Survey of Resources for Introducing Machine Learning in K-12 Context.

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Abstract*—The benefits of teaching machine learning to K-12 pupils include building foundational skills, useful mental models and inspire the next generation of AI researchers and software developers. However, introducing machine learning in schools has been a challenge even though several initiatives, curriculum design, platforms, projects, and tools exist to demystify the concept. The existing resources are scattered and sometimes overlap. Thereby selecting the appropriate tools to adopt in teaching becomes an arduous task for the teachers and other practitioners. More so, despite the increasing number of papers published in this field, there are still gaps in identifying specific tools and resources for teaching machine learning in K-12 settings. This study presents a literature review on machine learning in K-12 by selecting articles published from 2010 to 2021. Therefore, this paper presents a resource catalog and surveys of tools to help teachers find suitable teaching paths and make the decision to introduce activities that help students understand the basic concepts of machine learning. Based on the research objective, we utilized six databases to extract relevant information, while thirty-nine peer-reviewed articles were collected based on a systematic literature search and were analyzed. This study identified resources, tools, and instructional methods as the main categories of pedagogical items needed to ensure impactful teaching of machine learning in K-12 settings. Besides, the mode of operation, benefits and the challenges of the pedagogical tools for teaching machine learning in K-12 settings were unraveled. The findings also show the increased number of initiatives resulting in tools development to support machine learning teaching. Finally, this study provides recommendations for future research directions to help researchers, policymakers, and practitioners in the education sector identify and apply various resources to aid decision-making in practice and to democratize machine learning practices in schools.

Keywords—Teaching Machine Learning; Pedagogical tools and resources; Schools; K-12 education

I. Introduction

In recent times, the teaching of machine learning basics to K-12 students has attracted much attention from academics and practitioners. While the benefits cannot be overemphasized, offering early exposure and opportunities to learn machine learning allow pupils to learn foundational skills, build useful mental models, and inspire the next generation of AI researchers and software developers [1] [2] [3]. Teaching and learning processes are crucial at all educational development levels and require appropriate tools or intervention to enhance effective teaching and learning. Consequently, there is a need to employ teaching aids to improve machine learning pedagogy.

Design and development of resources and tools to demystify machine learning for K-12 education have increased lately. For instance, [2] designed Zhorai, a learning platform and curriculum for children to explore machine learning and knowledge representation. Similarly, William et al. [4] created PopBots, a curriculum to help young children learn about AI by building, programming, training, and interacting with a social robot. Rodríguez-García [5] relatedly developed LearningML, a platform intended to teach and learn ML by doing. More so, Teachable Machine by Google is being used for creating custom-made machine learning classification models without specialized technical expertise [6]. However, despite the proliferation of tools and curriculums designed to democratize and include young children in a machine learning discussion, these resources are not harnessed. These resources are scattered and sometimes overlap; selecting the appropriate tools to adopt in teaching becomes an arduous task for the teachers and other practitioners. In addition, despite the increasing number of papers published in this field, there are still gaps in identifying specific tools and resources for teaching machine learning in K-12 settings.

According to [7], to introduce new practices, researchers and developers should consider the contexts of teachers and invest in additional supports to facilitate the accessibility of AI resources for teachers. Therefore, this paper presents a resource catalog and surveys of tools to help teachers find suitable teaching paths and decision-making to introduce activities that help students understand the basic concepts of machine learning. This study believes that an overview of available resources to deploy machine learning for K-12 in the classroom could spark teachers' interest in the field and provide a quick guide towards choosing a suitable tool for their teaching. In this study, we conducted a systematic literature review on articles focusing on K-12 and, specifically, resources for introducing machine learning into K-12 settings. Earlier reviews focused on pedagogies of machine learning [8], games that support AI and ML [9] and instructional units available for teaching ML [10].

This study is one of the early analysis of research output focusing on resources such as interventions and tools to demystify machine learning concepts in schools. We are careful of overgeneralization since the present study utilized only five academic databases, as shown in Table 1. Nevertheless, we attempt to capture all relevant papers by snowballing into the reference list of a paper or the citations to the papers to identify additional article(s) for the literature review [11], [12]. The current study aimed to explore the resources for teaching and learning machine learning, specifically for K-12 education.

A selection of studies on teaching machine learning in the K-12 education context has been reviewed and analyzed to respond to the above aim. The summation of the recently published literature will explain the innovative interventions and tools employed across climes to enable instruction on the technological concept. Other sections of the study are organized as follows: “Methodology” presents the method adopted for the systematic review process, including information about databases, literature search, and selection of relevant papers. “Review Result” presents the result of the review as obtained from the relevant literature. “Survey of Resources” discusses the survey analysis of selected literature based on resources highlighted in the previous section. “Conclusion” summarizes the focus and findings of the study, and it further unveils challenges and future research opportunities and directions.

II. SYSTEMATIC LITERATURE REVIEW

To elicit state of the art and practices on how teaching and learning of machine learning are enabled in the K-12 context regarding resources such as interventions and tools utilized, we conducted a systematic review study following the procedure proposed by [13]. According to [14], the proposed approach systematizes and summarizes the empirical work in the focus area over time and aggregates the insights from the review.

In this study, the search focused on the literature on tools and resources for teaching and learning machine learning in the K-12 context. Six online academic databases search for related literature based on the search strings and keywords in 2.1. The six databases are Scopus, ISI Web of Science, IEEE, ACM, Science Direct, and AAAI (Association for the Advancement of Artificial Intelligence) website. These online databases are well known regarding education and technology [15] [16] and contained relevant literature suitable to achieve the aim of this research. The literaturesearch is limited to articles published from 2010 till March 2021, when the search was conducted. The limitation concerning the year of publication is necessary because the research area is still emerging. The document type was limited to peer-reviewed journal articles, book chapters, and conference papers written in the English language to ensure the quality and scope of the articles reviewed. Other inclusion criteria utilized in the study are further highlighted.

The following inclusion criteria were implemented to determine which papers could be included in this review.
Inclusion Criteria 1: Papers published in book chapters, scientific journals, and conferences.
Inclusion Criteria 2: Papers belonging to thesis or dissertation study.
Inclusion Criteria 3: Papers that reported studies conducted in K-12 for students.
Inclusion Criteria 4: Papers involved in teaching and learning machine learning

A. *Keyword Search*

The keywords employed the Boolean/Phrase search mode, and the search strings include the combination of teaching, machine learning, artificial intelligence, and K-12 depending on the peculiarity of each database utilized. Table 1 contains information about the number of identified articles per repository and the relevant articles selected. The search was conducted on 19th March 2021. The search produced 484 results by the search terms, including 18 duplicates, which were eventually deleted, and 39 articles were found relevant for the analysis after the inclusion and exclusion criteria were applied.

TABLE I. SEARCH STRUCTURE AND IDENTIFIED ARTICLES PER REPOSITORY

Sources	**Search String**	**Result**	**Relevant results**
Web of Science	("machine learning" AND "k-12" OR "artificial intelligence" AND "k-12") *OR* **TOPIC:** ("machine learning" AND "teaching" AND "K-12") *OR* **TOPIC:** ("artificial intelligence" AND "teaching" AND "k-12")	30	4
Scopus	(TITLE-ABS-KEY ("machine learning" AND "k-12" AND "platforms" OR "resources" OR "tools") OR TITLE-ABS-KEY ("artificial intelligence" AND "k-12" AND "platforms" OR "resources" OR "tools") OR TITLE-ABS-KEY ("machine learning" AND "teaching" AND "K-12" AND "platforms" OR "resources" OR "tools") OR TITLE-ABS-KEY ("artificial intelligence" AND "teaching" AND "k-12" AND "platforms" OR "resources" OR "tools"))	53	11
ACM	All: "machine learning"] AND [All: "teaching"] AND [All: "k-12"] AND [All: "artificial intelligence"] AND [All: "teaching"] AND [All: "k-12"] AND [Publication Date: (01/01/2010 TO 12/31/2021)	96	14
IEEE	("All Metadata":"machine learning" AND "All Metadata":"teaching" AND "All Metadata":"K-12") OR ("All Metadata":"artificial intelligence" AND "All Metadata":"teaching" AND "All Metadata":"K-12") OR ("All Metadata":"machine learning" AND "All Metadata":"K-12") AND ("All Metadata":"artificial intelligence" AND "All Metadata":"K-12")	20	3
Science Direct	"machine learning" AND "teaching" AND "K-12" OR "artificial intelligence" AND "teaching" AND "K-12."	112	4
AAAI Website	"machine learning" AND "teaching" AND "K-12" OR "artificial intelligence" AND "teaching" AND "K-12."	173	3

III. REVIEW RESULT

This section presents the result of the review as obtained from the previous section. Table II shows the tools and resources utilized to introduce the machine learning concept to K-12 education from literature. The table is organized into the authors, machine learning tools or platforms, and complementary categorization of the highlighted resources.

A. *Resources based on categories*

Based on the data obtained as shown in Table I, the learning platforms are categorized in table II. The table is organized into two columns: categories and resources (ML tools or platforms) as well as the corresponding references. In this study, the resources were complimentarily categorized based on the kind of tools, activity, or computer language. For example, ML tools such as Zhorai, SmileyCluster etc. are categorized under conversational agent. LearningML, Scratch, etc. are under programming environments. For robotic, there are Jibo robot, Alexa etc. and unplugged activities includes the use of picture cards, toy cookies etc.

TABLE II. RESOURCES BASED ON CATEGORIES

Categories	ML tools or platform
Conversational agent	Zhorai [2]
	SmileyCluster [32]
	MIT App Inventor [45]
	Personal Image Classifier [33]
	Teachable Machine [6][3][2][11]
	Machine learning for Kids [36]
	Web-based machine learning tool for image recognition [42][35]
	Gest: an ML gesture recognition system [47]
	Man, Machine Game [52]
Programming Environment	LearningML [8][9][10]
	PRIMARYAI [24]
	Scratch [21]
	Snap! [22]
	Cognimates [23]
	AlpacaML [26][27][28]
	DrRacket [25]
	RapidMiner [39]
Robotic	Popbot [4][29][44]
	Jibo robot, Anki's Cozmo robot, and Amazon's Alexa [30][40][43]
	Toy car controlled by Raspberry Pi [49]
	iRobot [23]
Unplugged activity	digital stick-like device [46]
	coin-sorting [41]
	Any-Cubes [37]
	Screw [50]
	Toy cookies [51]
	Picture cards [38][40]

IV. SURVEY OF RESOURCES

The resources found in the reviewed literature as listed and categorized in Table II are briefly described in this section. Previous studies such as [17] have presented a catalog of resources for introducing coding to schools. Relatedly, this study presents resources, tools, or interventions explicitly designed to facilitate machine learning for K-12 education.

A. *ML Tools in the programming category*

This section introduces the tools that are used for teaching AI and ML in K-12. These resources are categorized under the programming environment.

- LearningML

LearningML is an educational web platform designed and developed by [5] to help non-specialists quickly learn ML fundamentals. According to the authors, LearningML aimed to provide a platform supporting educators and students in creating hands-on AI projects based explicitly on machine learning techniques.

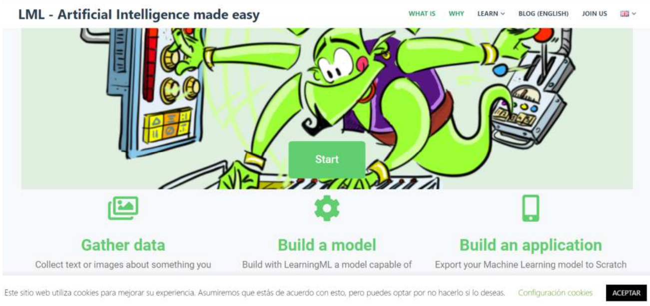

Fig. 1. LearningML website Interface

LearnigML, a platform that can be assessed from https://web.learningml.org/, has been evaluated utilizing students between the ages of 10 and 16 years. The findings show that the initiative had a positive impact on participants' AI knowledge which suggests that LearningML can be seen as a promising platform for the teaching and learning of AI in K-12 environments [5] [18] [19].

- Scratch

Scratch https://scratch.mit.edu/, the interactive graphical programming environment designed by MIT researchers [20] to introduce K-12 students to programming in a playful mode, has also been adopted to promote the ML K-12 community.

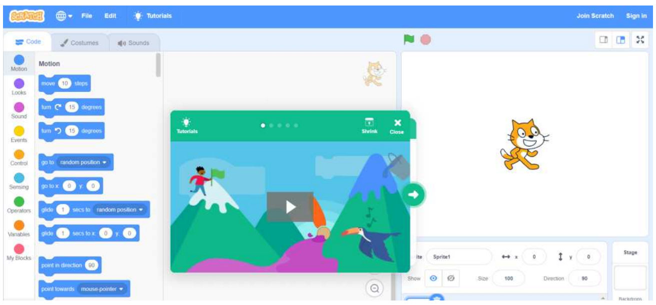

Fig. 2. Scratch web Interface

Estevez et al. [21] introduced AI fundamentals that can be performed at schools with Scratch. The focus was on mathematical descriptions adapted for 16-17-year-old students with some technological/mathematical background. The findings showed that the interventions have a differential impact on the way students understand AI [21]. Some ML platforms also allow a specifically designed programming environment such as Scratch. Examples of such include machine learning for kids' platform, LearningML, and cognimates.

- Snap!

Snap! https://snap.berkeley.edu/about is a visual, drag-and-drop programming language. It is an extended reimplementation of Scratch (a project of the Lifelong Kindergarten Group at the MIT Media Lab) that allows you to Build Your Blocks.

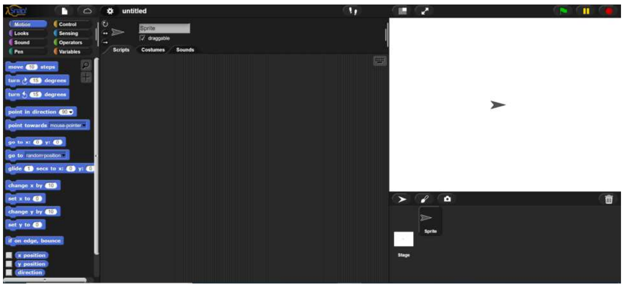

Fig. 3. Snap web Interface

The study of [22] presents how AI programming can be achieved using Snap!. Based on students of 16 and 17 years old, it was concluded that Snap! programing worked to introduce AI to children and help to provide an enjoyable environment to explore AI programming

- Cognimate

Cognimates http://cognimates.me/home/ is a tool that offers both the ML platform, called Cognimates Studio and the programming platform, called Codelab.

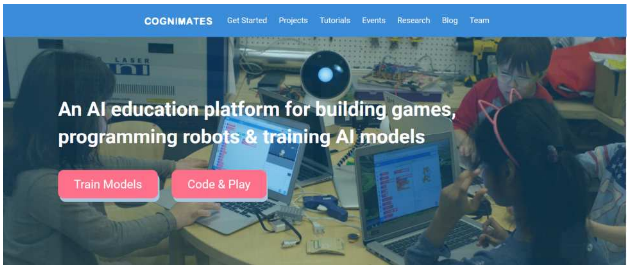

Fig. 4. The Interface of the Cognimate platform

Druga [23] designed the learning platform, which has been utilized to introduce ML to K-12. Children from 7 to 14 years old explored the Cognimates platform, and findings show that they can better understand AI concepts and programming [23].

- PRIMARYAI

PRIMARYAI is a collaborative game-based learning environment created to provide all students with AI learning opportunities [24]. In PRIMARYAI, students learn by engaging in problem-solving with AI tools explicitly designed to support inquiry-based life-science adventures. PRIMARYAI integrates AI-infused block-based programming to teach a range of AI methods, including image recognition, machine learning, planning, and automated decision making [24].

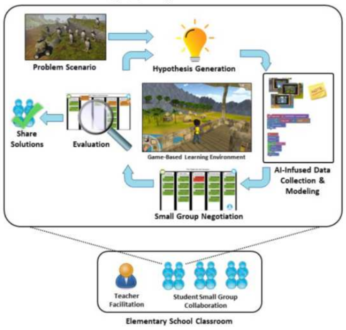

Fig. 5. AI-Infused Collaborative Game-Based Learning [24]

- DrRacket

DrRacket functional programming language is a tool that supports the comprehension and thorough understanding of blind search algorithms, informed search algorithms, search games trees, and machine learning algorithms [25].

- AlpacaML

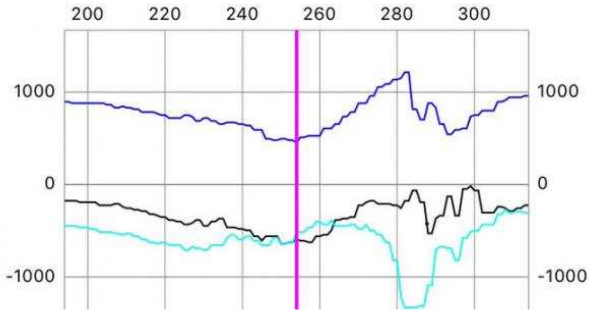

Fig 6. AlpacaML Visualization

AlpacaML is a prototype iOS application designed to facilitate the construction and use of ML gesture models based on data from wearable sensors. To instantiate this vision, users can train the app to identify different motions by connecting to a wearable sensor [26]. Zimmermann-Niefield et al. [27] found that with AlpacaML, youth could collect data, build models, test and evaluate models, and quickly iterate on this process. Another study by [28] with children aged 8–14 combine their ML models using AlpacaML with Scratch. They could incorporate models of gestures they built into Scratch projects and use those gestures to control them.

B. ML Tools in Robotic category

- PopBots platform

PopBots (Preschool-Oriented Programming Platform) is a hands-on toolkit and curriculum designed to help young children learn about artificial intelligence (AI) by building, programming, training, and interacting with a social robot.

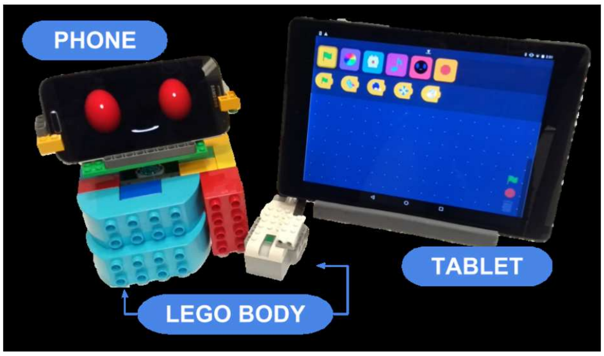

Fig 7. PopBot Components.

The platform consists of a social robot toolkit, a programming interface on a tablet computer, and three hands-on activities with assessments for young children to explore machine learning and reasoning algorithms [4] [29]. The social robot is made of a smartphone, LEGO blocks, motors, and sensors. The blocks-based programming interface resides on a tablet. The effectiveness of PopBots was evaluated using children of ages 4-5 and 5–6. It was found that the use of a social robot as a learning companion and programmable artifact was effective in helping young children grasp AI concepts [4] [29].

- Jibo robot, Anki's Cozmo robot, and Amazon's Alexa Echo spot

In the study of [30], children were introduced to three different embodied intelligent agents: Jibo robot, Anki's Cozmo robot, and Amazon's Alexa, home assistant.

Fig. 8. Robot Images

Children were allowed to explore their own interacting with the robotic agents, using both voice and existing interactive applications. After the initial play and interaction, the kids were encouraged to program the agents using their dedicated coding apps. All the coding apps deployed in the study used a visual block programming language based on Scratch Open Source Blocks and were comparable in terms of design and complexity

- iRobot

AI-course (called '*iRobot*') deals with important topics of AI/computer science (automatons, agent systems, data structures, search algorithms, graphs, problem-solving, planning, machine learning) was developed by [31]. The course was divided into seven weekly teaching units of two hours, comprising theoretical and hands-on components.

C. ML Tools in Conversational Agent category

- Zhorai

The Zhorai platform is an online web interface that can be accessed via a web browser at https://zhorai.csail.mit.edu, and the source code can be accessed at http://github.com/jessvb/zhorai.

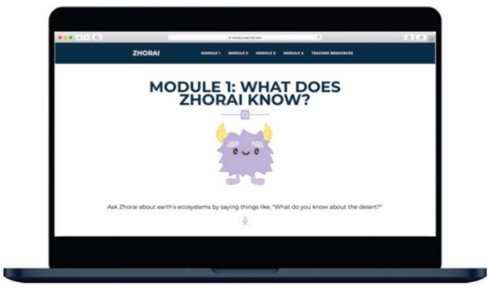

Fig. 9. Zhorai Interface

Children engage with Zhorai through conversation in a small group setting led by an adult facilitator. Children learn that Zhorai is an alien visiting Earth that wants to learn about Earth's life (i.e., ecosystems on earth). The curriculum is focused on Earth's ecosystems because children can describe ecosystems, defined as places where animals live, without much prior knowledge [2].

- SmileyCluster

SmileyCluster is a web-based learning environment that supports hands-on, playful, and collaborative machine learning activities. SmileyCluster was developed to utilize glyph-based data visualization and superposition comparative visualization to learn an entry-level ML technology.

Fig. 10. Two students are interacting with the SmileyCluster system [32]

The learning goals of SmileyCluster aims to support students to understand and apply k-means clustering in science contexts while maintaining a gradual learning curve [32].

- MIT App Inventor

MIT App Inventor https://appinventor.mit.edu/ is an intuitive, visual *programming* environment that allows everyone – even children – to build fully functional apps for smartphones and tablets.

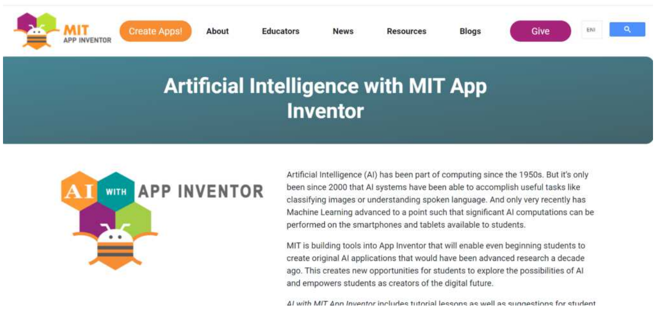

Fig. 11. MIT App Inventor Interface

Van Brummelen et al. [7] utilized Conversational Agent Interface for MIT App Inventor among 6th-12th grade students with little-to-no experience programming. The study presents AI literacy-focused curriculum to teach conversational AI concepts. Through interactive AI workshops, students learned AI competencies and developed conversational agents. Evidence for the effectiveness of AI design consideration-based curriculum to engage students and teach AI competencies was found [7].

- Personal Image Classifier (PIC)

PIC https://classifier.appinventor.mit.edu/ is implemented as an MIT App Inventor extension. It is an ML tool that builds image models and provides both the ML platform and programming platform [33].

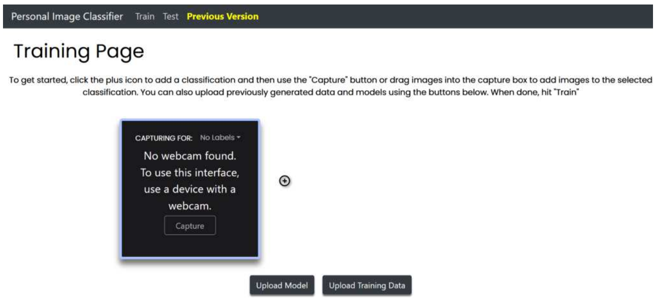

Fig. 12. PIC platform Interface

The findings of [33] using PIC indicate that high school students with no machine learning background can learn and understand general concepts and applications of ML. This is achieved through hands-on, non-technical activities and successfully utilize models they built for personal use.

- Teachable Machine

Teachable Machine is a web-based tool that makes creating machine learning models fast, easy, and accessible to everyone. https://teachablemachine.withgoogle.com/

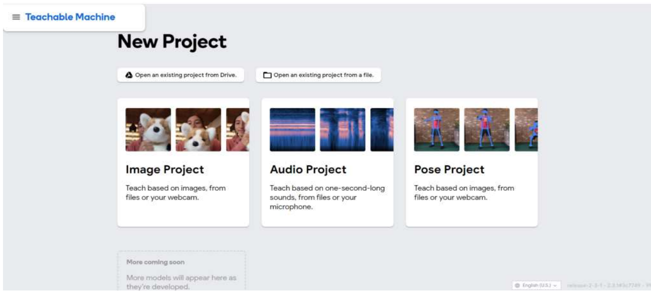

Fig. 13. Teachable Machine interface

Teachable Machine (teachablemachine.withgoogle.com) is a web-based GUI tool for creating custom-made machine learning classification models without specialized technical expertise or coding, using their webcam, images, or sound. It uses transfer learning, an ML technique, to find patterns and trends within the images or sound samples and create a simple and easy classification model within seconds [6]. Research evidence has shown that Google Teachable Machine is a feasible tool for K–12 education for learning machine learning [34] [3] [35].

- Machine Learning for Kids

Machine Learning for Kids is a free tool that introduces machine learning by providing hands-on experiences for training machine learning systems and building things with them. It can be accessed through https://machinelearningforkids.co.uk/

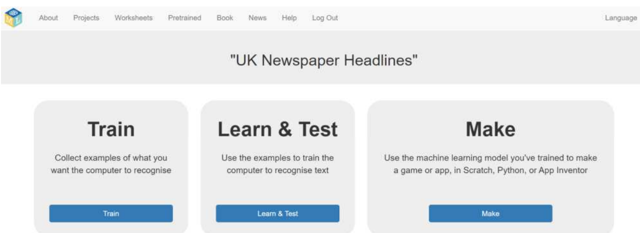

Fig. 14. Machine Learning for Kids Interface

The tool is entirely web-based and requires no installs or complicated setup to be able to use. It provides an easy-to-use guided environment for training machine learning models to recognize text, numbers, images, or sounds [36].

D. ML Tools in Unplugged activities category

Unplugged activities as widely utilized in computer science education has been introduced to teach ML in K-12 settings. According to [38], in the field of AI, little Unplugged material is available presently even though, Unplugged activities are well suited for the topic due to the complexity and versatility of the field. Researches have in recent times utilized various materials to demystify ML in schools such as coin-sorting [41], Screw [50], Toy cookies [51], Picture cards [38][40].

- Any-Cubes

Fig. 15. Prototype Any-Cubes

Any-Cubes is a prototype toy with which children can intuitively and playfully explore and understand machine learning and the Internet of Things technology [37]. Utilizing children between the ages of 6 and 12 to test the prototype, it was found that children quickly go beyond the original application and start using the cubes in creative ways [37].

V. COMPARISON OF ML RESOURCES

This section attempts a brief comparison of some ML resources. Based on some metrics as utilized in the study of [18], the existing resources for teaching ML were compared in Table III. The metrics include User registration, ML Backend, API Keys, Save Data, ML Algorithm control and Evaluation analysis tool. The user registration category in the table indicates the platforms that requires registration or not while using it. It reveals that most of the platforms do not require registration but some allows the learner to register if desired. The ML backend category showcase the different program use to develop the platforms which include Tensorflow.js and Watson IBM among others. The application programming interface (API) keys part reveals which of the ML platforms that do or do not possess API keys. API keys are normally used to assist in tracking and controlling how the platform interface is being utilized. For save data aspect, it indicates across platforms the ML tool that allows data to either be saved or not. The next category shows the platforms that either has Machine learning algorithm control or not. Table III finally shows there exist evaluation analysis tool in some of the highlighted resources. Table IV also shows the ML programming platforms allowed by each of the ML tools.

TABLE III. MACHINE LEARNING PLATFORMS FEATURES COMPARISON (ADAPTED FROM [18])

	TM	ML4Kids	Snap!	PIC	LML	Scratch	Cognimates
User registration	No	Yes	No	No	No	No	No
ML Backend	Tensorflow.js	Watson IBM	Pretrained cloud models	Tensorflow.js	Tensorflow.js	Pretrained cloud models	uClassify/Clarifai
API Keys	No	Yes	No	No	Yes	No	No
Save Data	Yes (locally)	Yes (cloud)	No	Yes (locally)	Yes (locally and cloud)	Yes (locally)	Yes (cloud)
ML Algorithm control	Yes	No	No	Yes	Yes	No	No
Evaluation analysis tool	Yes	No	No	Yes	Yes	No	No

TM=Teachable Machine; ML4Kids=Machine Learning for Kids; PIC= Personal Image Classifier, LML: LearningML

TABLE IV. PROGRAMMING PLATFORMS ENABLED (ADAPTED FROM [18])

	GTM	ML4 Kids	Snap !	PIC	LML	Scrat ch	Cognim ates
Scratch	No	Yes	No	No	Yes	Yes	Yes
MIT App Inventor	No	No	No	Yes	No	No	No
Python	Yes	Yes	No	No	Yes	No	No
Snap!	No	No	Yes	No	No	No	No
Javascript	Yes [custom]	No	No	No	No	No	No

VI. CONCLUSION

This paper presents a resource catalog and surveys of tools to help teachers find suitable teaching paths and make the decision to introduce activities that allow students to understand the basic concepts of machine learning. To achieve our aim, we conducted a review of articles focusing on K-12 and, specifically, resources (tools, learning platforms, or intervention) to introduce machine learning into K-12 settings. The identified resources are categorized into four based on the features and the activities involved. They are classified as a programming environment, robotic, conversational agent, and unplugged activities.

Aside from some unplugged activities utilized to teach ML basics, 20 tools or platforms were identified to have been employed to introduce ML concepts across K-12 settings. As shown in tables II, the identified resources are Zhorai, SmileyCluster, MIT App Inventor, Personal Image Classifier, Teachable Machine, Machine learning for Kids, Web-based machine learning tool for image recognition, Gest: an ML gesture recognition system, LearningML, PRIMARYAI, Scratch, Snap!, Cognimates, AlpacaML, DrRacket, RapidMiner, Popbot, robot, Toy car controlled by Raspberry Pi, and iRobot.

The tools are mainly targeted at K-12 in general and not specifically tailored to a certain category of pupils in K-12 settings. The identified tools are primarily free and web-based, which requires internet connection that is stable and uninterrupted. However, the requirement of the constant connection can constitute a challenge in some educational settings, for example, in some developing countries, including Africa. Some ML tasks reported in the studies are recognition, object detection, and speech synthesis. The kind of ML task mainly supported is recognition, for instance, image or speech recognition. In addition, a variety of data types are supported by the tools, but they are primarily images. Others include pose, motion, sound, and text. These findings are in tandem with the study of [53].

This study suggests lack of evidence on the kind of tools that may be best or appropriate for certain educational stages and contexts. It further shows a need for more empirical research analyzing diverse aspects of ML tools to improve these tools for ML education in K-12. The selection of the databases limits the scope of the study as including more research databases and relevant web sources can yield more data for analysis.

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