic. This is clear, for instance, in the two last questions related to Q-learning, which is a quite complicated and totally new algorithm for them, and yet most of the answers were correct.

Consequently, we can conclude that the engineering approach to AI teaching focused on embedded intelligence and learning by doing, provided successful comprehension results. This is an interesting outcome, because students without previous training in AI and without relying to specific theorical lessons, could acquire fundamental AI skills by developing the challenges.

Regarding teachers, Fig. 9 contains the results obtained in the final survey filled at the end of the project. Most of them agree with the practical methodology followed in the project, including the use of real-world devices like smartphones and Python language, although they point out that it takes more time to students to advance. Consequently, the number of different topics that can be trained is lower than following a more traditional methodology, or even following a user-based perspective, but they are retained more robustly.

In more general terms, teachers that were enrolled in the project feel confident to teach AI, mainly through dedicated subjects, but many of them not in the short-term. This is the situation of many secondary school teachers, that are interested on teaching AI, but they do not have the appropriate background. Hence, it seems mandatory to include specific teacher training and adapted materials in the digital education plans.

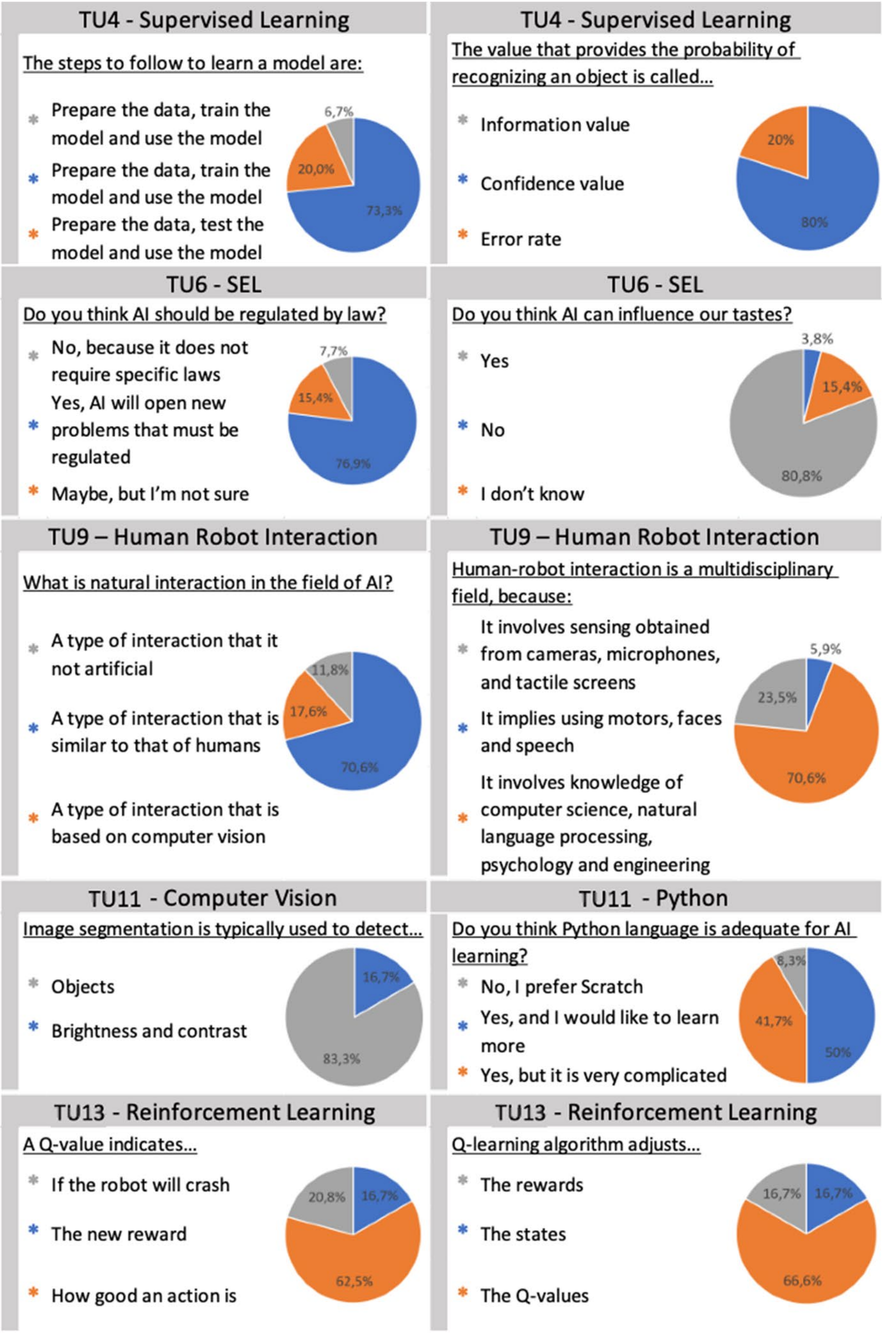

Fig. 8 Students' answers after TU completion

Fig. 9 Final survey filled by the teachers

Main Limitations

After presenting the proposed AI curriculum in detail, this section presents a brief discussion about its limitations, with the aim of clarifying its scope in terms of impact and contribution to AI education.

First, the curriculum is targeted to a specific group of students from scientific specialties or programmes. Consequently, the AI approach selected is mainly practical, implying that students must program real devices in three specific application areas in most of the TUs. These two design decisions make the curriculum scope more limited to extract conclusions that can be applied to other education levels, or to more general audience. However, the students considered here are make up a very relevant and large educational target, including all those interested in technical degrees at higher education. In addition, the adaptation of the TUs to Vocational Education or specialized professional courses would be straightforward due to the practical perspective that has been used.

Even with this technical background, during the TU realization we found problems to cope with the learning objectives because both teachers and students' skills on programming were limited. As shown in Fig. 5, to minimize delays, we decided to include specific TUs for App Inventor and also for Python in the final curriculum. However, mainly in the case of Python, and according to the answers displayed in Fig. 9, it would be recommendable to carry out specific training courses with teachers before the AI curriculum implementation. In the case of students, previous or concurrent training in Python is required too.

Another limitation of this proposal could be that of relying on Android Smartphones for the TU development. As commented above, the use of the student's one is encouraged, but in the case that it is not possible, it could imply budget limitations at schools to buy them. In this case, it is suggested to carry out a donation campaign between parents and local administrations to obtain used phones, which could be perfectly used for teaching, and which has been carried out in the past with high success. In the case of the real Robobo robot used in this approach, it could be changed by its open simulation software (RoboboSim, 2022), which also simulates the Smartphone and allows for online and blended learning.

Finally, although the curriculum has been tested by more than 30 students and 12 high school teachers with different skills and cultural background for 3 years, to develop a general AI curriculum that can be applied worldwide will require more time and test. This is why it is all the TUs are available at the results section of the AI + project, so they can be used as they are or adapted by teachers that could be interested in particular topics or activities. Comments received from other teachers and educators will be considered in the future to continuously improve the curriculum.

Conclusions

In this paper, a specific proposal of Artificial Intelligence curriculum for high schools has been presented. It has been developed within the scope of the Erasmus + programme, and it is targeted towards European educational system, although it could be adapted to any other. The curriculum has been structured into 8 main AI topics that are introduced to students in a progressive manner, following a fully practical methodology based on the concept of intelligent agent. Each of the teaching units present a challenge to the students based on solving a real problem using a smartphone-based technology that must be programmed and tested. Current smartphones have the appropriate technological features to carry out real embedded intelligence tasks, while they do not imply a relevant cost to schools, that could use the student's one.

The teaching units have been designed and improved in collaboration with high school belonging to the AI + project, increasing their reliability and applicability in the short-term, because teacher support has been considered as fundamental. In addition to the direct feedback of the partner teachers, the TUs have been presented in relevant conferences of the field (Guerreiro-Santalla et al., 2021, 2022), and the comments and reviews obtained from AI experts have been also used to improve them in technical and educational aspects.

Regarding direct impact, the current proposal will be included as an optional subject in the academic offer of the six involved schools from course 2022 onwards. In addition, it must be pointed out that it has been taken as the basis for a new official AI subject at high school in the Galician region (Spain), reaching potentially to more than 10.000 high school students (Xunta, 2021).

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Availability of Data and Material All the material developed in this work is available at the results page of the project: http://aiplus.udc.es/results/

Code Availability The templates used in the teaching units are available at the results page of the project: http://aiplus.udc.es/results/

Declarations

Conflicts of Interest The authors declare that there is no conflict of interest.

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