TEACHING MACHINE LEARNING IN K-12 EDUCATION: SYSTEMATIC REVIEW OF SCIENTIFIC LITERATURE

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Master's thesis

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Amos Oyelere Sunday: Teaching Machine Learning in K-12 Education: A Systematic Review of Scientific Literature

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Abstract:

The rate at which machine learning (ML) and artificial intelligence (AI) are being applied in everyday activities arose the interest in teaching the coming generation ML at an early age. This will prepare the pupils and get them acquainted with the technology they use every day. Also, this will make ML education in K-12 a developing research area of study. However, several attempts have been in progress to research teaching ML to K-12 students for a decade. This study aimed to identify the present status of K-12 machine learning education through a systematic literature review between 2011 and 2021. Data were collected from four reputable databases. Meanwhile, this study discovered that the first paper was published in Israel at a conference in 2012. Most of the articles published in this field were produced between 2020 and 2021, and more conference proceeding papers were published than journals in this field. However, 133 authors contributed to 50 articles studied, while the USA tops the list of authors' countries. Likewise, the high school received more attention than the other K-12 grade level. Researchers used workshop study settings more than other study settings, while plugged activities were majorly adopted. Meanwhile, most researchers adopted the qualitative research method, while most researchers also used interviews as a data collection method. This review will instigate continuous discussion and attract attention to ML K-12 education among educational researchers, practitioners, and the government.

Keywords: Machine learning, Artificial intelligence, K-12, School, AI education.

CR Categories (ACM Computing Classification System, 1998 version): Computing methodologies ~Machine learning ~Learning settings ~Learning from demonstrations

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List of abbreviations

ACM	Association for Computing Machinery
UEF	University of Eastern Finland
AI	Artificial Intelligence
ML	Machine Learning
IoT	Internet of Things
ACM	Association for Computing Machinery
IEEE	Institute of Electrical and Electronics Engineers
EdTech	Educational technology

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1 Introduction

1.1 Background and Motivation

Artificial Intelligence (AI) is one of the new-age technologies that has been influencing almost every area of human life. AI is a field in computer science where algorithms are used to build or carry out specific activities in a way that is related to how humans perform the tasks (Al-Shabandar et al., 2019; McCarthy et al., 1956). According to Chen (2020), AI can be defined as a study field in computer science that brings about innovations built into machines and other artifacts with intelligence like humans. AI features include learning ability, adaptive abilities, ability to make decisions, and cognitive ability. Furthermore, AI aims to study human intelligence, imitating it, and planting it into machines or artifacts to solve a specific real-time problem. AI can be applied in all fields of learning, which includes virtual personal assistant (Yang & Lee, 2019), natural language processing (Fisher et al., 2016), image analytics (Gozes et al., 2020), deep learning (Parloff, 2016), simulation modeling, machine translation, social network analysis (Hung et al., 2020), machine learning (Kühl et al., 2020), and robotics (Erikson & Salzmann-Erikson, 2016) among others.

ML is referred to as the techniques in AI, which uses algorithms to make machines perform specific tasks without the intervention of humans (Korkmaz et al., 2019). In other words, ML is the subdivision of AI that supplies the capability to automate learning and improve learning performance on a given activity without external control or influence (Sanusi et al., 2020). ML, an application of AI, is defined by Jordan & Mitchell (2015) concerning two related questions: how to build a computer system that will constantly improve itself automatically via the experiences gained and what the basic analytical or statistical computing-information-theory laws which control all methods of learning are? ML is designed to solve a particular real-world problem by building a computer system using algorithms that learn and continually improve through the experiences it obtains from its data. Many services and devices used in our everyday activities has ML embedded in them, for instance, ML in health services (Doupe et al., 2019; Abdelaziz et al., 2018), ML in ecosystems (Willcock et al., 2018), ML in financial services (Buchanan and Wright 2021). In order to make young people aware of ML basics and prepare them to be more responsible and creators of intelligence solutions, it is necessary to create popularity for the understanding of ML technology (von Wangenheim et al., 2021), most especially from their tender age. ML devices are developed to ideally detect unauthorized IoT devices for security experts (Meidan et al., 2017), ML device built for dictating and predicting epilepsy seizures and are used as a wearable devices (Beniczky et al., 2021)

For several decades ago, ML has been a course of study in many higher learning institutions across the globe (Torrey, 2012). However, there are recent calls to include ML as a subject in the K-12 educational curriculum. Accordingly, researchers developed Machine Learning Education Framework (e.g., Lao 2020), which served as a reference for ML curriculum development. Consequently, curriculum and tools to teach ML to begin to emerge. For instance, Lin et al., (2020) designed a learning platform and curriculum for children to explore ML and knowledge representation. William et al., (2020) also developed a curriculum to help young children learn about AI by building, programming, training, and interacting with a social robot.

Recently, the e-education sector has been experiencing a massive increase in technology (Agbo et al., 2019, Oyelere et al., 2021, Sanusi et al., 2021, Olaleye et al., 2019), especially integrating technology applications in teaching and learning (Oyelere et al., 2019, Agbo et al., 2020).

Teaching and learning ML in K-12 have enormous benefits, including obtaining efficient ML knowledge and becoming conversant with solving problems enabled by data (Tedre et al., 2021). Learners can also acquire intelligence advancement and easy navigation capability **(**Wan et al., 2020**).** Furthermore, teaching ML empowers the learner with the intellectual reasoning skills required for science-oriented investigation access to the exciting pattern of real-world data (Zhou et al., 2021).

1.2 Problem Statement

Several studies have been carried out in recent times to introduce the ML concepts to learners from primary to high school level (Mariescu-Istodor et al., 2019; Sanusi et al., 2020). As a result, we can conclude logically and suggest areas for further investigation based on the published articles. Therefore, this research aims to study the development and present the situation of ML education in K-12 globally. While teaching ML in K-12 is growing in different contexts, there is a need to review and synthesize these studies and provide insights into how the field has progressed, what characterized the studies, and future outlook.

1.3 Research Aim and Context

Majumdar (2021) stated that AI is ranked as one of the most contemporary ideologies applied in K-12 education technology and its outstanding education possibilities. Therefore, students will experience newer learning methods while the schools can depend on it in providing exceptional improved teaching and learning, which will mitigate barriers experienced in traditional teaching. Education technology (EdTech) has undergone several changes recently; these changes include the emergence of artificial instructors, interactive websites, cloud computing technology, online assessments, delivery systems, virtual facilitators, to mention a few, which were deployed into the education field through the ML (Sanusi et al., 2020, Agbo et al., 2019, Agbo et al 2020, Olaleye et al., 2020, Oyelere et al., 2019). ML is a developing offshoot of computational algorithms designed to mimic human intelligence through learning from its immediate environment (Naqa et al., 2015). This study aims to aggregate published literature on teaching ML to K-12 students. This review will be carried out in the K-12 education context, which means articles introducing machine learning to children from kindergarten to high school will be considered.

1.4 Research Objective

The rapid technological change and diffusion of ML technology in every aspect of life demand people of all ages to understand the basics. This includes children that grow with the smart and intelligent devices embedded with the ML applications. Consequently, attempts have been made in various climes to teach the ML in K-12 settings. In order to understand how the emerging concept has evolved and identify future directions, this study focuses on the aggregating scientific literature on ML education in K-12. This study aimed at carrying out a systematic literature review on ML education in K-12. The following main research question was formulated to guide the systematic review: "How did global research on ML education in K-12 develop from 2011 to 2021?"

1.5 Research Question

In other to seek solutions to the research objectives stated above, the following research questions were formulated:

RQ1: What is the current status of research in ML education in K-12, and how did it evolve over the past ten years?

RQ2: What are the predominant study characteristics of ML education in K-12?

RQ3: What are the predominant research designs of ML education in K-12?

RQ4: What are the future directions of ML education in K-12?

1.6 Chapter Summary and Thesis Structure

This thesis aimed to provide a systematic literature review of scientific articles published between 2011 and 2021, giving an overview of teaching and learning ML in K-12. The scientific literature was identified, selected, and analyzed critically using the systematic literature review method to answer the distinctly formulated research questions. The research was defined categorically, the protocols observed and the criteria followed was well stated. The material was searched transparently and comprehensively over four different databases.

The paper structure follows; in this first section, the researcher described and explained the study's background, stated the problem statement, the research aim and context, the research question, and chapter summary and thesis structure. The second section explains Artificial intelligence in K-12, Machine Learning in K-12, Curriculum and tool development for machine learning in K-12, and a Summary of related reviews on AI/ML in K-12. The third section contains the methodology, the systematic literature review, the 12 steps research strategy, and the chapter summary. The fourth section presents the findings, and the fifth section discusses the discoveries, while the six-section discusses the summary and conclusion, limitations, and future research.

2 CHAPTER TWO

The research on ML education in K-12 has been attracting much interest lately. This growing interest is connected to how ML could be incorporated into the K-12 education curriculum and how ML could be demystified to young children that grow with the emerging technology. While research continues to emerge in ML for K-12 education, this study accumulates the existing body of literature to understand the current status and propose future directions. This section discusses related literature under four sub-headings: AI in K-12 education, ML in K-12, curriculum and tools for ML in K-12, and a summary of associated reviews on AI/ML in K-12. These sub-sections give the background to the introduction of ML in K-12 and an overview of existing literature. This section studies several pieces of literature on ML and AI in K-12 education.

2.1 Artificial intelligence in K-12

Artificial intelligence is an idea of mimicking human intelligence inhuman objects. The concept of AI existed in the last fourteenth century (Hrastinski et al., 2019), even though the name artificial intelligence was coined in 1956 at the Dartmouth College workshop (McCorduc, & Cfe, 2004). The implementation of AI has been in existence for decades, and it has been the primary influencer of major technology recently. The interest to integrate AI concept in the education system has been on the research front because of its irresistible force. The Artificial Intelligence Education field majorly focused on research into the building of and assessment of computer software that improves teaching and learning, with further plans of interpreting students' reactions when learning through AI tools; to understand where and why students miss out on a learning process; to aid students' comprehension through a hint on the material used and majorly stimulate guidance and behavior of human teacher (Woolf, 2015, Agbo et al., 2021, Costas-Jauregui et al., 2021). AI has been introduced in Higher Education Institutions (HEIs) for decades (Popenici & Kerr., 2017, Bates et al., 2020, Agbo et al., 2021). It has been integrated into the curriculum where students were taught several aspects of AI implemented AI projects.

However, the introduction of AI in K-12 education has been considered necessary recently (Sanusi et al., 2022). As a result, AI for the K-12 research community developed AI literacy frameworks regarded as the Big AI Ideas, which served as references for AI curriculum development (Touretzky et al., 2019). Consequently, several curricula are designed by researchers across regions to introduce AI in schools across grade levels.

Different research papers have been written on AI education (Touretzky et al., 2019, Hao, 2019), and further research is carried out on how to teach AI to K-12 (Zhou et al., 2020, Lin and Brummelen, 2021; Chiu, 2021, Sanusi et al., 2022). Lin and van Brummelen (2021) identify privileges for promoting access to K-12 AI education by integrating AI into the main subjects and impacting students who do not study technology and computer science. The benefit derived by students in high institutions to K-12 students from AI education has increased daily. Alonso (2020) described how the high school students were taught to develop datasets that have no bias to create an explainable classifier and an interpretable multi-modal using AI. Lee et al. (2020) designed a collaborative game-based learning environment using AI technology to teach students to gain more experiences when applying AI to real-world science problems. This game-based learning environment helps K-12 students solve real-world problems through AI games.

Tools for AI K-12 education are the primary medium for teaching K-12 students AI. It gives learners an unforgettable experience that aids their learning (Zhou et al., 2020). Learners get attracted to learning through the experienced gain in using a particular tool (Agbo et al., 2021). Lately, there has been a call for action to build a curriculum for teaching AI to K-12 students (Brummelen 2021), which will make it easy to classify model development tools such as interactive activities (Park and Breazeal 2019, Agbo et al., 2021) teachable machines (Carney et al., 2020) and machine learning for kids (Lane 2020). Although, not all the tools have been evaluated regarding the framework of AI literacy for determining the best way to teach students.

2.2 Machine Learning in K-12

Peter et al. (2019) referred to ML as an essential part of future computational thinking skills. Therefore, it is necessary to incorporate ML into the K-12 educational plan. However, minor literature reveals attempts to teach ML to high school and primary school students. Mariescu-Istodor and Jormanainen (2019) show an effort to teach ML to high school students in Romania using a web-based ML tool for teaching image recognition design and implementation. The students express their joy from drawing an animal recognized by a computer. ML education in K-12 means developing future knowledgeable employees, such as ML developers, engineers, and researchers. Zhou et al.

(2021) attempted to introduce ML as a scientific discovery tool for K-12 using a SmileyDiscovery learning environment; this application help teachers to design and implement their curriculum and lesson plan, supporting teachers to understand K-means cluster rapidly, and also foster learning effectively. A series of co-design workshops were conducted with elementary school children, where they were taught to explore and design their ML using Google Teachable Machine. The study revealed that Google Teachable Machine is a viable tool for teaching ML to K–12. The ML models trained during the workshops are computationally effective, and the applications can be compatible with low-level mobile devices (Toivonen et al., 2020).

An idea to adapt games in introducing students to the ML field was proposed by Rattadilok (2018). This will engage them, integrate them into the learning process through the game situation, create context when learning, give incentives and conditions when defining the objectives of his suggestion, and reveal several ideas, such as gamification and machine teaching. On the contrary, a tool for visualizing cybersecurity education was also proposed by Castro et al. (2019) to develop a standard framework that will fit different types of topics for education in information technology.

2.3 Curriculum and tools for machine learning in K-12

Lately, different initiatives have been seen in hardware and software tools developed to aid K-12 students in learning AI and ML (Giannakos et al., 2020). The development of ML curriculum and tools is necessary for K-12 ML education. To prepare K-12 students for the future due to the fast growth of AI and ML technology there is a need to build appropriate tools for all age students to fully understand ML and become competent solution providers in the nearest future (Tedre et al., 2021). The ML tools can be used to introduce ML concepts to K-12 pupils. Many ML K–12 initiatives were centered on media (Hitron et al., 2019, Kahn et al., 2018). The K-12 students cover a range of a large number of students with distinct learning age objectives. Tedre et al., (2021) identify some differences in K-12 level education to be considered, such as differences in age teaching methods, teaching tools, learning context, and educational objectives. Furthermore, the age-appropriate variations should reflect in the span of objectives and challenges of educational initiatives of ML in K-12. The ML tools support the building of ML models and can be part of software artifacts, which were deployed by integrating them into a block-based programming platform (Wangenheim et al., 2021). Wangenheim et al. (2021) identified sixteen (16) visual tools built for teaching ML in K-12. Some of which are AlpacaML, BlockWiS-ARD, Google Teachable Machine (TM), DeepScratch, etc.

A curriculum is a planned educational process representing students' total learning experiences, taught by teachers to students in different learning environments or platforms, such as classrooms, after-school, individuals, online, and groups (Kelly, 2009; Marsh & Willis., 2003, Oyelere et al., 2021, Sunday et al., 2020, Agbo and Oyelere 2019). Brummelen & Lin., (2020) identify that teachers appreciate a curriculum that addresses students' assessments and participation. Researchers identified the importance of K-12 teachers' expertise and supporting their work throughout the design process (Severance et al., 2016, Agbo et al., 2019). Another co-design curriculum study researchers argued that working with teachers had significant effects on implementing the curriculum and tools and adding innovative concepts and social values (Durall et al., 2019). Heinze et al. (2010) suggested major considerations to curriculum co-designing with teachers to effectuate these advantages. These include tackling concrete, substantial innovative challenges, examining the classroom current practices and contexts, including a centralized quality of the co-design curricula products, accountability, etc.

2.4 Summary of related reviews on AI/ML in K-12

Even though research in K-12 AI and ML is still emerging, some literature reviews have been conducted to understand the growing research domain.

Giannakos et al., (2020) carried out a comprehensive literature evaluation on games for supporting AI and ML education using qualitative analysis to identify different games to teach AI ideas and topics. They pointed out the sources of fascinating and challenging quality games for pre-college pupils and teachers who desire to introduce AI basic ideas to their students. Cheng (2020) also discovered powerful AI technology has a significant impact on intermediate school education reformation and innovation through a systematic evaluation of literature on AI and information technology in China secondary education using a mixed-method (quantitative and qualitative) analysis. Way AI aids in deciphering students' challenges and identifying ways of providing solutions for them, improving students' creativity, and developing innovative educational experiences (Chassignol et al., 2018). Furthermore, Li (2020) carried out a comprehensive review of AI K-12 curriculum literature to identify and interpret the pedagogical approaches and fundamental curriculum elements in AI K-12 education. The paper found out that the four curriculums differ in contents, with the UK curriculum having more expansive and balanced contents. After applying the four curricula, the US curriculum best fits constructionism, while the Indian curriculum fits traditional methods.

Some contemporary literature evaluations were made on teaching ML to K-12 or ML K-12 education. For instance, Tedre et al., (2021) conducted a scoping review of literature on teaching ML in K-12 computing education, focusing on the pitfalls and potentials of teaching ML to K-12 education. It identifies the evolving trajectories in computing education typified by possibilities and mind changing. The paper discovered that learning at lower grades can be facile and not profound. Classical AI systems proved to be better than ML systems compared to learning the basic rules of traditional AI. The relationship between ML skills and knowledge and computational thinking has no agreement. The research conducted on teaching ML to K-12 is at the elementary stage. The ML state of the art for K-12 education goes a long way to determine the student's ability to comprehend ML concepts and be innovative. Marques et al. (2020) discovered 30 instructional units that focus on ML fundamentals and neural networks through a systematic mapping study of different kinds of literature on ML K-12 education to ascertain state of the art for K-12 education. However, this study adopted a systematic literature review framework by Kable et al. (2012). This study focuses on teaching ML to K-12 students to ascertain the present status of research in ML education in K-12, how it evolves, the study characteristics, the research design, and the future direction of K-12 ML education.

2.5 Summary of chapter two

This chapter presents the foundation for teaching Machine Learning to K-12 students review. The study described the meaning of Artificial intelligence in K-12 education and Machine Learning in K-12 education. The prior studies on AI K-12 and ML K-12 curriculum and AI/ML K-12 tools were developed to teach machine learning to K-12 students. It finally presents a deeper examination of various existing literature reviews on teaching AI to K-12 students and teaching ML to K-12 students. The discoveries of the study and the kind of literature review were identified.

3 CHAPTER THREE

3.1 Methodology

A systematic review of literature is a means of summarizing literature written regarding a particular topic/field of study to discover critical information in the field of study. Okoli and Schabram (2010) defined literature review as an approach for finding, assessing, and synthesizing the existing body of accomplished and documented research carried out by scholars, practitioners, and researchers; the review approach can be a systematic, unambiguous, thorough, and reproducible. Snyder (2019) stated that research findings synthesization revealed prove on meta-level to discover study field that requires more research that is crucial to theoretical framework elements and developing conceptualized models.

Literature reviews are conducted to extract specific information or ideas from previous research work or ascertain the stage at which literature is written on a particular topic. Through findings emanating from several empirical studies, the literature review can be utilized to answer research questions that no single scientific paper can do (Snyder, 2019).

In Medline, a review was conducted by Stanfill et al. (2010) to evaluate the performance of automated clinical coding and classification system, which revealed that automated coding and classification systems could not be generalized. The research shows that the systems are promising, although data must be in context with performance about the complexity of the task and the desired result. This research conducted a systematic literature review of published literature on teaching machine learning to K-12 students. The literature ranges from 2011 to 2021, and the search covers four different multidisciplinary databases.

3.2 Search strategy

The research started by gathering literature relevant to the research topic from chosen multifaceted databases following the method of systematic review (Shute et al., 2017, Agbo et al., 2021). As data collection proceeded, conference and journal literature was mainly reviewed. Several relevant kinds of literature were obtained on studies concerning artificial intelligence or machine learning education, AI or ML tools, AI or ML curriculum for K-12 education, teaching AI or ML at the K-12 level. The keywords used for the search include machine learning, ML, artificial intelligence, AI, AI education, K-12, or school.

A 12 steps search approach by Kable et al. (2012) was applied for building a practical framework for the review. This is listed in Figure 1 below:

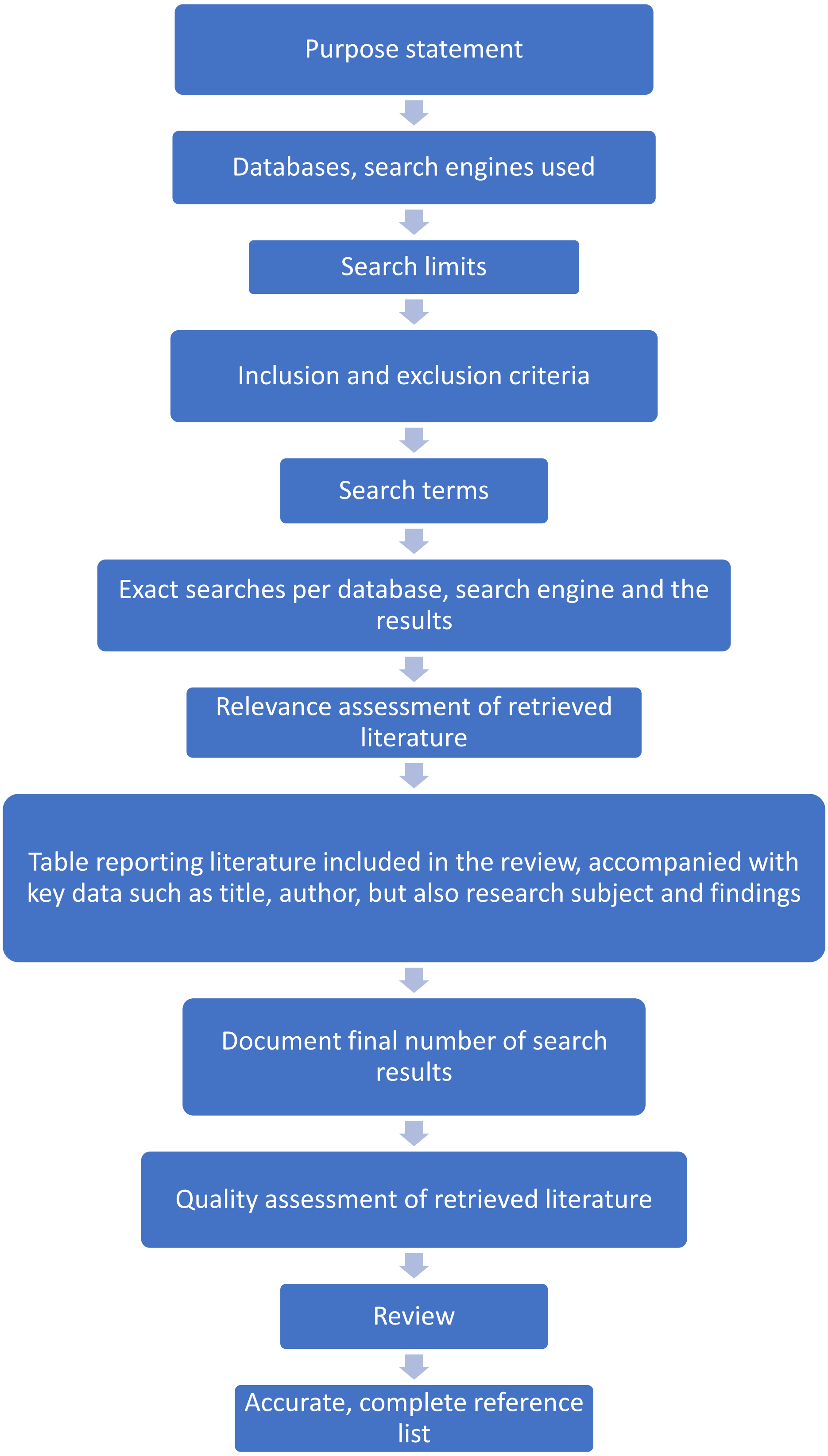

Figure 1: Kable et al. (2012) 12-step framework

This 12-step framework described a valued way of systematic review documentation that guides researchers to consider all areas needed for identifying relevant articles (Lange., 2014). To improve reading ability and facilitate readers' quick access to particular steps, this specific section described each step sequentially.

3.2.1 Purpose statement

The purpose formulation was made together with the principal and project supervisor. The purpose was to identify how global research on K-12 ML education grew over a decade from 2011 to 2021, the characteristics of K-12 ML education, ML designs in K-12 education, and future ML education in K-12 directions. An overview of the growing trend and development of teaching ML to K-12 were to be obtained.

3.2.2 Databases and search engines used

The search for relevant literature was conducted in four databases- ACM, IEEE Xplore, Scopus, and Web of Science. The four databases are well-established, warehouses published articles, and multi-disciplinary research platforms in computer science, education, and STEM (Science, Technology, Engineering, and Mathematics) (Agbo et al., 2019, Sanusi et al., 2022). The four databases were selected to make sure all relevant articles are included since there is the possibility that one or two databases may omit a paper that is relevant (Crossan and Apaydin, 2010).

3.2.3 Search limits

The following research limits were applied to our search:

- Journal and Conference articles in the English language

Our research was limited to journal articles and conference articles. A journal is a compilation of several scientific papers written on a particular topic, which went through peer-review and is frequently published. The journal paper offers well-proven knowledge and estimates topics and techniques in the current research (Mol and Wynstra., 2008). It is assumed that a peer-reviewed, highly impactful scientific paper on ML topic will have been translated to the English language. Therefore, it is believed that research papers with high impact will not be rejected based on language restriction (Lange, 2014).

- Articles published between January 1, 2011, and September 31, 2021

The time frame chosen for this systematic literature review is between January 1, 2011, and September 31, 2021. Quite a several initiatives have been developed in ML education over a decade. These initiatives cover the ML tools, integration, and implementation in K-12 ML education. These initiatives cut-across several countries of the world (Li, 2020). The cut-off year was set to assess the current status of teaching ML education in K-12 and how it progressed over a decade, considering that 2021 was the most recent research year representing the most recent ML K-12 development.

- **Search within**

The search was conducted through four different databases. The search in each database was done on the advance search page depending on each database outlook. Each database search is initiated in the "anywhere search" or "all Metadata" depending on the database. The search in each database was restricted to the title and keywords of conference and journal articles between January 2011 to September 2021 for easy discovery of relevant literature.

- **Subject area**

The search was restricted to Scopus digital library's computer science subject area to identify relevant literature quickly. Likewise, the Web of Science database search was also narrowed to Computer Science Artificial Intelligence, Education Educational Research, Computer Science Information Systems, Computer Science Interdisciplinary Applications, Education Scientific Disciplines. While for IEEE Xplore and ACM digital library, there is no restriction on the search area after limiting the search to title and keywords of conference and journal articles between 2011 and 2021.

3.2.4 Relevance assessment

The retrieved article inclusion or exclusion criteria were formulated in collaboration with the project supervisors. The primary rationale was to include only articles strictly written on teaching ML to K-12 students, which provided instances of current practices, methods adopted, study settings, and research procedures. The criteria were examined on 308 papers concerning their relevance. More than two researchers collaborated to build and test the requirements, making the 50 papers discovery process more factual (David et al., 2003). Inclusion and exclusion criteria are itemized below:

Inclusion criteria

- Articles that focus on teaching machine learning or artificial intelligence in K-12, s
- Articles that are published in conferences or journals.
- Articles that demonstrate tools, design, or artifacts used in teaching ML to K-12.
- Articles that demonstrate pedagogical approaches that are utilized to teach ML.
- Articles that present instructional materials, curriculum, and tools used in teaching ML.

Exclusion criteria

- Articles not written in English and articles not focused on keywords were excluded.
- Resources or materials such as audio/video files, PPT files, etc., were excluded.
- Non-journal and non-conference articles.
- Articles that do not present the teaching and implementation of ML in K-12 education.
- Articles that discuss ML without implementation in K-12 education.

3.2.5 Search Term

In collaboration with the research student, the supervisors developed the search term. The search term was used in searching through the four databases and was modified in different ways based on the database. Each database search includes machine learning, artificial intelligence, artificial intelligence education, K-12, and school. A search string was applied to the database. A search string combination example is (machine learning) OR (ML) OR (artificial intelligence) OR (AI) OR (AI education) AND (K-12) OR (School), ranging from January 2011 to September 2021. The string is modified where necessary to fit each database search pattern. The search outcome was subjected to some criteria to choose a relevant article for the study. Table 1 and Table 2 below present the research keywords and the search string from each database.

Table 1: Search keywords

Main concept	Synonyms

Machine learning	ML, artificial intelligence, AI, AI education
K-12	School, kids, children, teen

Table 2: Search string from each database

Source	Search Strings
ACM https://dl-acm-org.ezproxy.uef.fi:2443/search/advanced	44,024 Results for: [[All: "machine learning"] OR [All: "ml"] OR [All: "artificial intelligence"] OR [All: "ai"] OR [All: "artificial intelligence education"]] AND [[All: "k-12"] OR [All: "school"]]Edit SearchSave SearchRSS Searched The ACM Full-Text Collection (648,915 records)|Expand your search to The ACM Guide to Computing Literature (3,063,685 records)
IEEE XPLORE: https://ieeexplore-ieee-org.ezproxy.uef.fi:2443/search/advanced	Showing 1-25 of 56,229 for ("All Metadata":"Machine learning" OR "All Metadata":"ML" OR "All Metadata":"Teaching machine learning" OR "All Metadata":"Artificial intelligence" OR "All Metadata":"AI" OR "All Metadata":"Artificial intelligence education"") AND ("All Metadata":"K-12" OR "All Metadata":"School") Filters Applied: 2011 – 2021
https://www-webofscience-com.ezproxy.uef.fi:2443/wos/woscc/basic-search	21,818 results from Web of Science Core Collection for: "Machine learning" OR "ML" OR "Artificial intelligence" OR "AI" OR "Artificial intelligence education" (All Fields) and "K-12" OR "School" (All Fields) Analyze Results

	Citation Report Create Alert Copy query link | Timespan: 2011-01-01 to 2021-09-30 (Index Date)
https://www-scopus-com.ezproxy.uef.fi:2443/search/form.uri?display=basic#basic	10,956 document results (TITLE-ABS-KEY ("machine learning" OR "ML" OR "Artificial intelligence" OR "AI" OR "Artificial intelligence education") AND TITLE-ABS-KEY ("K-12" OR "School")) AND PUBYEAR > 2010 AND PUBYEAR < 2022

3.2.6 Documentation of Search Process

Table 3 below present the searches according to each database:

Table 3: Searches according to each database

Database	Number of papers =133,027	No. of analyzed results =6,737	No. of potentially relevant development =308	No. of relevant results
ACM	44,024	156	48	8
IEEE Xplore	56,229	2,394	44	7
Web of Science	21,818	1,467	108	23
Scopus	10,956	2,720	108	12

3.2.7 Test relevance of retrieved articles

The relevance of the papers found was evaluated in a three-step process.

A three-step process was adopted from Bettany-Saltikov (2010) to assess the papers' relevance. The assessment was made following the inclusion and exclusion criteria. All the titles were evaluated first. The evaluation of titles only benefits in identifying the relevancy of a scientific paper within a short period. This aided the quick elimination of irrelevant articles. If a title of an article had inadequate information to discover whether it is relevant or not, the paper is included. The assessment of the title was conducted in conjunction with the supervisors. Each title was evaluated first by the student and then the supervisors. Preceding the title assessment, any disagreement between the student and supervisors was resolved through a group discussion; this led to the criteria's redefining and reformulation to make it more understandable. The first screening reduced found articles from 6,737 to 308 papers. The second screening involved reading all 308 papers to judge their relevance following the inclusion and exclusion criteria. The student-initiated this process in collaboration with one of the supervisors, and the outcome was presented for the supervisors' verification and validation of the result. The second session screening stage ended with discovering 152 articles while one of the papers was not accessible to the researcher at the time of the data collection. The student researcher carried out the third and final screening process with the help of the two supervisors, who gave guidelines and necessary aid to students to extract the needed information from the scientific papers. Article duplicates were eliminated at this stage, and a total of 102 papers were excluded from the final analysis evaluation level, yielding a total of 50 articles for inclusion in the review.

3.2.8 Summary table of included articles

The summary of the completed list of articles included can be gathered from the authors.

3.2.9 Retrieved articles at the end of the search process

The sum of 133,027 articles was initially found in the search processes. The found articles were further limited by the time range between January 1, 2011, and September 31, 2021; other inclusion and exclusion criteria and removal of duplicates were also performed to come up with the sum of 50 articles for data extraction.

3.2.10 Quality appraisal of retrieved articles

Quality assessment is vital in ensuring that accurate findings of articles are achieved (Relman, 1990). This literature review included only conference and journal articles, which may discourage the need or desire for more quality evaluation.

3.2.11 Critical review

The critical review involves the extraction of data, analysis, and synthesis.

Extraction of data: A form for data extraction was developed with the project supervisors to extract essential data relevant from literature inclusion. These help sort each article into each category as presented in the classification table (scheme) Appendix. In order to obtain the completed data extraction form, a request can be made to the author.

The data extraction form was used in extracting data from the relevant articles. To avoid the complete reading of all articles, screening was done on each paper to extract information pertinent to the study. This particular process was carried out alone by the author, which may result in a subjective bias.

Data analysis: Data retrieved are analyzed to provide answers to the research questions. The complete study can be obtained in the Appendix Synthesis: A narrative synthesis was adopted to summarize our findings. The synthesis can be found in the next chapter.

3.2.12 Check the reference list for accuracy

Fifty articles were included in the review and were referenced in a separate list due to the number of articles studied. The request for the list of complete articles may be posed to the author.

3.3 Chapter summary

This chapter explained the overall research processes and how the study was planned and conducted following the adopted protocol. The study methodology firstly explains the term systematic literature review and its benefits and reasons. A 12-step framework was adopted for the search strategy this includes Purpose statement; databases; search engines used; search limits; inclusion and exclusion criteria; Search terms; exact searches per database; search engine and the results; relevance assessment of retrieved literature; table reporting literature included in the review, accompanied with critical data such as title, author, but also research subject and findings; document final number of search results; quality assessment of retrieved literature; review; accurate, complete reference list. The framework explained sequentially the methods adopted in the search.

4 FINDINGS AND DISCUSSION

4.1 State of ML in K-12 education

As part of the objective of this research is to ascertain the present state of ML in K-12 education. However, this was investigated by identifying and examining the trend in article publication on ML in K-12 education, the number of articles published annually, the article authorship, the sources of the preliminary study, and the publishing countries of the scientific papers on ML in K-12 education. Therefore, the systematic review of the literature will reveal the study's current state.

4.1.1 Annual publication

Initially, there was an epileptic flow in the publication trend. As presented in Figure 2, the number of papers published on K-12 ML education has gradually increased. There was no publication in 2011; a publication was made in 2012, while between 2013 and 2015, there was a "no show" publication on the ML in K-12 education. In 2016, a paper was published, and in the following year,2017, no article was published on the subject matter. There was a rising trend in several publications from 2018 upward. The increase in publication starting from 2019 can be attributed to the increasing trend in ML/AI in K-12 initiatives and the growing trend in K-12 computing education. In 2020, 19 papers were published, while 2021 had the most significant number of publications.

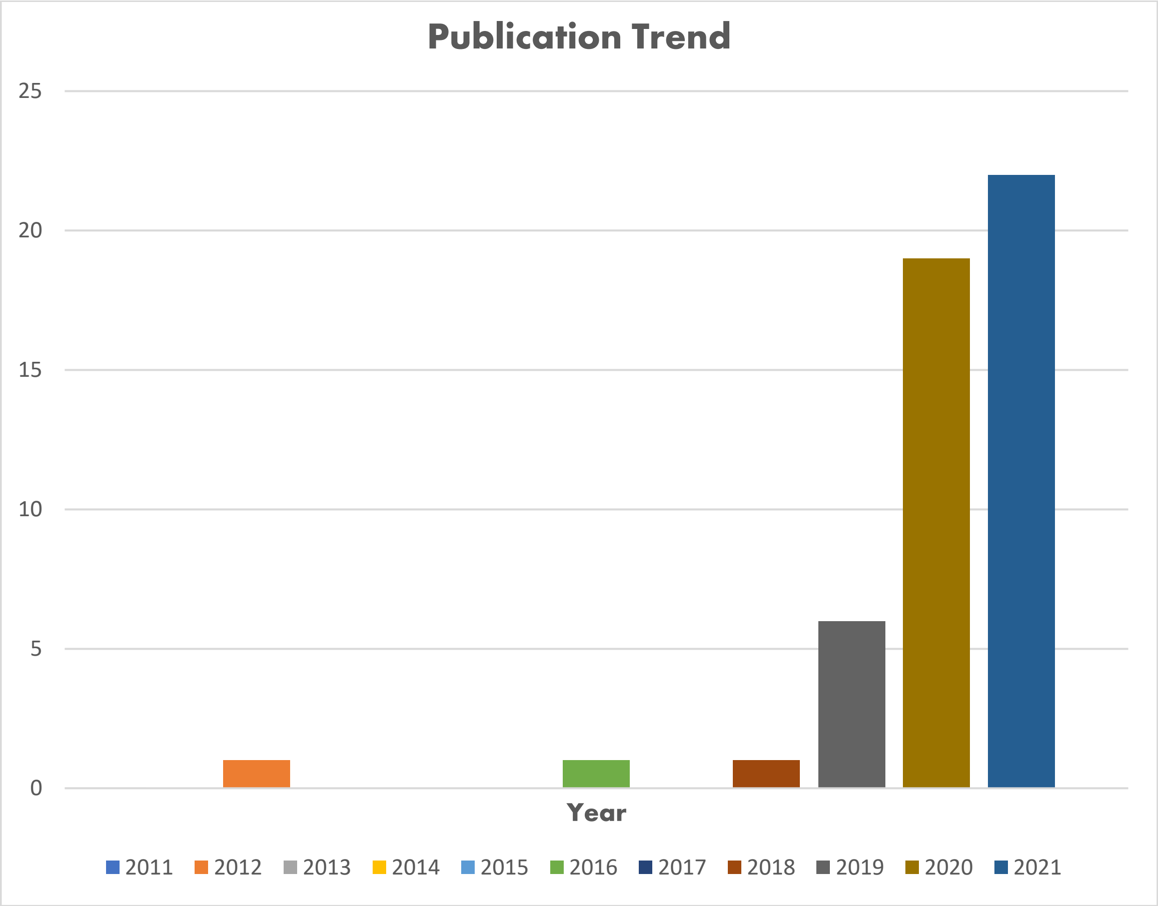

Figure 2: The number of research publications on ML in K-12 education between 2011 and 2021

4.1.2 Authorship

The initials were thoroughly checked to avoid duplicates of names, and duplicated names were eliminated. After filtering the copies, the sum of 133 authors contributed to the 50 articles. The majority of the authors published only one paper related to ML K-12 education (80.5%). Of the twenty-six authors that published more than one scientific paper, most of them published two, and only one person published three. The four authors, Matti Tedre, Ilkka Jormanainen, Henriikka Vartiainen, and Teemu Valtonen, are the most productive authors in the study, each having published five papers of relevance to this study, followed by Martin Kandlhofer, Gerald Steinbauer, Juho Kahila, and Tapani Toivonen, each of which published four articles of significance in this review. A list of the most influential authors can be found in appendix A.

Table 4: Articles authorship

Authorship	Frequency	Percentage%
Single Author	7	14%
Two Authors	10	20%
Three Authors	11	22%
Four Authors	7	14%
Five Authors	3	6%
Six Authors	8	16%
Seven Authors	3	6%
Eight Authors	1	2%
Total	50	100%

As shown in Table 4, over a decade, most of the research papers published on K-12 ML education were published by three authors (22%), followed by two authorships (20%) and co-authorship between six authors (16%). Single authors published only 14% of the articles. Also, 14% were published by four authors collaboration, while 6% were published by five and seven authors, respectively. The highest number of collaborative authorship contributing to one research article, as observed in Table 4, are eight authors, which had a minor percentage of publication (2%). As yearly publication analysis (Appendix A) shows that in 2021 two authors had the most prominent authorship, followed by the four authors and six authors, three and single authors also followed, while seven and five authors had lease authorship. Eight authors had no publication in 2021. The co-authorship between three authors became the most prominent in 2020, followed by six authors and single authors, while eight, seven, and four authors respectively had a single collaborative publication. Only five authors had no joint publication in 2020.

4.1.3 Primary study sources and number of publications

Fifty articles were identified on ML K-12 education. These articles were published from 2011 to 2021. Among these papers, 29 (58%) were conference proceeding papers, and 21 (42%) were published in Journals (Fig.3). Figure 4 consists of journals and conference proceedings issued per year. In 2012, 2016, and 2018, only one conference paper was published each year, while no journal paper was published. In 2019 five conference papers were published compared to one journal paper; likewise, in 2020, we have thirteen conference proceedings published. Only six journals were published, but in 2021, fourteen journals were published, while only three conference papers were published.

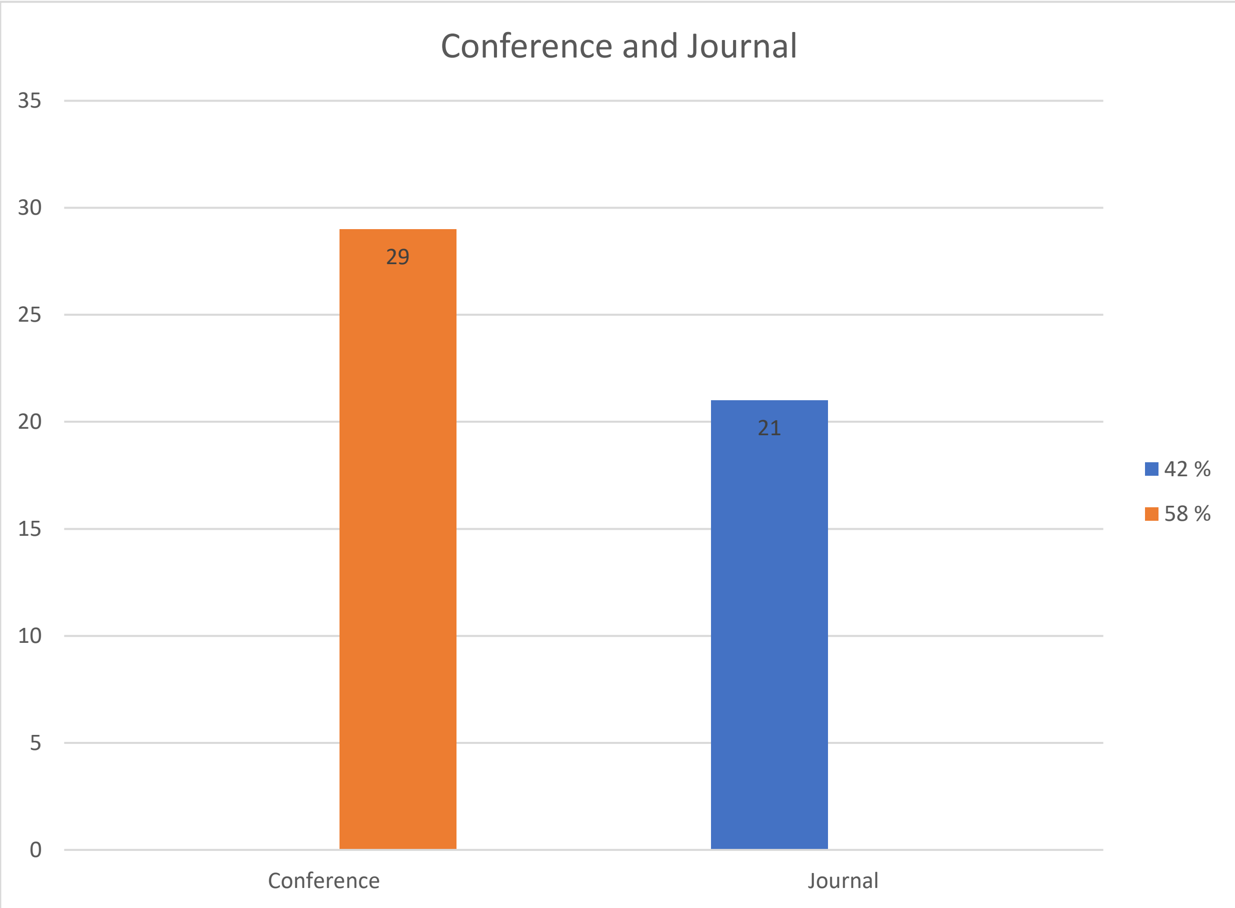

Figure 3: The number of conference and journal articles studied

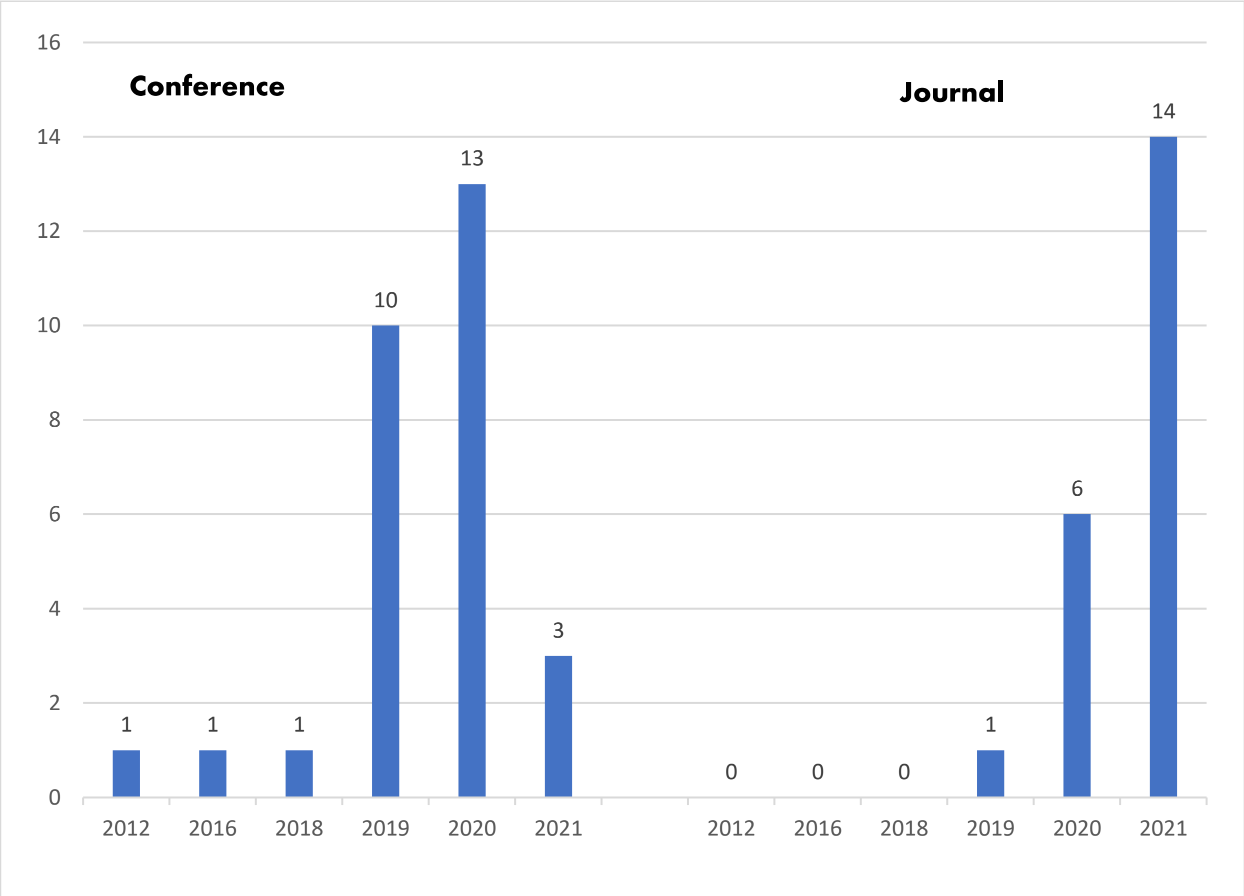

Figure 4: Conference and Journals published per year

Table 5 summarizes ML K-12 education-related studies in journals and conference papers from four notable scientific databases. Though ML in K-12 education is an emerging field, we rigorously work on literature and query round to identify these number of articles, focusing on only journals and conference proceedings. Ten conference papers on Computer Science Education and computing education were placed under the Association of Computing Machinery (ACM). This includes topics that contrate on Innovation and Technology in Computer Science Education, Human Factors in Computing Systems, Computing Education Research, Design Making in Education, etc. Eleven conference papers were published in IEEE, and some of the topics focusing on Frontiers in Education, Communication and Electronic Technology, Advanced Learning Technologies, etc.), likewise, five conference papers were published through SpringerLink, with topics on Technology Enhanced Learning, Machine Learning and Big Data Analytics for IoT Security and Privacy, etc. In addition, a paper from AAAI Conference was published on Artificial Intelligence. Also, the international conference on informatics in schools (ISSEP) published an article on AI teachers' perception and one paper from CoolThink on computational thinking education. Two publications were identified from IEEE, ten from springer, while others had one publication each.

Table 5: Primary study sources and the number of published article

Conference	Papers
Innovation and Technology in Computer Science Education (ITiCSE), ACM, New York, NY, USA	3
CHI Conference on Human Factors in Computing Systems (CHI ’21) ACM, New York, NY, USA	1
Koli Calling International Conference on Computing Education Research (Koli), ACM, New York, NY, USA	1
ICER, Virtual Event, USA, ACM, New York, NY, USA	1
[IDC] Interaction Design and Children June 21–24, 2020London,	1
An International Conference on Computing, Design and Making in Education (FabLearn Europe / MakeEd 2021), ACM, New York, NY, USA	1
The 15th International Conference on Computer Science & Education (ICCSE 2020) August 18-20, 2020. Online IEEE	1
IEEE Frontiers in Education Conference (FIE)	4
International conference on informatics in schools, ISSEP	1
2018 World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC) (pp. 1-6). IEEE	1
International Conference on Machine Learning and Big Data Analytics for IoT Security and Privacy (pp. 110-118). Springer, Cham	2
International Conference on EUropean Transnational Education (pp. 331-337). Springer, Cham.	1
2020 IEEE Integrated STEM Education Conference (ISEC)	1
2019 IEEE Tenth International Conference on Technology for Education (T4E)	1
2019 International Symposium on Computers in Education (SIIE)	1
CoolThink@ JC (2019), 157 Proceedings of International Conference on Computational Thinking Education 2019. Hong Kong:	1
Proceedings of the AAAI Conference on Artificial Intelligence (Vol. 33, No. 01, pp. 9795-9799)	1
KI 2016: Advances in Artificial Intelligence, 218.	1
The Sixth International Conference on Information Management and Technology (pp. 1-4) ACM Indonesia (ICIMTECH)	1
SIGCSE '21: Proceedings of the 52nd ACM Technical Symposium on Computer Science Education	1
In European Conference on Technology Enhanced Learning (pp. 260-274). Springer, Cham.	1
Communication and Electronic Technology (MIPRO) (pp. 747-749). IEEE	1
2020 IEEE 20th International Conference on Advanced Learning Technologies (ICALT) (pp. 308-310). IEEE.	1
Journals	
IEEE Access	2
TechTrends 65, 796–807 (2021) Springer	1
KI-Künstliche Intelligenz, Education in Artificial Intelligence K-12. Springer	9
International Journal of Artificial Intelligence in Education, 1-31. Springer	1
The Tenth AAAI Symposium on Educational Advances in Artificial Intelligence (EAAI-20)	1
International Journal of Computational Intelligence Systems Vol. 13(1), 2020, pp. 974–987	1
Informatics in Education, 2020 Vol. 19, No. 2, 283–321, © 2020 *Vilnius University* DOI: 10.15388/infedu.2020.14	1
Cogent Engineering2020, Vol. 7, No. 1	1
International journal of child-computer interaction, 25, 100182.	1
AI Magazine, 40(4), 88-90.	1
Educational Technology & Society, 24(3), 89-101	1
A ten-year systematic mapping. Education and Information Technologies, 1-46.	1

4.1.4 Publishing Countries

Each published article originated from a maximum of eight countries and a minimum of one country, depending on the authorship. All papers authors were identified and the publishing countries or conference location countries. Frequency analysis a decade of research (Table 6) revealed that study emanated in publishing and conference location country from eighteen different countries. Germany and USA dominated the research field by contributing 20% each, followed by Switzerland contribution 14% and Sweden 8%. While Canada, Hong Kong, Norway, and the UK contributed 4% each, the other remaining countries contributed 2% each.

Table 6: Article Publication/Conference Countries and the number of papers published

Publication/Conference Countries	Frequency	Percent
Austria	1	2%
Canada	2	4%
Croatia	1	2%
Cyprus	1	2%
Estonia	1	2%
Finland	1	2%
France	1	2%
Germany	10	20%
Hong Kong	2	4%

Indonesia	1	2%
Israel	1	2%
Italy	1	2%
Japan	1	2%
Netherlands	1	2%
Norway	2	4%
Sweden	4	8%
Switzerland	7	14%
UK	2	4%
USA	10	20%
Total	50	100%

Discovering the ML in K-12 education studies, we have considered a method to demonstrate how ML K-12 education studies have expanded over the last decade. Following (Appendix A2) shows that the first paper published on our topic was published in Israel in 2012. Another single article on the subject was published in 2014 in Austria, while a paper was published in the USA in 2018. Two were produced in the USA in 2019 out of the six articles published. The remaining four publishing country locations were Canada, Cyprus, Finland, and Hong Kong. Furthermore, USA and Sweden will top the list in 2020 with three publications from each country, followed by the UK, Norway, Switzerland, and Germany, while countries like Canada, Croatia, Estonia, France, and the Netherlands publish one paper each. In addition, Germany heads the publication table with eight articles in 2021, followed by

Switzerland, having five publications and four from the USA. While Sweden had two and Hong Kong, Indonesia, Italy, and Japan had one each.

Considering the top two publishing countries, from the table in Appendix A2, the table shows a rising trend of publication in the USA, starting with a single paper in 2018, two essays in 2019, three papers in 2020, and four in 2021. While on the other hand, Germany started with two in 2020 and skyrocketed to eight in 2021. This means that USA and Germany study and build more on teaching machine learning in K-12 education.

4.2 Predominant study characteristics

4.2.1 Grade levels

Table 7 classified the articles published between 2011 and 2021 based on different grade levels. Table 7 revealed that twenty-six percent (26%) of the papers did not particularly mention the specific grade level while some were particular on K-12 teachers, and they were generalized with the term "K-12". Some of the papers are "engaging teachers to co-design integrated ai curriculum for k-12 classrooms; teaching machine learning in k-12 education, teaching machine learning in k-12 classroom: pedagogical and technological trajectories for artificial intelligence education; can you explain ai to me? Teachers' pre-concepts about artificial intelligence; pedagogies of machine learning in k-12 context; exploring teachers' perceptions of artificial intelligence as a tool to support their practice in Estonian k-12 education; teaching machine learning in school: a systematic mapping of state of the art; envisioning ai for k-12: what should every child know about ai?; a differentiated discussion about ai education k-12; analyzing teacher competency with TPACK for k-12 ai education; can you explain ai to me? Teachers' pre-concepts about artificial intelligence; ai k-12 education service; a year in k-12 ai education; visual tools for teaching machine learning in k-12: a ten-year systematic mapping". Although, the number of published articles on high school grade level top the list of publications with 28%, middle school having 16% and elementary school with 14% related articles. Meanwhile, ten percent of the publications were explicitly made on high and elementary school, while two percent (2%) of the articles were on elementary and middle school; and Elementary and middle and high school, respectively. Furthermore, 2% of the paper mainly talks of K-12 but describes different thoughts on applying AI in teaching diverse disciplines.

Table 7: Grade Levels 2011 – 2021

Grade levels	Number of Articles	Percentage
Elementary school	7	14 %
Middle school	8	16 %
High school	14	28 %
K-12	13	26 %
High and elementary school	5	10 %
Elementary and middle school	1	2 %
Elementary and middle, and high school	1	2 %
Not specified	1	2 %
Total	50	100 %

Appendix B1 shows the publications based on the year and grade level.

They consider the publications based on the years in which the article was published and the grade level in Appendix B1. Elementary school top the list in 2021 with eight publications (which includes all articles published on elementary, middle, and high school; elementary and middle school; and elementary and high school), followed by middle school (including papers on middle and elementary school; and elementary, middle and high school) and high school (these include elementary, middle and high school; and elementary and high school) with each having six publications. Meanwhile, in 2020, high school has the highest number of published papers, seconded by the elementary and middle school, each having four articles published. Likewise, high school 2019 also had the highest number of published papers, while the elementary school had two. The first three papers published were made on high school grade level. Likewise, high school has the highest number of publications, implying that more research needs to be conducted on elementary and middle school grade levels.

4.2.2 Authorship Countries

Interestingly, considering the author's country where the papers originated from, the USA dominated this research field, then Finland, next China, and Spain. Statistically, as shown by Fig. 5, the total amount of research carried out by researchers in the USA is 11 (18%) out of the total contributions per author's country. In contrast, Finland, China, and Spain showed great interest in the topic with 13.1%, 9.8%, and 9.8% each. Sweden and Estonia shared a 6.6% interest in contributing to the field. Meanwhile, Germany and India shared 4.9% each, Israel, Brazil, and Hong Kong shared 3.3%. On the other hand, many other countries contributed, perhaps though the lowest, such author's country include Turkey, Denmark, Argentina, Estonia, Kazakhstan, Japan, South Korea, Ecuador, Slovakia and Belgium contributed 1.6% each.

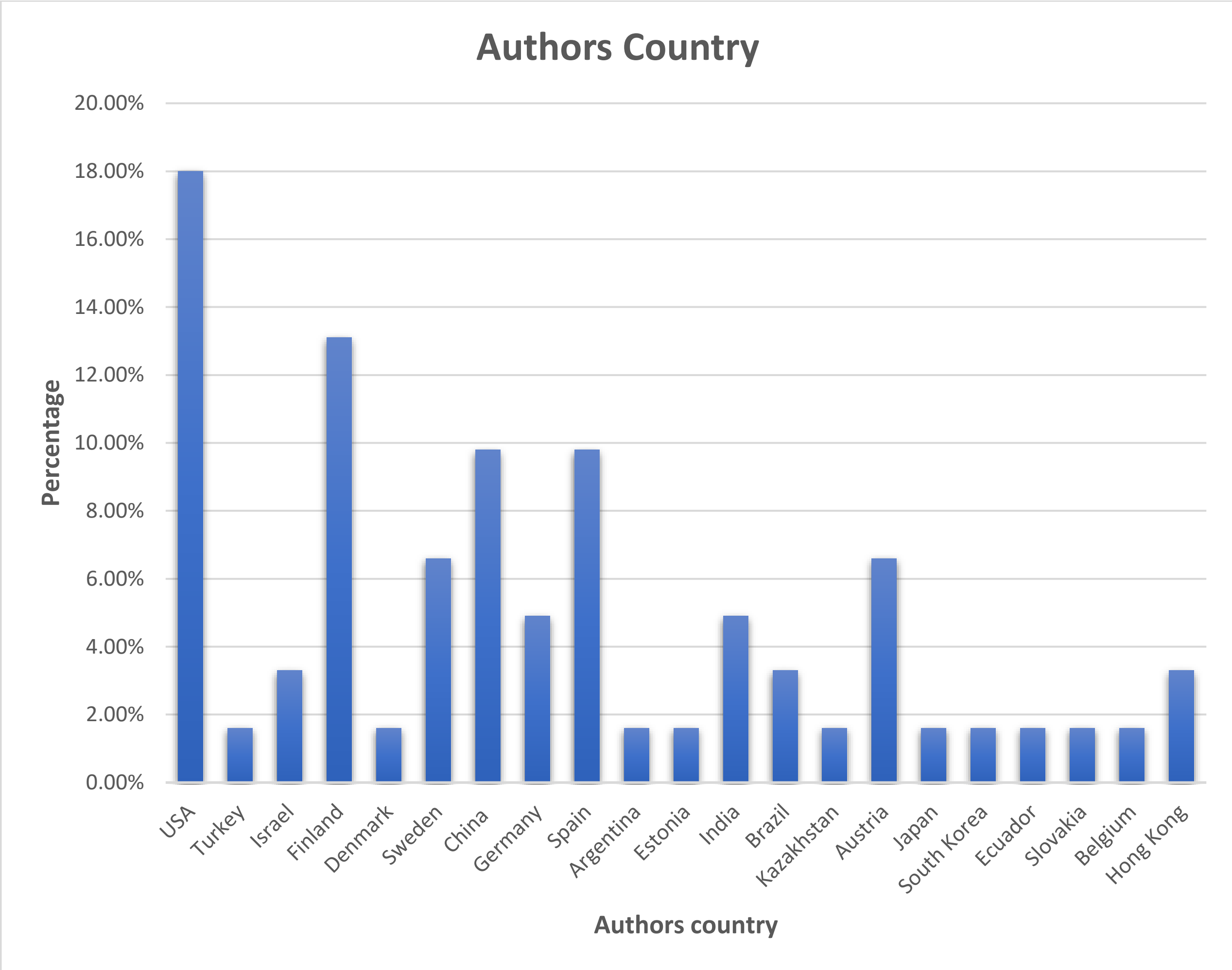

Figure 5: Authors Country

4.2.3 Type of Activities demonstrated in the study

The study type of activities identified in this empirical study are classified as Plugged, unplugged, and plugged and unplugged, unplugged, and robotics activities, and not specified (these are literature reviews and papers that do not significantly specify the king of activities adopted in their studies). Figure 6 shows that studies extensively utilized plugged activities in ML K-12 education research with 48%, while papers that do not particularly specify the kind of activities used have 20%. Papers that adopted both plugged and unplugged activities have 16%, then only 12% of the articles use unplugged activities. The combination of unplugged and robotics activities was the list of adopted activities.

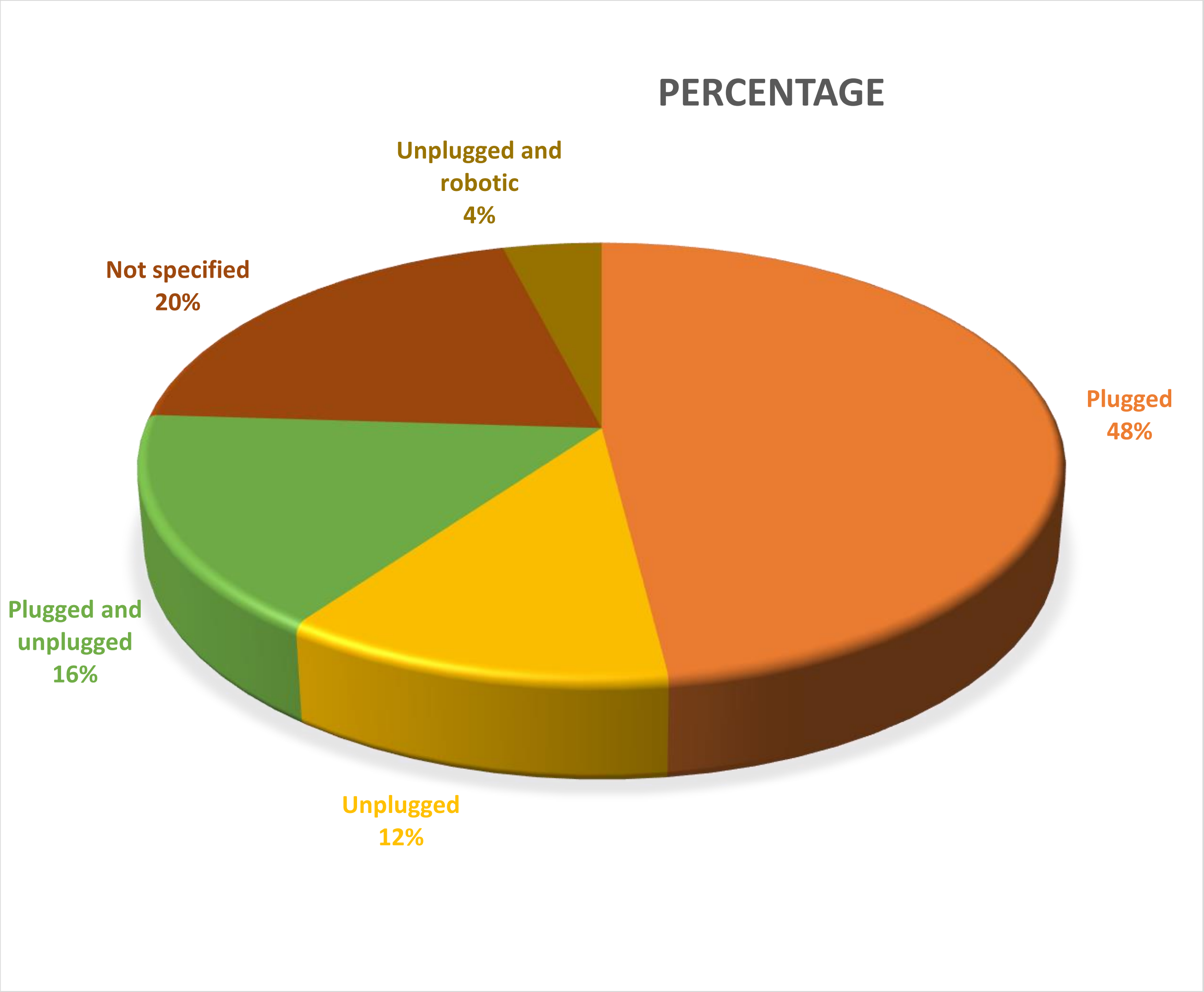

Figure 6: Types of activities

4.2.4 Types of activities demonstrated in the study and year

As shown in Appendix B3, the first and only published article les in 2012 adopted plugged activity in a conference paper on Integrating AI and Machine Learning in the Software Engineering Course for High School Students. The following article in 2016 utilized both plugged and unplugged activities, while the third paper published in 2018 adopted both unplugged and robotics activities.

In 2019 out of the six papers, five adopted plugged activities, while the six utilized unplugged and robotic activities. Papers in 2020 mostly use plugged activities, followed by not specified, plugged and unplugged activities and unplugged activities. In 2021 out of the 22 articles published, 10 of the applied plugged activities in their research work, six not specified, four unplugged, and two adopted plugged and unplugged activities.

4.2.5 Study setting

As presented in Figure 7, six different study settings were identified, and articles that did not specify their study settings and literature review papers were classified as not defined—a more significant number of the papers utilized workshop study settings in their research (38%). Meanwhile, scientific papers that did not specify their study settings were the next in line after the workshop with 26%. However, 20% of the identified papers applied classroom settings (classroom sessions, regular classes, and vocational classes) for their research. Only 8% of the studies utilized online study settings, and 4% adopted summer programs. At the same time, 2% adopted weekly study settings and non-school settings, respectively.

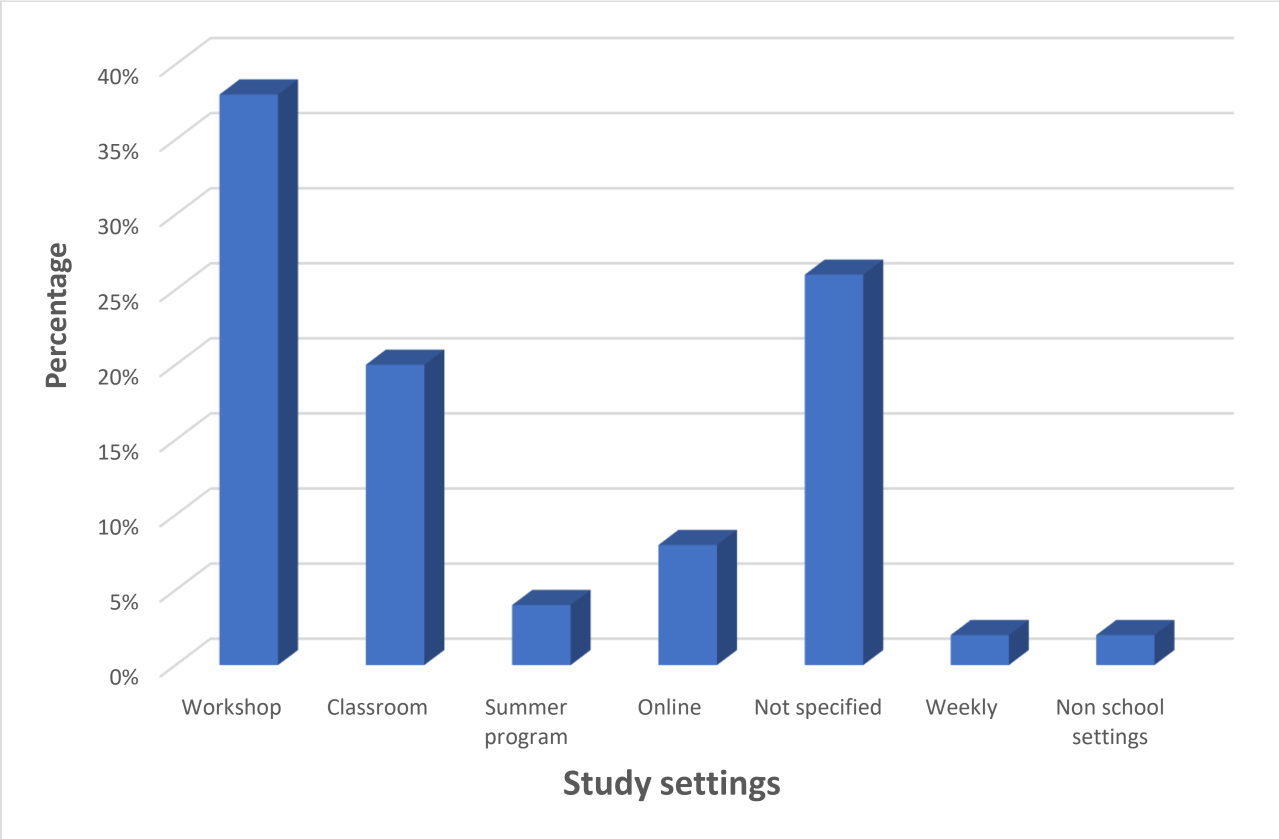

Figure 7: Study settings

Appendix B4 showed that out of the 22 studies conducted in 2021, 7 articles used workshop settings, seven were not specified, while the classroom and online studies were used by four papers each. Although, in 2020, seven essays use the workshop, and six article does not specify, while three pieces use classroom, two summer programs, and one adopted non-school settings. Furthermore, in 2019 out of the six studies, four used workshops while two used classroom settings. The only paper published in 2018 also uses workshops. Likewise, the only research conducted in 2016 uses weekly courses, while the only study in 2012 uses a classroom setting.

4.3 Predominant research designs of ML education in K-12

4.3.1 Research Method

A couple of theoretical methodologies, diverse types of research, and techniques were identified following the ML evaluation in K-12 education-related analyses. Though, these figures demonstrated internally those growths and exhibitions of the basics of teaching ML in K-12 studies undertaken in the last decades. Figure 8 revealed six theoretical approaches used in different studies identified in this research. The most frequently used research technique is the qualitative research method (34%), followed by a literature review (26%), a designed-based study, a mixed research method, and quantitative 14%, 12%, and 10%, respectively. At the same time, a game-based design study was the list research method used as identified in this study.

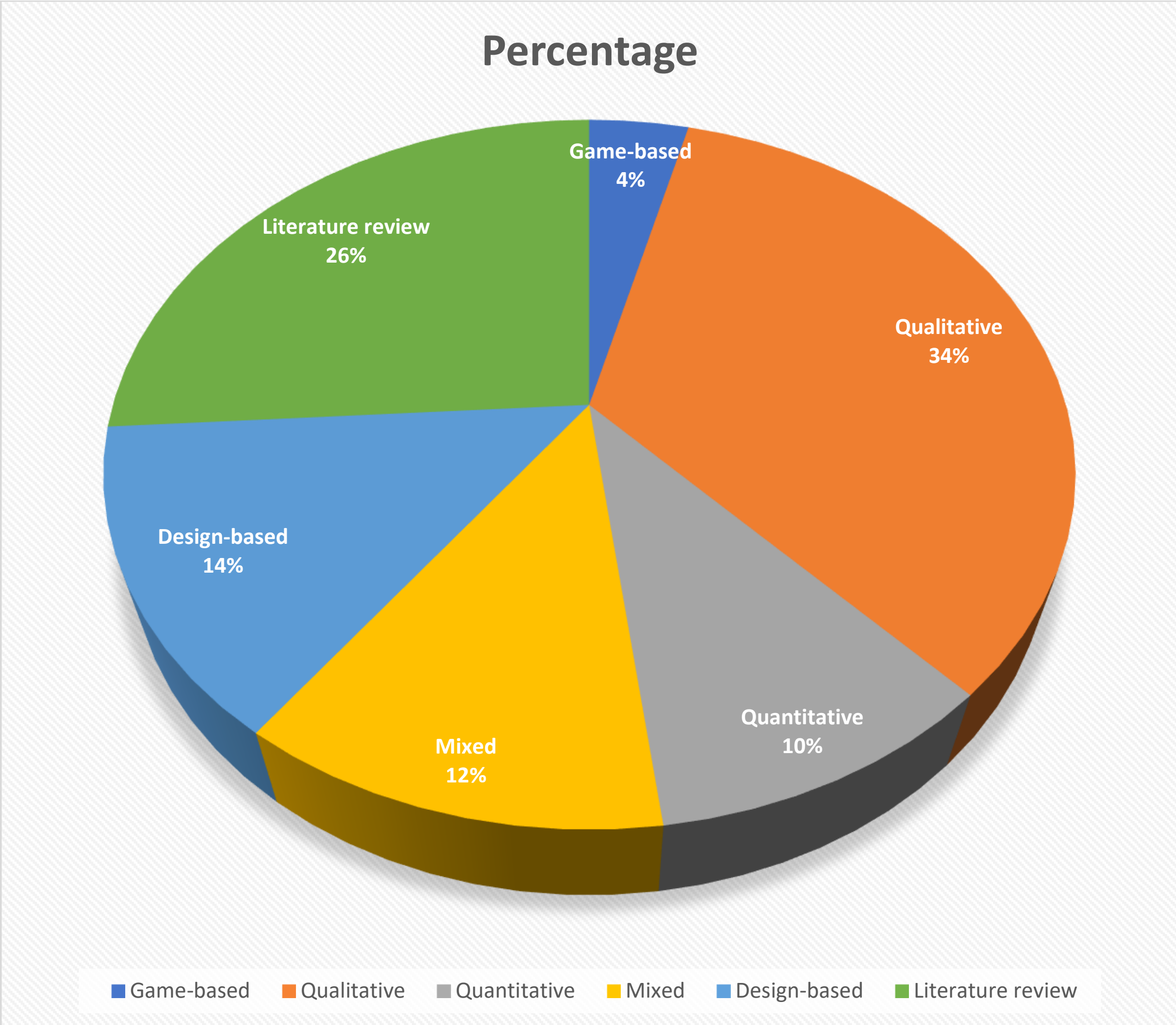

Figure 8: The research techniques applied

4.3.2 Research Method per year

As shown in Appendix B3, most of the papers published in 2021 applied qualitative techniques (11 articles), three papers used literature review, then design-based and mixed-methods were also used. The list method applied in 2021 is the quantitative research method. Likewise, in 2020, qualitative study techniques were applied, followed by a designed-based study, while a literature review study was the least used. Although, in 2019, only qualitative and mixed were applied. However, as identified in this study, the only paper published in 2018 used the qualitative research method. At the same time, the mixed method was applied in the only paper published in 2016. The designed-based research was applied in the first relevant article published on teaching ML to K-12, as identified in this study.

4.3.3 Data Collection Methods

As shown in Table 8, eight data collection methods were identified in this study. Some of the research papers applied two or more recognized data collection methods in their research, while others only used one. Interview (which includes semi-structured, structured, group or individual interview and group discussion transcription) have been the most dominant data collection method in this study; it was utilized by 24% of the articles. However, the second most often used method for collecting data is secondary data (these comprise academic literature and teaching documents). The third highest data collection method is a survey (including online survey and feedback), followed by a questionnaire (including pre and post-test), observation, and student design (development testing, prototype improvement, game testing, and co-design). At the same time, final projects and exercises were rarely used methods.

Table 8: Data collection methods

Data collection methods	Frequency	Percentage
Secondary data	14	22.2%
Interview	15	23.8%
Observation	8	12.7%
Questionnaire/survey	9	14.3%
Survey	10	15.9%
Exercise	1	1.6%
Student design	4	6.3%
final project	2	3.2%
Total	63	100%

4.4 Topics covered in ML for K-12

4.4.1 Topics

The topics uncovered during this systematic review study were included and considered during the screening process. The sum of identified and revied papers was 50; they were perceivably categorized into four main topics.

Curriculum design: these cover all related papers on designing or building K-12 AI/ML curriculum and developing methods for integrating AI/ML into K-12 education. Research papers presented describe associated topics.

Pedagogical design: these include all topics on teaching AI/ML concepts to K-12, interventions in teaching K-12 AI/ML, interviews on teaching K-12 students AI/ML, and literature reviews on ML/AI teaching tools.

Perception: covers all topics related to teachers' or students' perceptions of teaching AI/ML concepts, tools, or techniques used in K-12 education.

Tool design: these include all topics on AI/ML teaching tools development

As shown in figure 9, most of the scientific papers studied pedagogies, 36%, while the second most studied topic is perceptions, which was comparatively accessed by 28% of the articles. Next is tool design (20%), while the minority studied topic is curriculum design. This revealed that more study is required in ML curriculum design and tools design-related topics.

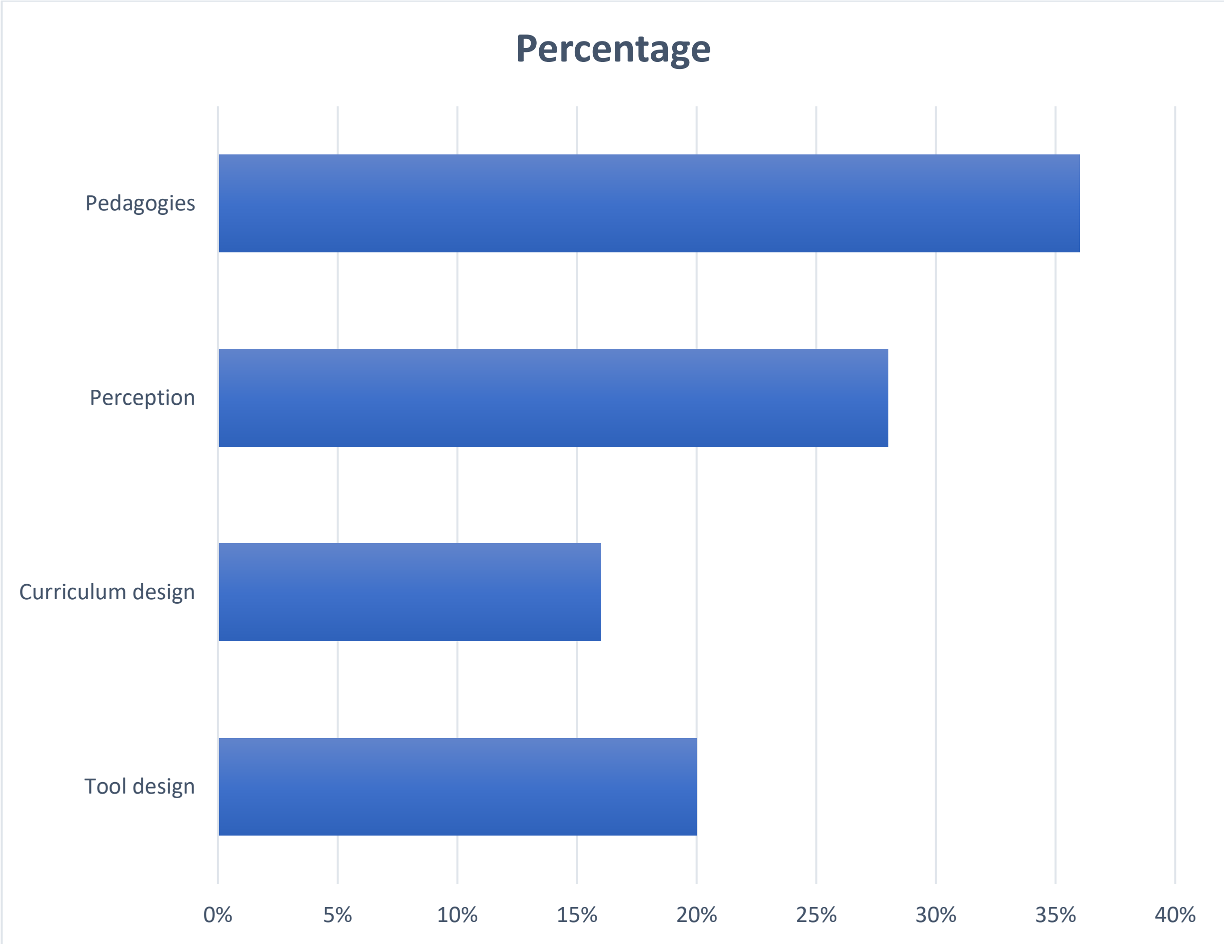

Figure 9: Topics 2011-2021

4.4.2 Topics per years of publications

They consider the various topics in their summarized form to the years of publication as presented in appendix C3 and C4. The first and only article published in 2012 is on curriculum design, which suggested the integration of ML and AI into high school education at a conference in Israel. Likewise, curriculum design is also the topic of the only paper published in 2016. At the same time, 2018 only published paper was on students' perceptions of ML teaching in high school. Out of the six papers published in 2019, three were on perception (two on teacher's perception and one on student's perception), two papers on pedagogies, and one on ML tool development. Meanwhile, the highest topic studied in 2020 is on pedagogies followed by tool design and perception, while the list published topic in 2020 is curriculum design. Furthermore, in 2021 pedagogies topics also top the list of article topics published, making the topic very important. The second top topic is perception and curriculum design the third top while the least published topic is tool design. This implies that studies are conducted on the AI/ML-designed tools that are currently available, while more ML tools are still needed.

4.5 Chapter Summary

In this chapter, the researcher presented the findings and discussion from the review process and analyzed the growing trend of the field from 2011 to 2021. The researcher discovers the state of ML in K-12 education, under which the researcher presents the annual publication, authorship, primary study sources, and publishing countries. Likewise, the research shows the predominant study characteristics, discovering and discussing the age-grade level, the study type of activities, and study setting. Furthermore, the researcher showcases the chief research designs; this includes the methods adopted in collecting data in each paper studied, the research method, and their application in papers published per year. The researcher finally presented each article published and categorized them into four main topics, i.e., perception, pedagogies, design tool, and curriculum design in ML K-12 related articles.

5 DISCUSSION

This study investigated existing scientific literature to unravel the present status of research on ML in K-12 education and how it has grown over a decade, demonstrating the study characteristics, research design, and topics. A systematic literature review was adopted, and several articles were analyzed to address the research questions. Firstly, ML in K-12 education publication trends, authorship, study primary sources, and publishing countries were presented. In addition, the grade levels, authorship countries, the kind of study activities demonstrated, and study settings used in teaching ML to K-12 students were also discovered. Furthermore, research design, data collection methods, and related topics on teaching ML in K-12 education were unraveled in the study articles.

The underlying motivation behind this study is to identify and study the present status, characteristics, research designs, future directions of ML in K-12 education. Several pedagogical studies on teaching ML to K-12 were identified in the review. For example, Sanusi and Oyelere (2020)suggested that the study method for teaching K-12 ML should be learners-centered such as inquiry-based learning, design-oriented learning, participatory learning, and active learning. Therefore, this was in line with the findings in this study, where 14% and 4% of the study focused on design-based and game-based study research methods, respectively. Some of the designed-based studies are: A learning platform developed to aid in demystifying ML technology to K-12 students was built (Wan et al., 2020). Also, a game-based learning platform was created to help in infusing AI into life science (Lee et al., 2020). Likewise, students were trained to personally develop ML applications using teachable google machine (Toivonen et al., 2020). Also, a platform was built to allow K-12 students to use ML to make voting predictions based on real-life voters' data (Kaspersen et al., 2021). Additionally, Shamir and Levin (2021) developed a curriculum and programming learning platform for primary school students. Meanwhile, more ML K-12 teaching design tools were required to aid the improvement and implementation of ML in K-12 education.

According to the findings discovered from this research work to the above RQ1, several research works related to ML in K-12 education were extracted. Particularly, attention was given to articles published recently between 2011 and 2021. In a systematic literature review perspective, several articles (which include journals and conference proceedings) were used from four reputable databases to gather primary studies for this review. Some of the discoveries in section 4.1 include the number of articles discovered within ML in K-12 education-related studies and their sources. However, this study focuses on conferences proceedings and journal papers to maintain the quality consistency of the recruited articles. This was in tandem with McDermott et al., (2021), which explain that conference proceedings and journals maintain a high standard in paper publications.

5.1 RQ1. What is the current status of research in ML education in K-12, and how did it evolve over the past ten years?

Interestedly, this research work revealed the growing trend in K-12 ML education as a fast-rising field of study, which attracted researchers recently. The majority of the articles were published between 2020 and 2021. This was about a discovery by Sanusi et al. (2021), which stated that teaching ML fundamental to K-12 pupils had attracted several researchers and practitioners. Likewise, Luan and Tsai (2021) attest that ML in education is a fascinating, fast-growing study area with high potential.

Furthermore, this study also discovered that most papers were mainly published by three authors and two authors team. However, most of the articles identified in this study were produced in eighteen countries, while USA and Germany top the list of publishing countries. USA became one of the top publishing countries because some policies and frameworks were put in place as revealed by Mao (2017), which stated that for more than two decades ago, USA school initiatives in K-12 and policies on technology programs have gradually been developing from integration phase of result focus to design learning era. Likewise, Touretzky et al., (2019) revealed the growing trend of the AI K-12 education community after the launch of AI4K12 in the USA. As Joseph South, the chief learning officer of “The International Society for Technology in Education" in September 2019, released a statement that more than 560 teachers completed their courses in AI for K-12 education, a broader frame containing ML in K-12 education. In addition, Szabo et al. (2019) identified that majority of the initiatives on K-12 education took place in the USA. This proves that the USA is the leading country in K-12 education development. To further demonstrate our discovery, the German education system has experienced many robust innovations over the years; for instance, the all-day school formation, the first-year preschool reformation, and the high school education system were modified according to Mao et al. (2019). Also, Germany has built a strategic plan to improve AI in the K-12 education system, which will stimulate the expansion of AI education in Germany (Bundesregierung, 2018). All this revealed the potency of our discovery. Meanwhile, this study identified the top publishing authors in this field are from Finland.

5.2 RQ2. What are the predominant study characteristics of ML education in K-12?

The study characteristics identified include grade levels, authors' country, types of study activities demonstrated, and the study settings. This study classified the K-12 grade level into high school, middle school, and elementary school. The majority of the studied articles focused on high school, while studies on the elementary school were the least. This implies a literature gap in elementary and middle school grade levels. Thereby suggest that studies focusing on elementary and middle school should be increased to enable pupils to acquire skills, which will help move from traditional rule-based thinking to ML data-driven based thinking (Tedre et al., 2020), which will aid the development of the ML K-12 curriculum and easy integration of ML into K-12 education.

Concerning the author's country, twenty-one authorship countries were discovered in this study. Most of the researchers in this field emerged from the USA, followed by Finland, China, Spain, etc. USA and Finland authors have authored several papers on teaching ML in K-12, covering different grade levels. Furthermore, the study activities help categorize the kind of activities used in teaching ML to K-12 students into plugged, unplugged, or combination of plugged and unplugged. This study further shows that plugged activities were majorly adopted by most researchers, which was in line with the findings of Kirçali and Özdener, (2022). Kirçali and Özdener, (2022) suggest that the student group Scratch (plugged activities) was used to introduce computational thinking to show tremendous growth in understanding and creativity. Students' ability to actively participate in the plugged activities study help in developing creative ability. In addition, Kobsiripat (2015) agreed that the use of Scratch (plugged activities) to teach programming yields positive results. Regarding the study settings used in teaching ML to K-12 students, workshop study setting was majorly adopted by most researchers on ML in K-12 education. This could be because teaching ML to K-12 students is an evolving study area that will require much study to be conducted to enlighten the populace about the emergence of the field. The workshop usually helps incorporate data collection into the workshop program and supports learners in externalizing their growing thoughts about ML (Toivonen et al., 2020).

5.3 RQ3. What are the predominant research designs of ML education in K-12?

Interestingly, several research methodologies have been utilized to demonstrate ML in education through the literature. For instance, this study showed that qualitative research approaches mainly were used in the literature, involving participants' participation in the study activities and responding to surveys or interviews for data collection. These methods were widely utilized in ML K-12 education research (Sanusi 2021, Vartiainen et al., 2020, Toivonen et al., 2020). However, Toivonen et al. (2020) indicated that their observation and the qualitative analysis they conducted revealed the viability and reliability of Google Teachable Machine as a tool for users who have little or no knowledge in programming or subjects related to it. Likewise, Vartiainen et al. (2020) explained that all the data (including video recordings and interviews) they gathered were analyzed by utilizing qualitative content analysis. In addition, the researcher realized that the qualitative approach helps researchers analyze the functionality and usability of ML design tools, evaluate perceptions of teachers, students, and other educational stakeholders, and examine the pedagogical studies to build the K-12 ML education field. It was also discovered that most of the studies were conducted with few participants (Steinbauer et al., 2021, Lindner et al., 2019). Therefore, the researcher suggested that further research be achieved with many participants to create more awareness about ML K-12 education.

The interview was the primary data collection method adopted by most researchers in this study, though other data collection methods were identified. This was in line with a statement made earlier in this study of identifying qualitative research method as the most used approach of research study adopted by the majority of the researchers because the interview was part of the methods used in conducting qualitative research. When teachers were interviewed, Lindner (2019) stated that they revealed the challenges students could face in learning ML, and the strategies instructors may use to help students understand. Lindner (2019) further noted that teachers also told that students' ideas are usually centered on ML characteristics rather than how they work. Interview in this researcher's opinion help in getting the student, instructor, or research participant's main ideas regarding the ML tools used, ML concept treated, or subject of discussion. The individual or group's feelings about the topic can easily be expressed without bias, which can be recorded either in video or audio and transcribed for analysis (Toivonen et al., 2020).

5.4 RQ4. What are the future directions of ML education in K-12?

Several kinds of literature have shown that many attempts had been made to develop and improve the teaching of ML in K-12 education recently, to build ML K-12 curriculum and integrate it into the K-12 educational system (Sanusi et al., 2020; Tedre et al., 2020; von Wangenheim et al., 2020; Sanusi et al., 2021). The future direction of ML in K-12 education could depend on the country or region of implementation. This is based on researchers' opinion because, as identified in this study, some countries have a limited number of publications in ML K-12 education-related articles while some countries have more publications. Although the ML K-12 education field generally requires more research in teaching tool design, Sabuncuoglu (2020) suggested that future studies should develop a digital task interface, including teacher and students' progress activities. Gresse von Wangenheim et al. (2021) also indicated that further research should concentrate on designing ML tools that focus on K-12 educational areas which offer better guidance on effective implementation of ML tools to schools and their improvement to aid comprehension in the learning process. Additionally, further study is required in curriculum design for K-12 ML education. Likewise, studies were also required for pedagogical development and gathering K-12 education stakeholders' perceptions of the field to help further development study.

6 SUMMARY AND CONCLUSION

6.1 Summary and conclusion

In this review study, the researcher analyzed the status of ML in K-12 education and how it globally developed over a decade (between 2011 and 2021). The researcher discovered the importance of the field studied by the recent significant rise over the years, which started in 2018. Many authors published only one or two papers, seeing that 133 authors were the publishers of the 50 papers reviewed in this study. This revealed that teaching ML to K-12 is not an isolated field of research rather a fast-growing field of study.

However, the primary source of this study were conference proceedings and journal publications on related articles on K-12 ML education between 2011 and 2021. The majority of identified papers were conference proceedings (58%). All the articles published between 2011 and 2018 were conference proceedings; these imply that the field was gradually developing. The first journal article on related K-12 ML education topics was published in 2019. By 2021 more journals were published on the subject area compared to previous years. This could be because further studies were conducted on conference proceedings to improve and implement it.

Furthermore, the fifty relevant studied articles publishing countries or conference location countries were nineteen different countries. While this shows variations, our study indicates that USA, Germany, and Switzerland led most countries that are influential, all on this topic, whereas there is sparsely output from others. Out of the two top publishing countries, the USA commenced publication in 2019 and continues to have a growing number of published articles each year. Germany started publication in 2020 with two articles and multiplied its output three-fold in 2021. Many countries join the number of publishing countries in 2020 and 2021, predominantly European countries. The most articles were published between 2020 and 2021: peradventure, the publication trend between 2020 and 2021 continues. Countries would have become more knowledgeable in the field, and ML for K-12 education would have matured to a state where most countries would have implemented ML teaching to K-12 students.

ML K-12 education study is primarily a practical field , demonstrated through different identified research methods. For instance, qualitative study (explorative and interview), design-based research, and quantitative research. The essential research method adopted in teaching ML to K-12 student-related articles were qualitative research techniques, while the least research method used is game-based study. The shortcoming identified is that most of the practical studies use few numbers of participants; this poses a limitation to the functional relevance of their discovery and could pose difficulty if generalized.

Although, this study concentrated on identifying the different grade levels as described in the relevant articles. The grade level eminently studied was high school; these were reviewed by 28% of all evaluated articles. Likewise, 26% of the studied papers do not specify the grade level in which the research was based, including literature revied papers. The middle school study experience was 16%, while elementary school was the least studied. This implies that more study is required in elementary and middle school. Other studies combined two or more grade levels during their research. Furthermore, 10% of the identified research combined High school and elementary school, while the combination of elementary and middle school had 2% study, likewise elementary, middle, and high school were studied by 2%.

Considering the author's country, twenty-one different authors' countries were discovered in this study. Meanwhile, the author's countries were the USA, Turkey, Israel, Finland, Denmark, Sweden, China, Germany, Spain, Argentina, Estonia, India, Kazakhstan, Austria, Japan, South Korea, Ecuador, Belgium, Slovakia, Hong Kong, and Brazil. Meanwhile, the USA had the highest number of publishing authors in this field, followed by Finland, China, and Spain. In contrast, lower article publishing authors' countries were Argentina, Ecuador, Japan, Estonia, Belgium, Denmark, Slovakia, Kazakhstan, Turkey, South Korea. in this field.

In this study, all identified data collection methods were summarized to eight for clarity. They are as follows: interview, survey, secondary data, observation, questionnaire, exercise, final project, and student design. A minority of the studied literature used student exercise to collect data, while the majority of the articles used interviews. Many researchers also use secondary data (22.2%), surveys (15.9%), and questionnaires (14.3%). Only a few articles use students' to exercise and final project as a means of data collection.

Presenting various kinds of teaching activities used in different research articles studied. Plugged activities were the most highly utilized in this review, whereas unplugged activities were only used by 12%. However, 16% of the identified papers combine plugged and unplugged activities. Likewise, about 4% of the studied papers combined unplugged and robotics as their study activities. Some articles did not specify the type of activities used in their studies. This analysis implies that teaching ML to K-12 requires more plugged activities. Plugged activity teaching aid tools and equipment will be more needed for further future studies in ML K-12 education. Additionally, more studies are required in using Unplugged activities in K-12 education; this will help teach the K-12 student ML in an environment where there is not much access to plugged activities facilities.

Intriguingly, several study settings used in the identified articles were studied: workshop, classroom, summer program, weekly program, and non-school settings. Although some papers did not specify the study activities, these are classified as not specified. The study revealed that most of the study settings identified in this review utilized workshops (38%), followed by classrooms (20%), then online (8%), and summer programs (4%). The lowest study activity used as identified in this review is the weekly program.

Finally, the K-12 ML education field covers several topics, although all the topics identified in this study were perceivably generalized into four different topics. Pedagogies topics were the most studied topics in K-12 ML education. It was studied by 36% of the articles, while the second top studied topic perceptions were analyzed by 28%. Tool designs topics were merely studied by 20%, and the list reviewed topic was curriculum design study of 16%. Most pedagogy topics were studied between 2020 and 2021, while perception and curriculum design topics were mainly studied in 2021. However, the tool design had its peak study in 2020. This revealed that nearly all explored topics took place between 2020 and 2021. Only a limited number of topics were studied between 2011 and 2019. Additionally, more studies are required in tool design and curriculum design for teaching ML in K-12. Also, more game-based design research is needed for teaching ML concepts and ideas to K-12 students.

6.2 Review limitation

This review study is, however, subjected to some limitations. Part of the limitations is that the primary author singlehandedly conducted the process of categorizing all the scientific papers; likewise, the research team usually does the relevance assessment. The data extraction stage is critical to the discovery's validity and the accurate representation of the findings in the field. This study focuses on making the review process translucent and allowing other researchers to examine, inspect or assess the results. Although replicating research work is a personal interest, it is essential to make this research work relevant to ML K-12 education researchers. Meanwhile, many fascinating discoveries were made; it would be a loss if the findings were not published.

Furthermore, the limitation is excluding relevant articles published in other languages rather than English. This has limited the possibilities of discovering more topics that might have been dealt with in the different languages; this limitation affects these findings negatively. The search restriction to only these four databases (IEEE Xplore, web of science, ACM, and Scopus) may not give all the relevant scientific papers.

6.3 Directions for future research

Future research should be conducted to address the limitations in this review by replicating fully or partially this literature review work for validation of the findings discovered in work. However, fully replicating should consider putting into account the limitations in this study such as performing the analysis alone and limiting the study to articles published in the English language from the four databases, possibly using mainly the four-database used in this study with the excellent quality requirement, which may be strict for infant fields.

It is expedient to replicate this review study in a few years to encourage discovering how the field of K-12 ML education will row after 2021. Since the trend recently has been studied, for example, the direction of the publishing countries, authors country, and the time intervals, the different grade level studied compared with the time interval, the study activities, and the type of research method adopted, etc., all as identified in this study. However, this can be different in subsequent years after 2021.

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APPENDIX

Appendix A1

Authorship with yearly publication

Authorship	Frequency	Percentage%	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	Total
Eight Authors	1	2		1										
Seven Authors	3	6	2	1										
Six Authors	8	16	4	4										
Five Authors	3	6	2		1									
Four Authors	7	14	4	1	2									
Three Authors	11	22	3	6		1		1						
Two Authors	10	20	4	2	3							1		
Single Author	7	14	3	4										
Total	50	100	22	19	6	1		1				1		50

Appendix A2

Top publishing authors

Authors	Publications
Matti Tedre	5
Ilkka Jormanainen	5
Henriikka Vartiainen	5
Teemu Valtonen	5
Tapani Toivonen	4
Juho Kahila	4
Gerald Steinbauer	4
Martin Kandlhofer	4
Fredrik Heintz	3
Ismaila Temitayo Sanusi	2
Annabel Lindner	2

Marc Berges	2
Julian Estevez	2
Gorka Garate	2
Thomas K. F. Chiu	2
Tara Chklovski	2
Sven Koenig	2
Christiane Gresse Von Wangenheim	2
Juan David Rodríguez García	2
Jesús Moreno León	2
Marcos Román González	2
Gregorio Robles	2
David Touretzky	2
Christina Gardner-Mccune	2
Fred Martin	2

Deborah Seehorn	2

Appendix A3

Number of papers published by each author

Number of papers published by Authors	Total	Percentage
Single paper authors	107	80,5
Two papers	17	12,8
three papers	1	0,8
four papers	4	3,0
five papers	4	3,0
Total number of Authors	133	100

Appendix A4

Publishing countries

Publication/Conference Countries	Frequency	Percent	2021	2020	2019	2018	2016	2012	Total
Austria	1	2%					1		
Canada	2	4%		1	1				
Croatia	1	2%		1					
Cyprus	1	2%			1				
Estonia	1	2%		1					
Finland	1	2%			1				
France	1	2%		1					
Germany	10	20%	8	2					
Hong Kong	2	4%	1		1				
Indonesia	1	2%	1						
Israel	1	2%						1	

Italy	1	2%	1						
Japan	1	2%	1						
Netherlands	1	2%		1					
Norway	2	4%		2					
Sweden	4	8%	1	3					
Switzerland	7	14%	5	2					
UK	2	4%		2					
USA	10	20%	4	3	2	1			
Total	50	100%	22	19	6	1	1	1	50

Appendix B1

Grade level with year of publication

Grade levels	Number of Articles	Percentage	2021	2020	2019	2018	2016	2012

Elementary school	7	14 %	8	4	2			
Middle school	8	16 %	6	4				
High school	14	28 %	6	7	4	1	1	1
K-12	13	26 %	8	4	1			
High and elementary school	5	10 %	3	1	1			
Elementary and middle school	1	2 %						
Elementary school and middle school and high school	1	2 %	1					
Not specified	1	2 %						
Total	50	100 %						

Appendix B2

Authors country and year of publication

Authors Countries	Number of Publication	Percentage	2021	2020	2019	2018	2016	2012	Total
USA	11	18.0%	5	5	1				
Turkey	1	1.6%		1					
Israel	2	3.3%	1					1	
Finland	8	13.1%	3	4	1				
Denmark	1	1.6%	1						
Sweden	4	6.6%	4						
China	6	9.8%	3	3					
Germany	3	4.9%	2	1					
Spain	6	9.8%	3	2	1				
Argentina	1	1.6%				1			
Estonia	1	1.6%	1						

India	3	4.9%		2	1				
Brazil	2	3.3%	1	1					
Kazakhstan	1	1.6%		1					
Austria	4	6.6%	3				1		
Japan	1	1.6%	1						
South Korea	1	1.6%	1						
Ecuador	1	1.6%	1						
Slovakia	1	1.6%		1					
Belgium	1	1.6%	1						
Hong Kong	2	3.3%	1		1				
Total	61	100%	32	21	5	1	1	1	61

Appendix B3

Types of activities identified and year of publication

Type of activities	Frequency	Percentage	2021	2020	2019	2018	2016	2012	Total
Plugged	24	48%	10	8	5			1	
Unplugged	6	12%	4	2					
Plugged and unplugged	8	16%	2	5		1			
Not specified	10	20%	6	4					
Unplugged and robotic	2	4%			1		1		
Total	50	100%	22	19	6	1	1	1	50

Appendix B4

Types of study settings identified and year of publication

Study settings	Frequency	Percentage	2021	2020	2019	2018	2016	2012
Workshop	19	38%	7	7	4	1		
Classroom	10	20%	4	3	2			1
Summer program	2	4%%		2				
Online	4	8%	4					
Not specified	13	26%	7	6				
Weekly Courses	1	2%					1	
Non school settings	1	2%		1				
Total	50	100%	22	19	6	1	1	1

Appendix C1

Research method per year of publication

Research Strategies/Methods	Frequency	Percentage	2021	2020	2019	2018	2016	2012	Total
Game-based	2	4%		2					
Qualitative	17	34%	9	5	3				
Quantitative	5	10%	2	3					
Mixed	6	12%	3	1		1		1	
Design-based	7	14%	3	2	2				
Literature review	13	26%	7	4	1		1		
Total	50	100%	24	17	6	1	1	1	50

Appendix C2

Data collection per year of publication

Data collection methods	Frequency	Percentage	2021	2020	2019	2018	2016	2012	Total
Secondary data	14	22.2%	7	4	2		1		
Interview	15	23.8%	8	5	2				
Observation	8	12.7%	5	2				1	
Questionnaire/survey	9	14.3%	3	2	2	1		1	
Survey	10	15.9%	4	6					
Exercise	1	1.6%		1					
Student design	4	6.3%	2	2					
final project	2	3.2%	1	1					
Total	63	100%	30	23	6	1	1	2	63

Appendix C3

Topics per year of publication

Topics	Frequency	Percentage	2021	2020	2019	2018	2016	2012	Total
Tool design	10	20%	3	6	1				
Curriculum design	8	16%	4	2			1	1	
Perception	14	28%	7	3	3	1			
Pedagogies	18	36%	8	8	2				
Total	50	100%	22	19	6	1	1	1	50

Appendix C4

Title of Article	Topics	Year of publication	Publication/ Conference location Country
Designing a Collaborative Game-Based Learning Environment for AI-Infused Inquiry Learning in Elementary School Classrooms	Tool design	2020	Norway
Designing One Year Curriculum to Teach Artificial Intelligence for Middle School	Curriculum design	2020	Norway
Engaging Teachers to Co-Design Integrated AI Curriculum for K-12 Classrooms	Curriculum design	2021	Japan
Machine Learning for High School Students	Perception	2019	Finland
Teaching Machine Learning in K-12 Education	Perception	2021	USA
Integrating AI and Machine Learning in Software Engineering Course for High School Students	Curriculum design	2012	Israel

SmileyCluster: Supporting Accessible Machine Learning in K-12 Scientific Discovery	Tool design	2020	UK
Votestrates ML: A High School Learning Tool for Exploring Machine Learning and its Societal Implications	Tool design	2021	Switzerland
Teaching Machine Learning in K-12 Classroom: Pedagogical and Technological Trajectories for Artificial Intelligence Education,	Perception	2021	USA
Thoughts on Application of Artificial Intelligence in Teaching of Different Disciplines	Perception	2020	Netherlands
Machine Learning Introduces New Perspectives to Data Agency in K-12 Computing Education	Perception	2021	Sweden
Teachers’ Perspectives on Artificial Intelligence	Perception	2019	Cyprus
Pedagogies of Machine Learning in K-12 Context	Pedagogy	2020	Sweden

Gentle Introduction to Artificial Intelligence for High-School Students Using Scratch	Pedagogy	2020	USA
Why Are We Not Teaching Machine Learning at High School? A Proposal	Perception	2018	USA
A Holistic Approach to the Design of Artificial Intelligence (AI) Education for K-12 Schools (2021)	Curriculum design	2021	Hong Kong
Education in Artificial Intelligence K-12 (2021).	Pedagogy	2021	Germany
Exploring Teachers' Perceptions of Artificial Intelligence as a Tool to Support their Practice in Estonian K-12 Education (2021).	Perception	2021	Germany
Influence Factors of Using Modern Teaching Technology in the Classroom of Junior Middle School Teachers Under the Background of Artificial Intelligence—Analysis Based on HLM (2021).	Perception	2020	Switzerland
Applicational Status Analysis of Artificial Intelligence Technology in Middle School Education and Teaching (2021).	Pedagogy	2020	Switzerland

Expansion of an evidence-based workshop for teaching of artificial intelligence in schools (2021).	Pedagogy	2021	Switzerland
A Preliminary Work on Visualization-based Education Tool for High School Machine Learning Education (2020).	Tool design	2020	USA
Lessons learned from teaching machine learning and natural language processing to high school students (2020).	Pedagogy	2020	USA
Teaching explainable artificial intelligence to high school students (2020).	Pedagogy	2020	France
Teaching machine learning in school: A systematic mapping of the state of the art (2020).	Pedagogy	2020	Germany
The use of machine learning "black boxes" explanation systems to improve the quality of school education (2020).	Tool design	2020	UK
Focusing on Teacher Education to Introduce AI in Schools: Perspectives and Illustrative Findings (2019).	Perception	2019	USA

Developing Computational Thinking at School with Machine Learning: An exploration	Tool design	2019	USA
Classroom activities for teaching artificial intelligence to primary school students (2019).	Pedagogy	2019	Hong Kong
Envisioning ai for k-12: What should every child know about ai? (2019).	Pedagogy	2020	Canada
IRobot: Teaching the basics of artificial intelligence in high schools (2016).	Curriculum design	2016	Austria
A Differentiated Discussion About AI Education K-12	Perception	2021	Switzerland
Current situation of artificial intelligence education in primary and secondary schools in China (2021).	Perception	2021	Indonesia
Early Introduction of AI in Spanish Middle Schools. A Motivational Study (2021).	Pedagogy	2021	Germany

Contextualizing AI Education for K-12 Students to Enhance Their Learning of AI Literacy Through Culturally Responsive Approaches (2021).	Curriculum design	2021	Germany
Analyzing Teacher Competency with TPACK for K-12 AI Education	Pedagogy	2021	Germany
Neural Network Construction Practices in Elementary School	Tool design	2021	Germany
Evaluation of an Online Intervention to Teach Artificial Intelligence with LearningML to 10-16-Year-Old Students	Pedagogy	2021	USA
Surveying Teachers' Preferences and Boundaries Regarding Human-AI Control in Dynamic Pairing of Students for Collaborative Learning	Tool design	2021	Italy
Machine learning for middle-schoolers: Children as designers of machine-learning apps	Tool design	2020	Sweden
Can you explain AI to me? Teachers' pre-concepts about Artificial Intelligence	Perception	2020	Sweden

Artificial intelligence - A new topic in computer science curriculum at primary and secondary schools: Challenges, opportunities, tools and approaches	Curriculum design	2020	Croatia
Learning machine learning with very young children: Who is teaching whom?	Pedagogy	2020	Germany
Co-designing machine learning apps in K-12 with primary school children	Tool design	2020	Estonia
AI K-12 Education Service	Pedagogy	2021	Switzerland
A Year in K-12 AI Education	Pedagogy	2019	Canada
Teaching Artificial Intelligence to K-12 Through a Role-Playing Game Questioning the Intelligence Concept	Curriculum design	2021	Germany
Visual tools for teaching machine learning in K-12: A ten-year systematic mapping	Pedagogy	2021	Switzerland
Three Interviews About K-12 AI Education in America, Europe, and Singapore	Pedagogy	2021	Germany

Perceptions of and Behavioral Intentions towards Learning Artificial Intelligence in Primary School Students	Perception	2021	USA