Introducing the Fundamentals of Artificial Intelligence to K-12 Classrooms According to Educational Neuroscience Principles

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Introducing the Fundamentals of Artificial Intelligence to K-12 Classrooms According to Educational Neuroscience Principles

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***Abstract*— The rise of Artificial Intelligence (AI) has brought to the fore the need to educate students about AI. The aim is not to keep AI a black box and at the same time to be recognized as a transferable literacy with multiple learning benefits per age group of students. In order to strengthen this perspective, the design of workshops to introduce the basics of artificial intelligence to middle school students according to educational neuroscience principles is presented. With these workshops, the importance of AI literacy is emphasized, and students are given space for hands-on activities. The proposals are based on the axes of perception, representation and reasoning, learning, physical interaction, and social impact and include sections on Introduction to Machine Learning, Machine Learning Application Examples, Supervised Learning, and Training-Test Processes, Unsupervised Learning, and Machine Learning Algorithms.**

Keywords*— *Artificial Intelligence, K-12 Education, Machine Learning, Computing Education, Workshops, Computational Thinking, Educational Neuroscience

I. INTRODUCTION

The Artificial Intelligence (AI) era has brought to the public spotlight a series of algorithms designed for simplifying, supporting, and enhancing decision-making [1]. These algorithms have been exploited for implementing applications involved in many diverse domains, such as health care, space exploration, travel, education, law enforcement, politics, agriculture, earth observation, and logistics [2]. However, as the ongoing revolution in AI affects and shapes society, AI mechanisms remain a black box for most users, leaving them out from assessing the social implications of new technology [3].

AI education can address this gap by enabling students to understand the fundamentals of AI as part of the 21st-century critical skills [4]. Thus, it is an important issue on the agenda of policymakers to enhance next-generation AI knowledge and competencies and provide them with all the essentials for meeting the needs of the future industry and society [5], [6]. Nonetheless, the definition and conceptualization of AI literacy along with the design of a related curriculum for K-12 schools are still under exploration. AI education has to overcome barriers connected to the intersection of different disciplines, from computer science to ethical cases, which increases the complexity of knowledge transfer. The present proposal focuses on middle school students. The selection of middle school students is based on their increasingly daily contact with AI and the beginning of thinking about their future career interests. Along with the need to build students' AI literacy, it is important to inspire and embrace educators to participate in the creation of instructional interventions that negotiate AI issues. In the present work, a relevant 3-hour program is presented.

The proposal focuses on the design of workshops that will introduce AI fundamentals to middle school students, highlight the importance of AI literacy and give room for hands-on experiences. Specifically, the current study is structured as follows: Section II presents a literature review on the existing tools and methods for introducing AI education to K-12 learners. Section III delineates the theoretical background of educational neuroscience which enhances the design of the present proposal, whereas in Section IV the involved workshop activities and materials are described in depth. The concluding section highlights limitations, recommendations, and directions for future research.

II. K-12 AI EDUCATION

The basic concepts of AI have been initially introduced to K-12 learners via syntax-based programming, which results in many challenges for both educators and learners [7], [8]. The improvement of the learning process requires the adaption of more age-appropriate software tools and activities.

Currently, a series of AI tools for kids do exist as standalone products or extend computer science curricula globally. Machine Learning for kids [9] provides users the potential of training and testing machine learning models via Scratch or Python. It comes with a public repository with many worksheets, educator guides, and pre-trained models. In addition, the Computer Science Teachers Association (CSTA) and the Association for the Advancement of Artificial Intelligence (AAAI) have launched in the United States an AI education program for K-12 students with the latter including topics such as machine learning, knowledge representation, and ethics [4]. The AI for K-12 recommendations [10] aimed at developing a

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framework for transferring AI knowledge to each grade level by providing a repository of videos, software, and activities that can be adapted to teachers' lesson plans. Moreover, the Massachusetts Institute of Technology (MIT) has developed and offered a complete suite of resources for AI learning [11].

Cognimates for extending Scratch with AI modules [12], Calypso for Cozmo for teaching robotic AI [13], TensorFlow Playground for direct visualization of deep networks [14] and ML Playground for exploring basic ML algorithms [15] are additional software tools that include AI concepts and components.

The AI for K-12 initiative identifies five big ideas in AI, which are a) The idea of perception, that is, computers perceive the world through sense, b) The idea of representation and reasoning, that i.e. agents maintain representations of the world, and use them for reasoning, c) The idea of learning i.e. computers can learn from data, d) The idea of natural interaction i.e. intelligent agents require many types of knowledge to interact naturally with humans and e) The idea of social impact that AI can affect society in positive and negative ways (Fig. 1).

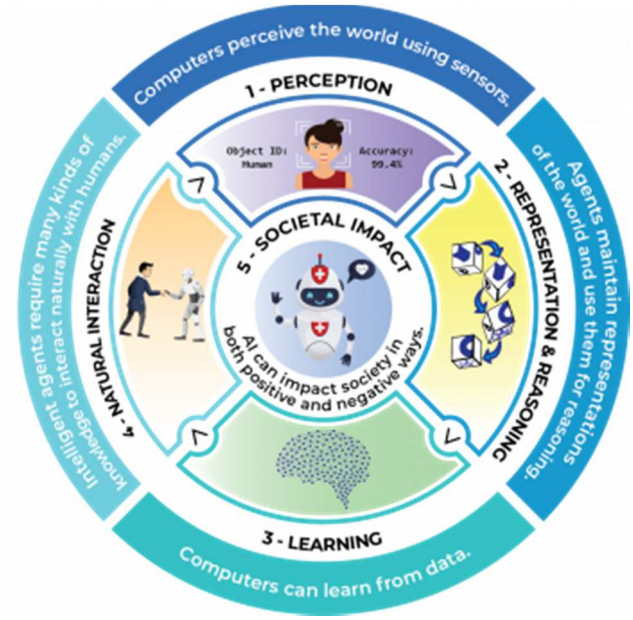

Fig. 1. Five Big Ideas in AI (https://ai4k12.org/)

The aforementioned platforms and tools provide great activities for integrating AI into classrooms. However, they are offered as standalone AI tools. On the contrary, the development of a core AI course taught by K-12 educators and designed by researchers is of great importance. The workshops must be designed and prepared by researchers, AI engineers, and K-12 educators. This structure has been selected in the workshop design that will be presented in this work, which has several notable advantages compared to other related proposals. It blends the pedagogical approach of educators with the knowledge and experience of AI developers. This is crucial for the success of the project and its potential integration of it into a core course in K-12 classrooms in Greece.

In this context, the need for professional development of in-service and pre-service computer science educators to be able to work and develop learning activities to integrate artificial intelligence into classrooms is highlighted. It is argued that computer science educators should be well versed in Computer Science and additionally have knowledge of digital technologies that can support their teaching [16]. The professional development of teachers is important to focus on preparing them to develop activities a) that favor Computational Thinking, which is a fundamental goal in Computer Science education, b) that strengthen the practice of computational thinking in multiple ways, c) that contribute to interpretation, where relationships and abstract concepts abound in the area and demand extensive work to investigate, explain, and make conclusions in order to gain a deeper understanding, d) that strengthen the application, where students work with real-world applications of computer science concepts, e) that favor evaluation in which students evaluate the work of others or self-assess, working critically and gaining a deeper understanding of concepts and processes and f) that foster creativity, where students engage in activities that require inspiration and imagination.

In addition, the Association for Computing Machinery (ACM), emphasizes the need for Computer Science educators' professional development in pedagogical approaches in order to be able to transform their teaching and learning practices and support students [11]. Moreover, the authors of the report of the CSTA highlight the need to certify the Computer Science teachers' knowledge in both Computer Science and Pedagogy [12]. To this end, it seems necessary to develop the Technological Pedagogical Content Knowledge of in-service and pre-service educators in order a) to be able to recognize and use productively the technological tools to function as a means of developing knowledge and skills, b) to be able to define the pedagogical context in which relevant learning activities will be initially attempted and integrated along the way, and c) to be able to integrate into the existing curriculum learning activities for the teaching of artificial intelligence in the classrooms or to be able to contribute for the development of a core AI course that will be taught to K-12 learners. Communities of practice can also play a crucial role in sharing activities to strengthen, improve and offer to the public the material that they will develop, for the benefit of learners and computer science.

III. Educational Neuroeducation

In recent years, the need to transform educational practices to strengthen the learning framework setting as prime goal the improvement of learning according to the findings of educational neuroscience has become apparent [17]. Learning is connected and achieved due to the brain's learning systems. This results in acquiring and storing information in the memory system during the learning process. The amygdala and the Hippocampus, both located in the temporal lobe, are considered to be two main modules that contribute to the learning process. In any learning process, the brain is able to detect spatial-temporal patterns of neuronal activation, correlating perceptual information and motor responses. These associations, which may be conscious or unconscious, are influenced by emotional structures and stimulus-response processes. Although synapses are the initial stage of learning, learning results from

organizational processes in neural circuits and distributed systems. Thanks to these processes, the brain creates and develops ”concepts”. Thus, a memory event is stored as changes in neuronal synapses based on environmental stimuli [18] and the cellular phenomenon of long-term potentiation takes place, which supports the generation and storage of an event in memory. Therefore, the brain learns and acquires skills by observing others and modeling their behavior and actions, using its available neural circuits related to perception and understanding. Furthermore, to form new concepts and new structures through learning, it can tap into neural circuits. All the aforementioned systems work uniformly and respond differently a) over time and b) in different educational contexts. Educational neuroscience aims at enhancing learners' attention, motivation and ability. Thus, learners have the potential to meet the requirements of the learning results that have been predefined in a specific teaching and learning context. The focus is on three issues: a) engaging learners, b) building new knowledge, and c) storing knowledge so that it is permanent, accessible, and useful [19]. In the context of the workshop design, the above three issues have been considered with the goal of enhancing the learning experience.

A. Learning and the Brain

The brain is characterized by plasticity, a key element in achieving learning [20]. The design of the activities of this proposal offers multiple opportunities that can enhance learner participation. The aim is the involvement of the trainees and their active participation in the learning process. Thus, the opportunity to activate synapses and neural circuits is given, which has as a result significantly increased opportunities to gain experience and build new knowledge as opposed to a process where the learner is a passive participant listening to the educator and/or watching with or without digital technologies a presentation or a lecture.

In the context of building, consolidating, storing, and recalling new knowledge, it is important to offer opportunities for a) diagnostic, b) formative, and c) summative assessment. By making use of the assessment processes that have been included in the workshop design, the educator can a) recognize the learners' preexisting perceptions, b) identify whether the learners have the knowledge that is required, and c) observe the learners' transformation/progress. Assessment has a decisive role both in the diagnosis of a person's knowledge and in the development of his knowledge [21]. To enhance learning, it is important to provide frequent and at the same time non-threatening assessments. In addition, it is crucial to offer learners feedback on the extent to which they have understood an idea or concept. Memory is enhanced through assessment and is therefore a methodology that can be used by instructors to help learners store important information in their memory during the learning process.

Taking advantage of the barriers that students/learners face in their learning, or that the educator identifies while teaching, can help develop the brain. By actively involving learners in the learning process and by dealing with issues that arise in the group, their learning can be enhanced. The goal is to allow learners to review the learning barriers that appear (either their barriers or barriers that other learners meet) both individually and collaboratively, in order to eliminate misconceptions [22]. In addition to the opportunity for the educator to assess their learners, the learners themselves have the opportunity to discuss how they worked to identify and eliminate misconceptions in order to share useful strategies. These strategies can provide students with opportunities to acquire skills through observing others [22].

The interconnectivity of the brain also necessitates a multidimensional approach to a concept that can be attempted through different types of teaching and learning approaches. It is important to integrate open-ended and closed-ended problem-solving activities and different strategies within the teaching approach. In this regard, learners are given the opportunity for participating in activities via multi-method approaches. These multiple representations have a special involvement and effects in the classroom context. During the last decade, multiple representations have been proven to be an important element of learning. Engaging students with a concept or idea in multiple ways contributes to the acquisition of new knowledge, problem-solving skills [23], and the application of knowledge in their daily lives. For example, it is interesting for learners to approach and solve the same problem in different ways such as: a) applying algebraic approaches, b) creating graphs or diagrams, c) developing computer programs (algorithms or coding), and d) writing a story or creating an image/video/artifact for this problem [24].

In summary, it seems that in the context of learning, it is important for the educator to focus on: a) the active participation of the learners, b) how he/she will integrate the assessment of learners, c) the utilization of learning obstacles and d) the multidimensional approach of the lesson plan. The educator's focus on the above needs to take place in an appropriately designed educational environment.

B. Learning and Educational Environment

The educational environment also plays a decisive role in the achievement of learning. As evidenced by the research in educational neuroscience, incoming information to the brain is first processed in the limbic system of the brain. This system can be described as the neuroanatomical background for the perception and expression of emotional states, the mobilization and at the same time the emotional part of the memory process. Long-term memory and learning are significantly affected by this system. For this reason, both threat and stress have negative effects in the context of learning. Therefore, learning environments that include positive emotional experiences and connections for students contribute to and enhance learning. As a result, it is important that it works in such a way that learners are given the time they need to be creative. For this reason, learners must engage with procedural knowledge-enhancing activities to reduce the reproduction of material and minimize the value of speed, as the development of synapses and neural circuits is a complex and multidimensional process.

Finally, in the context of learning, teamwork contributes to learning and enhancing brain activity. Assigning group work is important because it allows learners a) to share their ideas, their concerns, and study the problem given to them as a team and b) to recognize and understand how their classmates work and think. By working together, learners have the opportunity to

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think critically about their learning and realize that learning is a process where learners face similar or identical problems/obstacles to overcome. In addition, learners have the opportunity to make connections between ideas and formulate opinions. This enables learners to explore ideas and collaborate to solve problems. Studies have shown that the activation of the medial orbitofrontal cortex and frontoparietal network is strongly related to people's collaboration. This opens the door for the development of executive functions [25]. Hence, the aforementioned areas are also called "social brain" revealing not only the added value of a sociocultural approach to learning but also the requirement of providing learners collaborative opportunities. Cooperation, therefore, is a complex issue that plays a key role in learning, goal achievement, and brain development. All of the above have been considered in the workshop design presented in the next section.

IV. METHOD

The co-design workshop will last approximately three hours. There will be two parts; the first one will focus on the theoretical background, while in the second one participants will see AI in action. The two parts are also divided into modules for a better understanding and identification of differences among the concepts.

A. Workshop Design

The full structure of the proposed AI workshop is demonstrated in Table 1. The workshop is most suitable for middle school students for the reason mentioned before. There is no required prerequisite for participation. However, coding skills are an asset for the participants. After the end of the workshop, students will be asked to join a Kahoot! quiz to understand their experience and the possible outcome of the workshop.

1) Part I: The theoretical background: As AI is considered to be a complex topic that encompasses dense information, it is important to present the theoretical background, why, and how AI is penetrating everyday life. This part is based only on presentations and discussions with the audience.

Introduction to AI. The first module introduces the core concepts of AI to students. Participants will understand the difference between human intelligence and AI. The module also focuses on applications that make usage of AI and also the main reasons for adopting AI in everyday life. The learning objective of the module is to identify and resolve students' potential misunderstanding of AI.

Machine Learning and Deep Learning. The second module focus on Machine Learning (ML), a subset of AI. Specifically, supervised and unsupervised types of ML are presented, along with a series of important algorithms (i.e. K-Means). As the ML approach is data-driven, students will also highlight the importance of data gathering and cleaning. Finally, an introduction to the sophisticated approach of deep learning (DL) takes place so to show how DL tackles ML challenges.

TABLE I. WORKSHOPS TOPICS FOR PART I

Topic Name	Estimated Duration (minutes)
Introduction to AI	10
Examples of ML Applications	10
Supervised Learning	25
Unsupervised Learning	25
Deep Learning	20

2) Part II: AI in action: During this part (approximately 90 minutes) educators present a set of activities that showcase the end-to-end creation of an AI application. The second part is based on Google's Teachable Machine (GTM) and Google Colab Notebooks [25]. Google Colab Notebooks can be utilized for third graders (ages 13-14) in the same workshop, while for the first graders (ages 11-12) in a next workshop. GTM is provided free by Google and is considered to be a web-based system for teaching the basic principles of ML without the need for coding. It provided the essential steps for ML training by allowing the upload of training datasets and setting several parameters, while it makes use of powerful classification algorithms such as convolutional neural networks (CNN), all combined in an easy-to-learn graphical user interface. The basic idea of the workshop is for students to be able to design their ML-based applications with GTM by using images, poses, or sounds input data for training. The GTM aims to teach principles and the basic workflow of ML applications to students, educators, makers, and hobbyists with no previous experience with ML [26].

Data Collection. One of the most important steps in building AI pipelines is data collection and preparation. The collected and cleaned datasets are used to train a model, acting as the base for the latter to learn from. The datasets are composed of text, images, and sounds collected from various sources and can be used as input data for the training process of the model. By the completion of this process, the model should be able to label new, unlabelled data on the trained classes, for example, to understand if an object is a car or not. It becomes apparent that the accuracy of an AI model is directly proportional to the quality of the training data. The selected type of input data for the workshop is images as they are considered to be more attractive for the students. The students are divided into two groups. Kaggle is introduced to students as the prime source for searching and downloading image classification datasets [27]. Using the aforementioned platform, students are able to select several datasets that include images from two classes, for example, Asian and African Elephants.

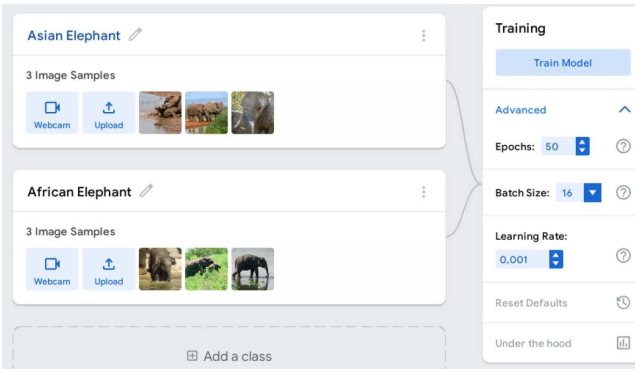
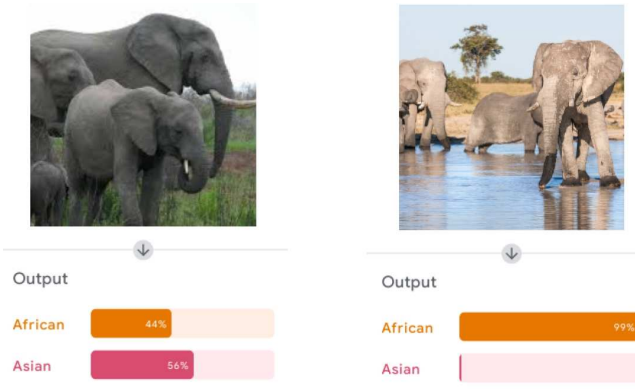


Fig. 2. Graphical User Interface of the GTM's Image recognition

Train your model with GTM. The training process requires the upload of a dataset. Therefore, students have to upload the images to two separate repositories, one for each class. As the images have been stored in these repositories, the students have the potential to start the training process by setting the required parameters as they are depicted in Figure 2. Having already introduced to the students the term overfitting in Part I, they can make suitable adjustments by changing the number of epochs parameter so to investigate possible changes in the model's accuracy.

Test your model with GTM. After the completion of the training process, students have the potential to test the developed model. In that direction, they can upload images that have not been used for training so the algorithm to classify them. The algorithm's accuracy is presented to the GUI, showcasing the confidence of the model during the prediction process. Students are prompted to understand the low accuracy in some cases and the ways they can increase this metric, enabling the fine-tuning of the machine learning predictive model, which is a very crucial step for the entire process.



(a) Low Predictive Confidence

(b) High Predictive Confidence

Fig. 3. Examples of two predictions applying the trained model

V. Discussion

The ever-increasing contribution of artificial intelligence to everyday life and the social impact it brings has sparked the interest of the educational community in engaging students in artificial intelligence activities at all levels of education. The effort to build student capacity has led to the collaboration of AI researchers, educators, curriculum leaders, and industry professionals to identify ways to integrate K-12 Artificial Intelligence Education.

The first important conclusion is that AI doesn't have to be and must not be a black box [28]. It is critical for the future that students recognize how AI systems work and evaluate AI models and their societal implications. The workshop that has been designed attempts to empower students to be able to describe the types of problems that artificial intelligence can solve as well as its limitations. In addition, the design focused on the Five Big Ideas in AI to prepare educators, to help parents to recognize, and students to outline the key concepts and major issues of an emerging field [29]. From the first idea: "Computers perceive the world using sensors" students need to recognize that perception is more than sensing. Furthermore, in the context of the first big idea, students must explain the abstraction process of transformation from signal to meaning. The second idea "Agents maintain models/representations of the world and use them for reasoning" comes to strengthen students' ability to represent data and data structures and reasoning using algorithms. Students need to recognize the interdependence of representation and reasoning. This idea is sufficiently reinforced through the workshop since students come into contact with data and need to perform representation and reasoning. From the third idea: "Computers can learn from data." it is important that students distinguish human learning from what the computer does through machine learning.

At the same time, it is an expected learning outcome that students construct a reasoner and explain that learning new behaviors is caused by changes in the internal representations of a model. In the workshop, special emphasis is given to this idea, with the students being asked to build a reasoner themselves and change an existing structure. Additionally, "finding patterns in the data" allows students to distinguish between both supervised learning, where the data are labeled, and unsupervised learning, where they are not. The fourth big idea is related to how computers interact with people. The themes that make up this big idea are a) natural language understanding, i.e. understanding human requests, extracting information from text, and translating from one language to another, b) common sense, c) emotional computation, that is, recognizing and dealing with human emotional states such as sensitivity to the tone of voice, facial expressions and body language and its ability to adapt to respond to moods of frustration, boredom, etc. and d) consciousness/theory of mind to assess questions about whether computers have minds, or could have minds. In the context of the workshop, many of the above issues are identified. The fifth big idea "AI can affect society in positive and negative ways" has a significant impact on the future of students. It is critical that students recognize the potential effects of AI, as there is strong concern about its use in decision-making areas about people, the economy, culture, and society in general.

Another critical issue is the preparation of students in order for the knowledge and skills they acquire can be transferable to others, so that on the one hand they can strengthen other people (such as their parents or other elderly people) and on the other hand, to recognize how what they learn can be applied in other contexts [28]. For this purpose, appropriate pedagogical approaches and the development of teachers' technological pedagogical content knowledge in the field of artificial intelligence are necessary. It is important, that the activities incorporate real-life problems, problems that are meaningful to students, problems that cover different communities, and problems based on fundamental knowledge that the students already know. Additionally, it is critical and necessary to consider research results from other similar interventions such as STEM education and educational neuroscience. At the same time, designing and delivering an integrated approach by introducing AI concepts into other subject areas can greatly enhance AI education.

Finally, the importance of strengthening the connection between industry and the school environment needs to be determined [28]. In industry artificial intelligence is used to a high degree and many companies have integrated it into their production process and other activities. There, students can see in practice what they learn in class, and at the same time, they can see possible career options. In the same context, it is necessary to study two more issues. The first is the cooperation of disciplines and organizations for the better development of education in artificial intelligence so that there is diversity and strategic planning. The second is relevant funding for AI education to design AI standards, AI curricula, AI teacher professional development programs, and research actions that will link AI education to learning outcomes so that AI is accessible and affordable to all students.

VI. Conclusion

The growing contribution of artificial intelligence to everyday life and its impact on society is a critical issue for the education of future citizens. In this context, international organizations and universities are preparing frameworks for training primary and secondary students in artificial intelligence. A corresponding small-scale proposal for middle school students was described in the previous sections. The proposal attempts to highlight the topics: Introduction to AI, Examples of ML Applications, Supervised Learning, Unsupervised Learning, and Deep Learning as well as showcase the end-to-end creation of an AI application through a set of activities. The implementation and evaluation of the teaching intervention will contribute to the need to explore the importance and value of relevant interventions, which will have an impact on current students and future citizen.

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