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Educational Robotics: Platforms, Competitions and Expected Learning Outcomes

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ABSTRACT Motivated by the recent explosion of interest around Educational Robotics (ER), this paper attempts to re-approach this area by suggesting new ways of thinking and exploring the related concepts. The contribution of the paper is fourfold. First, future readers can use this paper as a reference point for exploring the expected learning outcomes of educational robotics. From an exhaustive list of potential learning gains, we propose a set of six learning outcomes that can offer a starting point for a viable model for the design of robotic activities. Second, the paper aims to serve as a survey for the most recent ER platforms. Driven by the growing number of available robotics platforms, we have gathered the most recent ER kits. We also propose a new way to categorize the platforms, free from their manufacturers' vague age boundaries. The proposed categories, including *No Code*, *Basic Code*, and *Advanced Code*, are derived from the prior knowledge and the programming skills that a student needs to use them efficiently. Third, as the number of ER competitions, and tournaments increases in parallel with ER platforms' increase, the paper presents and analyses the most popular robotic events. Robotics competitions encourage participants to develop and showcase their skills while promoting specific learning outcomes. The paper aims to provide an overview of those structures and discuss their efficacy. Finally, the paper explores the educational aspects of the presented ER competitions and their correlation with the six proposed learning outcomes. This raises the question of which primary features compose a competition and achieve its' pedagogical goals. This paper is the first study that correlates potential learning gains with ER competitions to the best of our knowledge.

INDEX TERMS Educational robotics, educational robotics learning outcomes, educational robotics competitions, educational platforms.

I. INTRODUCTION

Educational Robotics (ER) is defined as a ''research field aimed at promoting active, engaging learning through the artifacts students create and the phenomena they simulate'' [1]. More specifically, ER is a field of study that aims to improve the learning experience of students through the creation, implementation, improvement, and validation of pedagogical activities, tools (e.g., guidelines and templates), and technologies, where robots play an active role, and pedagogical methods inform each decision [2]. ER has emerged as a unique learning tool that can offer hands-on, fun activities in an attractive learning environment feeding students interest and curiosity [3].

Over the years, several robot construction kits have been specifically designed for educational and special education use [4], [5]. The robots' morphology may be static or variable, allowing the student to build, plan, and program different kinds of robotics artifacts that have been designed to follow the learning principles derived from Piaget and Papert's theories [6]. Constructivism and constructionism theories are particularly bearing for the field of educational exploitation of robotics. According to Piaget, in the constructivist approach, learning is a result of mental construction by the learner [7], [8]. Papert [9] extended Piaget's theory of constructionism by creating the learning theory of

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constructionist learning and the creation and development of the LOGO programming language and the floor robotic device he named 'Turtle'. Papert argued that students learn by doing that allows them to construct their knowledge by interacting with objects. Analytically, students construct their conceptualizations through their experiences gained from the real world. Besides, he argued that learning is accomplished when the child builds a robotic structure. The construction process allows the child to invent from the beginning techniques and ways of solving problems that enhance problem-solving and reasoning skills [10]. Through constructionism theory, Papert gave a slightly different perception of learning, where learners construct knowledge and meaning through making or tinkering with a tangible object or an entity [11].

Robotics has been endorsed by many researchers as an innovative learning tool, able to transform education and support students in many learning contexts. Many studies indicate that robotics is a supporting tool for teaching subjects related to the robotics fields, such as programming, construction, or mechatronics [12], [13]. Moreover, the integration of artificial intelligence in educational robots results to intelligent teacher assistants which can be used to undertake different teaching tasks, such as teaching students to read and pronounce words [14], [15]. ER involve a synthesis of many interdisciplinary activities from various areas, including mathematics and physics, design and innovation, electronics, computer science and programming, and psychology [6]. With robotics, students work on real-world applications of engineering and technology concepts, and the abstractness of science and mathematics is removed [16]. Thus, according to researchers, robotics is introduced as special educational leverage as they mitigate the lack of students' interest in STEAM (Science, Technology, Engineering, Art, and Mathematics) topics. At the same time, they motivate them to pursue a career in one of these fields [16]–[18]. Moreover, several studies show that, even when students are not interested in robotics or technology, they are motivated when robotics are used as a teaching tool [12], [13].

Through hands-on robotics activities, students are transformed into active learners able to develop essential skills by acting as researchers. They explore, make hypotheses, conduct experiments, and receive feedback from their physical work [18] increasing their critical thinking, problem solving and meta-cognitive skills [13], [17], [19], [20]. The hands-on nature of ER constructs a fun, playful, and exciting learning environment that motivates students to engage in learning. As a result, students advance their self-confidence, decision-making, self-direction, creativity, and innovation [13]. Research also reports a positive impact on students' social learning when robotics are used in the classroom [6], [20], [21].

Robotics exists in education since the late 80s, but they have only gained so much attention from educators due to a combination of factors. First, constant technological advances accelerated the speed of innovation faster than ever before. Eguchi [22] characterized students as 'digital natives' who are growing using technology. As the modern technology environment must be reflected in the content of school education, education has reformed to keep up with the societal and technological changes [23], [24]. Educators boost their teaching, with new features and ideas such as game-based learning, interactive methods, and virtual classes. Bragg [25] in his research, found that game-based lessons led to 93% of class time spent on class tasks. He also pointed out that 34 % of the conversation time was dedicated to math when games were used, compared to 11% when they were not [26]. Takeuchi and Vaala [27] surveyed 700 teachers to found that 74% of them have used digital game-based learning to enhance their lessons. Barth [28] research exposed a 38% increase in virtual school enrolment in only two years between 2011 and 2012, and 47% of the students engaged in online courses according to research in the period 2007-2009 [29]. Also, several educational movements, such as the Hour of Code, strengthen educational innovation. During the first Hour of Code event in 2013, 15 million students from 170 countries participated in online programming activities. Educational programs had to adapt to the changes [22]. Simultaneously, robotics has been integrated into all society levels and has become a benchmark of science and technology. As technology shapes learning and teaching processes, educators utilized robotics as a useful add-on to learning.

Besides, the young generation should stay competitive by effectively forming the knowledge, abilities, and competencies to participate in society. Eguchi and Uribe [24], in their research, pointed out the need for STEAM education to meet the needs of a STEAM-educated workforce and the development of a STEAM literate public. Additionally, the Office of the Chief Economist's research presents faster-growing employment in STEAM occupations than in non-STEAM occupations over the last decade [30].

Moreover, ER has been attracting more attention because of the increased availability of robotics platforms and programs suitable for students of different ages and intellectual levels [31], [32]. During the early 2000s, students had very few available options for robotics kits. However, with the development of less expensive robotics kits and devices like Arduino and Raspberry Pi, more students had access to more advanced tools [24]. As a result, the robotics kits' cost has dropped exponentially, making them accessible to schools with even modest budgets [33]. Almost all of the available robotics kits offer different options of programming through free applications [34].

Another reason influencing the trend mentioned above is the growing number of robotics competitions, tournaments, and events [35], [36]. Over the years, the number of participants in the robotics competitions has grown as well. Today, hundreds of thousands of students participate in a wide variety of educational robotic competition programs. For example, in 2017, 584 teams participated in the World Robot Olympiad (WRO) in Germany, comparing to 32 teams who participated five years earlier [36]. In the same year, 18,000 teams from 40 countries competed in virus robotics challenges during the VEX competition [37]. Each competition has unique features with a variety of activities. Competitions' differences are mainly found in the target audience, the pedagogical goals, the organizational background, and the target region [38].

Despite their differences, robotic competitions bring together researchers, students, and robot enthusiasts. By pursuing a technological challenge, robotic competitions can benefit both the research community and education [13]. Those events foster or initiate research to STEAM relevant topics, and under some conditions, they can also consider as benchmarks for objective performance assessment. Moreover, to support research, many competitions require the winning teams to share their systems' technical details of their systems publicly [39], [40]. Some robotic competitions are embedded in technical conferences where participants and researchers can present and discuss related ideas and methods [39], [41].

Based on the literature, educational robotics competitions positively impact education for all the participants, including students, teachers, and mentors [36], [42]. ER competitions as a goal-oriented approach to teaching, impact education on various levels [11], [31], [43], [44]. Most of the competitions primary goal is to promote students' interest in STEAM domains and increase their likelihood of considering STEAM professions later in life [37], [45]–[47]. As preparing future STEAM professionals has become a growing concern for educators and researchers, robotics competitions are integrated into classrooms as an educational activity or as a part of the curricula [48]–[51]. According to a survey from the FIRST robotic competition, 69% of the students who participated in the competition from 2002 to 2005 were interested in pursuing a career in science and technology [35]. Simultaneously, students become confident in using technology and widening their knowledge of physics, programming, mechanical engineering, electronics, and science [42]. Studies on educational robotics competitions also highlight that a well-designed challenge provides an environment for learning problem-solving techniques, promoting creative thinking, brainstorming, critical thinking, and creativity [52].

Robotics competition have proven to increase motivation, engagement, self-determination, self-confidence and self-efficacy [13], [42], [49], [52], [53]. Murphy [54], in her article, supported that a competition must be seen as an opportunity for intellectual growth, according to Perry's model of intellectual development. Students within a competition can mature, through the nine stages of increasing complex reasoning based on Perry's model, to finally accept that there may be more than one right answer to a given problem. However, some education psychologists suggested that competitions may sometimes be harmful to many students' self-esteem. In most cases, there is only one winner in the competitions and several losers [39].

Robotics contests, support team-based learning and enhance skills of communication and personal development, as they require from students to work in teams or allow inter-team alliances [16], [42], [48], [50]. Additionally to the results of the FIRST survey mentioned above, concerning team working, results showed that 95% of the students recognized the value of working on a team, and 83% of them realized the importance of grate professionalism [35]. Competitions that require alliances between the teams help participants enhance their leadership skills and develop responsibility and strategy making skills. Even though collaboration allows individuals with different skills to work together, to achieve a larger goal, a careful balance of competition and collaboration must be achieved to be effective [16], [55].

Competitions are a tool to support and strengthen education, especially in concepts related to technology such as robotics. While competitions are closely related to winning, when it comes to education, the focus is concentrated on teaching the methods that ultimately lead to success [54]. Thus, some characteristics of the robotics competitions such as the competition design, the competitive nature of the activities, the teacher's role, and the applied teaching pedagogy are crucial for a competition to be beneficial for the students [13], [56].

It is worth noticing that this work does not constitute a systematic review of the related literature, rather an attempt, to propose an updated definition and re-approach the field of ER. This paper takes into account the current state of the art, the continuously evolved platforms and investigates the correlation of the learning outcomes that a student is expected to gain from an educational robotics-related activity such as the robotics competitions, a subject of growing interest.

More precisely, Section III proposes a set of 6 key learning outcomes that a student is expected to gain upon completion of an educational robotics-related activity. Section IV categorizes the most recent ER kits based on three new categories, the first time proposed in this paper: No Code, Basic Code, and Advanced Code. In Section V, the most popular robotic events and competitions are overviewed, followed by the correlation of the competitions with the proposed set of expected learning outcomes. In Section VI, the correlation of the learning outcomes with the competitions is being presented based on each competitor's characteristics, rules, and goals. Finally, in Section VII correlates the proposed learning outcomes with the ER competitions.

II. METHODOLOGY

This section briefly presents the adopted methodology and procedures, highlighting how these contribute to the aims and objectives of the study. Even if the relevant literature was selected using systematic techniques, the work described in this paper is not intended to serve as a systematic review of the ER literature; but rather as a compilation of evidence that educational robotics can contribute to the educational procedure.

The literature review in the domain under study involves a keyword-based search for a peer-reviewed journal and conference articles which was performed from the scientific databases IEEE Xplore, Scopus and Google Scholar. Google Scholar was also used to evaluate the impact of each article, taking into account the number of citations is has.

A. PURPOSE OF THE STUDY

This paper aims to re-approach the continually evolving field of ER, through the analysis of its related concepts. More particularly, our study focuses on the learning outcomes that a student is expected to develop by engaging in educational robotics-related topics, the available ER platforms, the most popular robotics events and their educational aspect. This paper can be considered as an essential guide for future readers that wish to use robotics in the education sector. Through the study of an extensive list of learning outcomes found in the literature, the paper proposes a set of six learning outcomes that a student expects to gain by participating in an ER activity. The proposed learning outcomes can be used as the basis for the design of practical robotic related courses.

At the same time, the paper offers a detailed overview of the most recent ER platforms. It proposes three new categories to differentiate them, based on students' prior knowledge and skills in programming. Students' interests, motivation and involvement in learning can be influenced by the difficulties faced in the teaching process. This categorization can support ER educators in choosing the most appropriate robotic tools for teaching their students efficiently.

Also, through robotic competitions, students can develop or improve specific skills. While perceiving robotic events as an additional teaching method, the paper presents some of the most popular robotic events and describes their challenges and characteristics. The paper also discusses their efficacy by evaluating competitions concerning the proposed learning outcomes. To the best of our knowledge, this is the first approach that aims to generalize the correlation between the learning outcomes that a student is expected to gain from an educational robotics-related activity with the robotics competitions. This is an attempt to explore the primary features that compose a competition, able to achieve its' pedagogical goals. This will benefit ER educators and ER competition organizers who aim to promote specific learning outcomes, as they can embrace the corresponding practices proposed in this paper.

B. ANALYSIS STRATEGY

To examine the parameters that would lead to robust conclusions and support the purpose of the study, we have adopted a four-dimensional analysis procedure.

Aiming to reformulate the definition of Educational Robotics, we have adopted a meta-analysis research approach. This approach takes into account keywords from ER related papers and produces a correlation network and a bibliometric map of them. As search keywords, we used the following query on Scopus digital library, considering three metadata fields: title, abstract and keywords: 'Educational Robots' OR 'Educational Robotics' OR 'Robotics Education' OR 'Robotics Learning' OR 'Robotics Teaching' (hereafter will be referred to the query as Q_1). The 2078 resulted articles were analysed within the framework of a classification scheme, taking into account the keywords given by the authors. This procedure constitutes the first dimension of our adopted analysis procedure. More details are given in Section III.

To investigate the expected learning outcomes we used a meta-analysis of the literature on ER for education that was framed by the following question "*What are the learning outcomes when ER is used?*" following the paradigm of Belpaeme *et al.* [57]. Analytically, for the meta-analysis, we used published studies extracted from the scientific databases IEEE Xplore, Scopus and Google Scholar by using the following search terms: Q_2 =(('Educational Robots' OR 'Educational Robotics' OR 'Robotics Education' OR 'Robotics Learning' OR 'Robotics Teaching' OR 'Competition' (with manual filtering of those relevant to education)) AND 'Outcomes'). The selection of papers was based on specific including and excluding criteria. The including criteria were articles reporting evidence from empirical research. Therefore, studies reporting qualitative or quantitative data were included in the literature. Articles that were reporting participants' belief of what they learned from their experience with ER and did not contain a comparative experiment or evidence on learning outcomes were excluded. In addition, extended abstracts were omitted since they usually contained preliminary findings and not complete results. At first, a total of 57 articles, published in the last five years were selected based on the aforementioned criteria; matching the search keywords. A supplemental review and analysis of these articles, identifying articles that focused on the benefits and effectiveness of the interaction of educational robotics and students from various educational levels and settings resulted in only 14 articles with either qualitative or quantitative information. The learning outcomes of the different studies included both cognitive and affective outcomes. Cognitive outcomes are regularly measured through pre- and posttests of student knowledge whereas affective outcomes are typically measured include self-reported measures and observations by the experimenters [57]. This procedure constitutes the second dimension of our adopted investigation procedure. The result of the analyses of the educational robotics literature is the classification of learning outcomes and is being described in the Section III. It is worth noting that the results of the first dimension of the proposed analysis, in several cases, reinforce and confirm the results of the second dimension of the proposed framework. For example, the meta-analysis of the keywords clearly indicates that there is a strong correlation between ER and 'Computational Thinking'. In the sequel, the meta-analysis of the articles clearly shows that 'Computational Thinking' is one of the expected learning outcomes.

Our third goal was to identify and describe the most commonly used or unique ER platforms. To achieve this goal, we have followed a specific research approach, which consists of a combination of specific queries in scientific and non-scientific databases. This approach shapes the second dimension of our analysis procedure. Initially, this approach takes into account the Scopus digital library results of the query: Q_3 = ((’Educational Robots’ OR ’Educational Robotics’ OR ’Robotics Education’ OR ’Robotics Learning’ OR ’Robotics Teaching’) AND (’Platform’ OR ’Kits’)), considering only keywords of metadata fields. The original search identified 197 English language papers that were further narrowed down to 110, by limiting the search to the last five years. Additional criteria for selecting robotic platforms to be introduced in this paper included their commercial availability, the existence of recent versions that are still available in the market and whether these tools were used as learning platforms. It is worth noting that our objective was to identify and record the ER platforms and not to analyse the methods, the results and the findings of the retrieved articles critically. At the same time, we conducted a similar study on the conventional search engines to discover more ER platforms that the initial investigation on Scopus did not reveal. For those platforms, in the sequel, a more extensive search in other scientific databases (IEEE Xplore, Google Scholar) was done to identify the existence of published studies on them. This paper presents and describes only the platforms that are cited in peer-reviewed published works. Also, with specifically formulated queries in Google Scholar, we have extracted the number of articles referring to each ER platform. More details are given in Section IV, Table 1.

The same research approach was used to gather the most popular robotic events and competitions. The initial query used on Scopus was Q_4 = (’Educational Robots’ OR ’Educational Robotics’ OR ’Robotics Education’ OR ’Robotics Learning’ OR ’Robotics Teaching’) AND ’Competition’) considering only the keywords of the articles. Searches were restricted to peer-reviewed articles written in English and resulted in a list of 81 papers. This number was reduced to 46, as only the papers that were published over the last five years were selected. In parallel, information about robotics competitions was achieved from non-scientific sources and correlated with relevant scientific studies. Again, the retrieved documents were used only as a means of recording and identifying robotics competitions. The analysis, findings, and conclusions of the articles were not the subject of this study. The criteria by which the competitions will be presented in this study include the following: There should be a relevant reference to either the competition or the platforms used by the competition in a scientific article, the participation on the competition should be open, and the competition should be active. Another criterion was their popularity, which is evaluated by the number of participants they have each year.

The forth dimension of the utilised analysis procedure engages a critical analysis of the robotics competitions aiming to highlight their educational aspects. To correlate the proposed learning outcomes (Section III) with the ER competitions (Section V), we estimated the efficacy of each expected learning outcome according to the characteristics, rules, and goals by exhaustively analysing the parameters and the objectives of each competition.

III. EDUCATIONAL ROBOTICS AND EXPECTED LEARNING OUTCOMES

This section attempts to present an updated definition of the scientific field of Educational Robotics is, as well as to present the expected learning outcomes that a student is expected to gain upon completion of educational robotics-related activities.

A. REFORMULATING THE DEFINITION OF EDUCATIONAL ROBOTICS

The 2078 results of the query Q_1 on Scopus revealed that ER is a growing field with the potential to significantly impact the nature of science and technology education at all levels, from kindergarten to university. Figure 1 depicts the number of publications per year that use the terms of the specific query. The reader can easily observe that more than 50% of those articles have been published in the last five years. This observation underscores the growing interest of researchers in the field of educational robotics. Moreover, it is essential to highlight that the articles originate or combine different research areas such as computer science, engineering, social sciences, mathematics, and art & humanities.

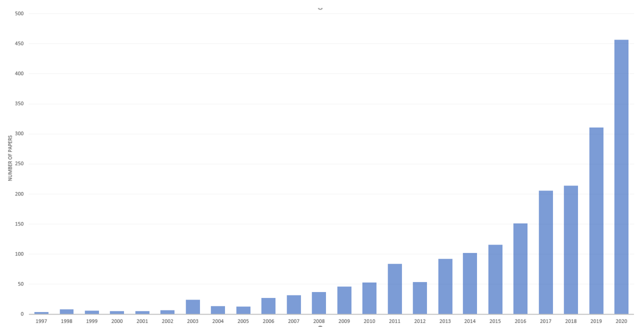

FIGURE 1. Number of Publications Related to Query Q_1 Per Year, Based on Scopus Data.

It is interesting to observe the co-occurrence of the keywords used to index scientific and technical *Educational Robotics* related articles on Scopus. By adopting the method proposed in [58], and taking into account the keyword co-occurrence analysis, a graphical representation of the links between the keywords was produced. This representation is also known as a bibliometric map. Figure 2 illustrates the bibliometric graph representing each keyword, located at a point on a 2-Dimensional plane. The keywords found to co-occur are linked through a line, with width proportional to the co-occurrences, that is to say, the similarity (link strength) between the terms. The distances between the objects are indicators of their dissimilarity.

Based on the bibliometric map, this paper attempts to reformulate the definition of Educational Robotics. By observing

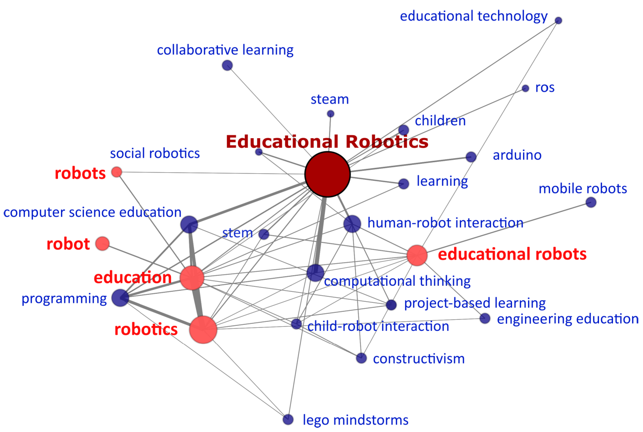

FIGURE 2. **Overview of *'Educational Robotics'* - (Q1) Index Term Bibliometric Map based on Scopus data.**

the connections between the keywords, the authors concluded that:

The Educational Robotics field of study was born, evolved, and flourished at the intersection of educational science and computer science, intending to serve and contribute to both scientific areas. Considering the social nature of the student-robot interaction, the research questions posed by Educational Robotics, implemented by activities designed by the theory of constructionism, focus on the development of computational thinking skills, collaborative learning, and project-based learning. ER, primarily, aims at teaching programming skills, sequencing, coding, and algorithmic thinking. Moreover, as an essential branch of educational technology, the ER field of study seeks to increase traditional teaching practices' efficiency and effectiveness while simultaneously intends to bring pedagogical changes to enhance education.

B. INVESTIGATING THE EXPECTED LEARNING OUTCOMES

The integration of educational robotics in educational settings has been noted both in and out of school environments to enhance K-12 students' engagement and academic achievement in various fields of STEAM [59] and non-STEAM education [60]. Many systematic reviews on educational robotics in diverse educational settings highlight their potential learning gains [61].

Benitti, in her systematic review [12], reported that the learning gains deriving from the use of robotics could be summarized into two categories: (i) the learning concepts/subjects and (ii) the development of skills. The first category describes the acquisition and construction of knowledge from various domains (e.g., mathematics) being taught in multiple educational settings, whereas the second category the development of skills (e.g., communication, collaboration), which are highly appreciated by employers [62].

A number of studies is documenting that the use of educational robotics as a pedagogical tool in curriculum courses or after-school programs promotes the better understanding of abstract concepts from various fields (e.g. [63]–[66]). For example, the interactive nature of educational robotics can aid learners to construct mathematical knowledge through hands-on experience [67]–[69]. Williams *et al.* [70] measured the effectiveness of an afterschool program in implementing hands-on LEGO Mindstorms-based lab robotics activities. Their results documented that learners improved their conceptual understanding of the content in science and mathematics subjects after participating in the activity based on pre- and post-evaluation surveys.

In addition, educational robotics can also be utilized for fostering and promoting the development of skills. These skills vary from thinking skills [71] to problem-solving skills [72] to creativity (e.g., [73]) and teamwork [74]. Also researchers documented that educational robotics enhance motivation [75]–[77], promote collaboration [78], [79] and foster computational thinking [80], [81].

Having thoroughly studied the educational robotics' recent literature, this paper proposes a set of learning outcomes (LO) that should be included and achieved in both formal (e.g., classroom) and informal (e.g., contests and events) K-12 learning environments. In general, learning outcomes represent what is formally assessed and accredited to the student. They offer a starting point for a viable model for the design of activities and courses, which shifts the emphasis from input and process to the celebration of student learning. In other words, the proposed learning outcomes are statements that describe what a student expects to know or what they will be able to do upon completion of an educational robotics' related course or activity. We have identified six learning outcomes. It is worth noting that, although the bibliographic map aimed to reformulate the definition of Educational Robotics, the output in several cases reinforce and confirm the proposed learning outcomes. The proposed learning outcomes are formally analyzed as follows:

- **LO1: Problem-solving skills**
  Researchers have reported that educational robotics can constitute an effective instructional tool for the development of problem solving skills [72], [82]–[84]. Problem-solving skills empower learners to search for a solution for a given problem; therefore, they are considered important cognitive activities. Students are asked to apply knowledge and monitor their understanding of [85]. Atmatzidou *et al.* [72] revealed that students, who were provided strong guidance in solving problems regarding their activities with educational robotics, obtained greater problem-solving skills with the students belonging in the control group. Castledine and Chalmers [82] suggested that educational robotics can be used as a useful problem-solving tool conducting a qualitative study with twenty-three grade six students participating in LEGO robotics activities. Their study included data collected from researcher observations of student problem-solving discussions, collected software programs, and data from a completed questionnaire. The study indicated that the robotic activities helped

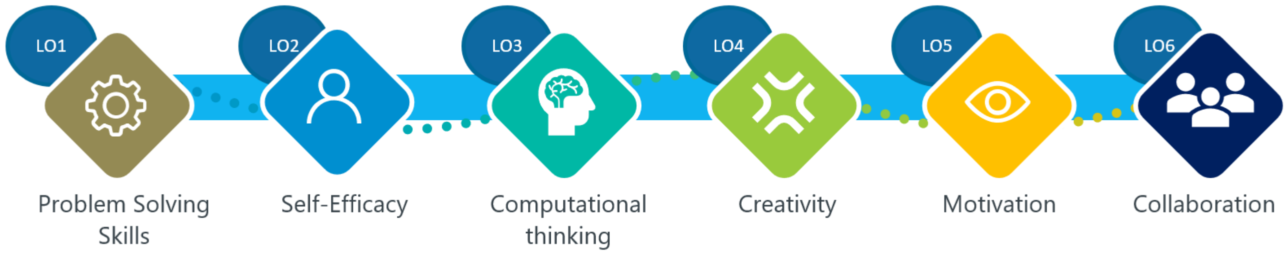

FIGURE 3. The Expected Learning Outcomes.

students reflect on the problem-solving decisions they made. Besides, the authors documented that students with robotic activities could relate their problem-solving strategies to real-world contexts.

At the same time, by observing the terms of the bibliographic map illustrated in Figure 2, one can easily recognise terms, directly or indirectly, related to the 'Problem Solving' definition. For example, the terms 'STEM', 'STEAM', 'Engineering Education' and 'Programming' indicate related to the specific learning outcome activities [86]–[88]. This fact demonstrates that much of the ER literature focuses on aims and objectives that are within the scope of the specific LO.

- **LO2: Self-efficacy**

  Self-efficacy is considered to be among the guiding factors of human activity since it allows a person to estimates what he can accomplish with his skills in a particular task [89]. By studying the relationship between self-efficacy and educational robotics as an instructional approach, Stewardson *et al.* [37] designed research that used robotics and game design to develop middle school students' computational thinking strategies. Their participants were one hundred and twenty-four students that used LEGO EV3 robotics and created games using Scalable Game Design software. The study results revealed students' self-efficacy on video gaming increased significantly in the combined robotics/gaming environment compared with the gaming-only context.

  Meanwhile, trying to investigate correlations between the bibliographic map and the learning outcomes, one could reasonably associate the 'Self-efficacy' with the term 'Constructivism.' Constructivism is a theory of learning according to which, that learners actively construct their knowledge and meaning from their experiences [90]. Educational efforts based on constructivist theory are associated with the self-efficacy beliefs of the students [90].

- **LO3: Computational thinking**

  Computational thinking is being defined as "the process of recognizing aspects of computation in the world that surrounds us, and applying tools and techniques from computer science to understand and reason about natural and artificial systems and processes" [91](p. 29). A large body of literature emphasizes the importance of effective integration of the development of computational thinking in education (e.g. [92]–[94]) since computational thinking is important for educating the next generation of computationally literature students [95] and is enlisted among the 21st century skills [96], [97]. Studies in computational thinking have concluded that educational robotics represent an effective instructional tool for developing the skills of computational thinking. Atmatzidou and Demetriadis [17] in their research used Lego Mindstorms NXT 2.0 educational robotics kit for their training robotics seminars four Junior high and four High vocational schools. Their interventions were conducted during the typical school schedule, and the class teachers helped students with the implementation of their robotics activities. Their results showed that although computational thinking skills need time to develop fully, educational robotics constitute a fruitful and meaningful teaching tool.

  In this case, relating the specific learning outcome to the terms of the bibliometric map is relatively easy, as the term 'Computational Thinking' matches one of the listed keywords. Moreover, the term appears geometrically-related close to the core of the map, indicating a strong correlation.

- **LO4: Creativity**

  ER is an innovative educational technology proven to strengthen student's creativity. Creativity is believed to be directly connected with the mental procedure that permits people to generate mental products such as useful and novel ideas or solutions to problems [98]–[102]. Research testimonies document that robotics' training impacts students' creativity. Badeleh [103] conducted quasi-experimental research with one control and one treatment group with the administration of pretest and posttest. The participants of the study were 120 students from 11th grade. The research data were collected after an eight-session treatment period with a questionnaire. The findings indicated that Robotics training improved creativity and learning in physics among the participants.

  The term 'Creativity' may not be explicitly referred in the bibliometric map as a keyword but is directly related to the terms 'STEAM', 'STEM' and the objectives of the term 'Project-Based Learning' [104]. However, there are keywords that their connection to the specific LO is not so obvious. For example, the terms 'Human-Robot Interaction', 'Social Robot' and 'Child-Robot Interaction' also contribute to this LO. Several studies highlight that children interacting with the highly creative robot formed more ideas, explored more themes of ideas, and generated more creative ideas [105]. Although social robots are not the only way to provide this creativity support through behavioural modelling, they certainly are a compelling way [105].

- **LO5: Motivation**
  Motivation refers to an individual's choice to devote effort to, engage in, and persist at a particular activity [106], [107] as an exemplary study driven by the idea that educational robotics can be a tool to encourage and enhance students' motivation is the empirical study of Aris and Orcos [74]. More specifically, participants in their research were 158 students from the secondary education level and 61 teachers from several schools who participated in the FIRST LEGO League tournaments in 2017-2018. They spent approximately five hours developing robotics projects 12 to 20 weeks. Data consisted of both students' and teachers' answers to questionnaires that documented their perceptions and assessments after participating in the tournament. The researchers concluded that educational robotics promotes high motivation in students and autonomy in decision-making. The findings report that with educational robotics in the learning procedure, it is possible to achieve students' motivation because of mutual interaction with classmates and teachers positively impacts performing practical activities.
  Again, this LO does not match with any of the keywords of the bibliometric map. However, it is directly connected with several included terms such as the 'STEM' and 'STEAM'. STEM and STEAM activities help students to become motivated independent learners-one of the main goals of education [108], [109]. However, the absence of the terms 'Motivation' and 'Creativity' may reveal that researchers take for granted that these learning outcomes arise from their actions and do not focus their efforts to achieve them.
- **LO6: Collaboration**
  Collaboration is being recognized as an essential skill for 21st-century students in working and communication [22]. It is an interpersonal attitude and the most common component that almost every STEM discipline stressed [110], [111]. Collaboration is defined as the process that enables people from the same working environment to complete a task or achieve a predefined goal. In educational settings, collaboration is essential to the fostering of a student's capacity for social interaction. Hwang and Wu [78] designed a study with three different scenarios were students used controlled robots to move dice. The plans were: three students to three robots, three students to two robots, and two students to three robots. The experimental samples comprised sixth-grade students in elementary schools, 16 groups in total, and each group formed three students. The researchers investigated the students' collaborative strategies engaged in the three different scenarios and their behavioral interactions. The results revealed three joint plans the independent-control, the mutual-control, and the coordinator-directed. The study also reported that the students completed a task better with the least required time to adopt the mutual-control strategy.
  The correlation of the specific learning outcome with the terms of the bibliometric map, in this case, is comparatively straightforward, since among the keywords set, the term 'Collaborative Learning' occurs.

IV. EDUCATIONAL PLATFORMS

This section presents and categorizes the most common Educational Robotics kits and platforms. Most manufacturers recommend using their educational robotics tools based on students' ages and the capabilities and difficulties an age group will face when building or programming them. However, when implementing them, those age boundaries are vague as most of the ER kits offer more than one option of programming, like onboard buttons and visual or textual programming, making them suitable for more age groups. Moreover, the programming background of students and their general cognitive skills, in combination with an ER kit that can maintain their interest, can affect their motivation and engagement in learning [17], [112], [113].

Following the above, we have chosen to categorize the ER kits based on the prior knowledge and programming skills a student must have to use them efficiently. In this paper, we propose three categories of robotics: *No Code*, *Basic Code*, and *Advanced Code*.

The 'No Code' category includes all the educational robotic kits programmed with a Tangible Programming Language (TaPL). The program flow can be specified by haptic programmable onboard buttons or physical code cards or bricks that correspond to programming elements and commands. Although no specific programming language or platform is used, students can compose instructions and learn basic programming concepts [114]. Tangible programming languages rely on real-world interaction where students don't use a computer, a mouse, or a keyboard to create their program. In this way, tangible programming languages evoke growth in students' intuitive, everyday knowledge and human abilities to manipulate physical materials to combine objects and program their robot [114], [115].

In the 'Basic Code' category, we categorize the robotics platforms that can be programmed through a Visual Programming Language (VPL). With the VPL, the amount of traditional hand-code writing is reduced as pictures replace the commands. The robotic kits can be programmed through a friendly graphical user interface, with visual programming blocks, a student can drag and drop to compose a program. While VPLs are free of language syntax and semantics, students must still follow some visual form rules. Moreover, students can experiment with their program by merely changing the order or the parameters' values in the graphical blocks [115], [116].

'Advanced Code' Robotics consist of robotics kits that can be programmed with Textual Programming Languages (TPLs). In TPLs, students use linear sequences of text, numbers, and punctuations to create their program [116]. Some of the robotics kits found in this category use interfaces that support professional programming languages, like Java, C, C++, C++, Python, or custom-made text-based applications developed for educational purposes. To create a textual representation of a program follow, students must learn to cope with a broad set of language concepts.

Researchers support that the physical form of the tangible programming languages is perceived as an engaging, easy, and apprehendable way of learning, especially by younger students and novice programmers [114], [115], [117]. In Sapounidis and Demetriadis [117] work, it is highlighted that between the three different age groups (i.e., 5−6, 7−8 and 11−12 years old) which were used to compare two operationally equivalent interfaces - one tangible and one graphical - only the younger students found the tangible interface to be easier. The older students who had more experience characterized the graphical interface as easier. Moreover, studies that compared tangible with visual programming interfaces concluded that even though both are perceived as equally easy, tangible prevails over visual as it fosters collaboration and is found to be more interesting [115], [118], [119]. Regarding gender, Horn *et al.* [120] supported that boys favor graphical interfaces. However, tangible interfaces seem to be equally accepted by both genders, while according to Sapanoudis *et al.* [119] girls were more fascinated by tangible interfaces.

Researchers also compared VPLs with Textual Programming Languages (TPL), and they agree that VPLs are more suitable for beginners as they positively influence their motivation and productivity [112], [113], [116]. VPLs requires less background knowledge of programming while providing an environment with immediate visual feedback that they let the user incrementally and interactively create the program flow [116], [121]. On the other hand, TPLs are more suitable for large scale and complex tasks [112], [116]. With TPLs, advanced students have more opportunities to develop their programming skills and knowledge. Moreover, to advance to professional programmers, they must familiarise themselves with the programming formalism of professional languages that use textual programming languages [112], [116], [121]. Finally, many researchers agree that visual programming languages can be seen as the pathway to textual programming languages [112]. Similarly, the proposed categories 'No Code', 'Basic Code', 'Advanced Code' can correlate with the stages a student must go through to learn to program. Using this distinction and recognizing the students' prior knowledge and programming skills, an educator may select the most appropriate robotic kit for them.

A. 'No CODE' ROBOTICS

Terrapin offers various educational floor robots suitable for three to fourteen-year-old students, including Bee-Bot, Blue-Bot, Pro-Bot, InO-Bot, and Tuff-Bot. Those robots are designed to introduce kindergarten and lower primary school children to basic programming, directional language, and mapping skills [122], [123]. The programming of the robots mentioned above is based on the LOGO programming language. Research testimonies on the LOGO programming language have shown that programming, when introduced with a structured framework, can help students to develop a wide range of cognitive skills, including basic math and language skills, the development of their visual memory [124], and the development of computational thinking. Programming with robots offers a range of observable cause-and-effect actions; it can be used as a platform for engaging children with abstract ideas [125]. Simultaneously, it allows students to develop concepts related to sequence, classification, and logic in accessible ways. In this way, they can apply fundamental concepts of technology and information technology in their contact with the real world [115].

Bee-bot is a robot designed to resemble a yellow bee with black stripes and has seven haptic programming buttons on its surface used to enter up to forty commands. Four of them serve for a backward/forward motion and rotation to the left/right, while the central command key 'Go' can start executing the commands entered by the student. The other two buttons correspond to the 'Clear' command that can clear the robot's memory and the 'Pause' command that can pause the robot for a second while executing commands. Students can enter commands to Bee-bot to make it move on prepared story mats or move through designed routes made with building blocks to reach specific destinations [126]. The length of the robot's step is fixed to 15 cm, and the size of the angle rotation is 90 degrees. Bee-bot notifies the students that it has completed the given sequence of instructions by blinking its eyes and beeping, providing playful and straightforward feedback to the students [127].

Blue-Bot is an advanced version of Bee-Bot that introduces new features such as remote control with Bluetooth connection. It has the same shape and buttons as the Bee-Bot and is transparent so that its components can be seen. It can be programmed by pressing the buttons on the robot's back - like Bee-Bot- or using a suitable application. Its' Bluetooth technology allows students to program the robot through a computer or a tablet or with the use of its custom-made programming bar and the sequential instruction cards [128]. Bee-Bot and Blue-Bot are accompanied by their downloadable tablet apps that enable students to create a program on screen and send it to the robots via Bluetooth. The Blue-Bot TacTile Reader is a hands-on programming device to control Blue-Bot offering extended commands for Blue-Bot, including 45-degree angles and repeat sequences.

Pro-Bot expands learning opportunities provided by the Blue-Bot and Bee-Bot, and it is specially designed for kids from 8 to 10 years old. Unlike the two previous floor robots, Pro-Bot looks like a race car and has a built-in LCD screen and several built-in sensors like touch, sound, and light sensors. Students can enter commands via a set of arrows and number keys mounted on the robot's back. Unlike Bee-Bot and Blue-Bot in Pro-Bot, arrow keys can be combined with the number buttons with distances entered for movement and degrees entered for turns. Students transition smoothly from one mode to another as their skills develop. They also can program the robot with the Terrapin Logo coding application based on the Logo language [129].

Tuff-Bot (the Rugged Robot) is a robot that differs from the previously mentioned, It also has multiple speeds that make it operationally adaptable in a range of environments with 20cm travel distance for each step and can store up to 256 steps. It can be programmed via onboard buttons and remotely via a free downloadable tablet app or the TacTile Reader. Finally, it includes recordable messages to confirm when commands have been entered and a hole to insert the camera mount.

Due to their ease of use and the fact that they promote students' effective engagement, more educational robots functionally equivalent to Bee-Bot were proposed. Colby is an automated mouse-like educational floor robot with tangible buttons on its surface for programming. It comes with its Code & Go Robot Mouse activity set, consisting of maze grids, parts to create walls and tunnels, 30 double-sided coding cards, ten double-sided activity cards, and a cheese wedge [53].

More advanced programming concepts (e.g., loops, events, conditionals, functions, and variables) suitable for young ages are introduced with similar robots, like Botley The Coding Robot and Sammy Kids First Coding & Robotics. Sammy, peanut butter and jelly sandwich shape robot, uses an optical scanner to read the program through the corresponding physical code cards as it drives over them. Botley can be programmed by entering commands on its remote control Remote Programmer. It has an object detection sensor at the front and a line-following the sensor at the bottom. It can help students follow and remember their program's sequence by using the forty coding cards that mirror each step in their program [130].

Another concept is proposed with Cubetto and KIBO, which are made of tactile and hard-wearing wood. Cubetto robot is a robotic set that includes a wooden cubic device with wheels, sixteen coding blocks (four forward, four right, four left, four-function). A programming table was the sequence of commands being displaced. Cubetto programming is based on lucid language, which is a functional dataflow programming language. Children with ages from three to nine years old use iteration and recursion to navigate Cubetto by placing the coding blocks in the programming table's command lines.

KIBO was created by the Developmental Technologies Research Group at Tufts University and became commercially available through KinderLab Robotics in 2014. KIBO is a robotics construction kit that contains the KIBO robot, tangible programming blocks, and mechanical components such as wheels, motors, light output, and a variety of sensors. The robot contains an embedded scanner than scan the barcodes on the programming blocks. Each programming block is color-coded and represents an action or instruction. Programming is accomplished by connecting interlocking wooden blocks that comprise a sequence of commands followed by the KIBO robot. After a sequence is built, starting with a 'Begin' block and ending with an 'End' block, children scan the set of blocks in sequence using the KIBO's barcode scanner and push a button to see the robot perform the sequence of commands they created [131].

All the aforementioned robots are characterized by programming-learning tools without using screens; therefore, they do not require screen time on a separate computer. Consequently, they innately minimize both the complexities of manipulation and coding comprehension, resulting in reduced cognitive load. Also, because they include a visual interface, face-to-face interactions with teachers and peers can be promoted. This is aligned with the American Academy of Pediatrics' recommendation that young children have a limited amount of screen time per day.

'Cubelets' were manufactured by Modrobotics and are a modular robotic construction kit consisting of various cubes connected via magnets designed to create tangible Microworlds outside of the computer screen. There different categories of cubes implementing different functionalities. Actuation Cubelets include Cubelets with a single wheel, a rotating face, and a lamp. Sense Cubelets include brightness, temperature sensors, a potentiometer (Knob), an infrared distance sensor. Think Cubelets include Inverter, which performs a mathematical operation equivalent to 1-value, a Maximum Cubelet, which forwards only the maximum value that it receives on any of its faces, as well as the Blocker, which only forwards energy, and the passive Cubelet, which forwards both energy and power it receives [132]. Cubelets exchange sensor information and transmit data and power between the blocks [133].

Another straightforward option for young children who don't yet know how to write is Ozobot robots. Ozobot offers two versions for robots, the Bit 2.0 and the Evo. Both of them are compact (2.5 cm tall and 17g weight). While they look alike, Evo features more sensors and technologies than Bit. Ozobots have a polycarbonate shell, two micro motors, a micro USB Port, optical sensors for navigation purpose, color sensors, and LEDs diodes [134]. Evo also includes a speaker, a proximity sensor for detecting objects, and allows Bluetooth connection [135]. Primary students can start programming Ozobots by drawing lines and color codes, called OzoCodes, that Ozobots detect with their sensors. Those drawings are combinations of Black, Blue, Red, and Green color lines that correspond to commands for adjusting their speed direction and timing. Besides drawing on a paper, students can draw their programs or experiment with OzoCodes on a tablet, using the official Ozobot applications. Students can advance their skills by programming their Ozobots with Ozoblocky, a visual programming language similar to Scratch [136], [137].

Edison is an educational robot that can teach programming and robotics to students of any age and skill level. It is small and can be used as a base for building engineering and STEAM projects using its construction kit or any other Lego brick. The robot's sensors can react to sound and light while also following a line or avoiding obstacles. Students, with ages ranging from 4 to 16 years, can program Edison using a variety of programming environments. Younger students can program Edison using a remote control, bar-codes printed on paper, or with the use of the graphic language EdWare, which is a drag and drop programming interface. EdScratch an alternative for older students, is a block-based programming language, like Scratch, which is offered for more complex programming structures. Advanced programmers can use EdPy, a python-like text-based programming language [137].

Lego education, a department in the Lego Group, designed educational robotic kits for different age groups - early learning, primary and secondary school. Starting from preschool, the Lego Education Coding Express uses action bricks to teach young learners coding concepts such as sequencing, looping, and conditional statements. Children can build a train, combine tracks in various shapes and process different exercises in the form of a story, based on their skills and knowledge (beginner, intermediate, or advanced level). By positioning the action bricks on the tracks, they can change the train's behavior, including making it turn the lights on and off or change direction. There is a compatible application and the physical set, allowing the user to further explore in learning through other areas such as music, character, journey, and math. As a result, children can improve their problem-solving skills and their computational thinking. At the same time, they can develop their interpersonal skills, such as collaboration, to advance their confidence and creativity.

B. 'Basic CODE' ROBOTICS

InO-Bot (Input-Output-Bot) is suitable for kids up to 14 years old, and it can be programmed via Scratch programming language. It has two LED headlights, eight multicolor RGB running lights, sounds, and builds in sensors like light sensor, sound sensor, range finder sensor, proximity sensors, and a line follower.

Another family of robots that are ready to program is Dash, Dot, and Cue. Dash and Dot can be used by children as young as six, while for Cue, the age range is 10 to 15 years old. Dash has an infrared (IR) sensor, three proximity sensors, a gyroscope, an accelerometer, and three microphones. Dot is also equipped with an accelerometer that helps detect Dot's movement. Their compatible interface app uses drag and drops code blocks that fit together like puzzle pieces. Cue has the same sensors as Dash, but it can be programmed either with a drag-and-drop block interface using Block or Wonder app or with text coding using JavaScript editor [130].

For primary students ages seven and up, Lego Education designed Wedo 2.0 robotics kit. This kit consists of classic Lego bricks, several mechanical parts, a Lego USB hub, two sensors (one motion sensor and one tilt sensor), and a motor. Students are familiarizing with scientific subjects such as engineering, physics, earth and space science, and life sciences through the available guided and open projects. Students can follow instructions or use their fantasy to create different robots [138]. They can then intuitively program them using the original Lego software or third party coding platforms like Tickle, Tynker, Open Roberta and Scratch. All software solutions use graphical programming blocks representing instructions and helping students program their robot by drag and drop the coding blocks. The WeDo programming environment is a blank canvas with a palette of pictorial coding blocks on the bottom. Students can drag and drop the instructions and combine them to make their robots interact with their environment. Third-party options help students shift from the horizontal icon-based block coding of the LEGO Education WeDo 2.0 app to vertical text-based block coding. However, this combination of text commands, even if they are in an intuitive puzzle piece shape, is more difficult for novice programmers. It is more suitable for students who have used the Lego WeDo software before. Scratch also offers students the opportunity to use extra elements such as the if-then-else statement while only implementing if-statement on the official Lego WeDo software. Students can also create interactive animated stories or games and control them with their physical Lego WeDo build. With all these opportunities, Lego WeDo can be used for different age groups students from novice to more advanced programmers in primary school, to familiarize themselves with computer science concepts, develop critical thinking and problem-solving skills and learn how to collaborate [139].

Following the Lego WeDo concept, Lego Education created its newest robotic kit Lego Spike Prime suitable for grades 6-8. Students on the Lego Spike Prime box can find a set of Lego building elements, including the programmable hub, one large angular motor, two medium angular motors, and three sensors - an ultrasonic sensor, a color, and a touch sensor. Lego Spike Prime hub is more advanced than the Lego WeDo hub. It features six input/output ports, a 5×5 light matrix, Bluetooth connectivity, a speaker, a 6-axis gyro, and a rechargeable battery. Students can program it through the Lego Education Spike App, which is based on the Scratch programming language. Focusing on STEAM learning combined with critical thinking and problem-solving skills, Lego Spike Prime offers the teacher a set of lesson units focusing on different subjects. Unit plants include Invention Squad, Kickstart A Business, Life Hacks, and Competition Ready. Invention Squad aims to teach students the engineering design process, including finding solutions for a problem, making prototypes, testing, and evaluating their solutions. Kickstart A Business helps students develop computational thinking skills and teach them how to decompose a problem, create algorithms, and debug their codes. Life Hacks familiarize students with computer science features like working with variables, operations, arrays, and qualitative and quantitative data. Finally, the Competition Ready unit helps students implement all the knowledge conquered from the previous units by building and programming robots for competitions. This unit also teaches the students how to collaborate with others while working in teams to complete their missions.

Lego Mindstorms EV3 is one of the most popular and widely used robotics kits in education for grades 9-12. Lego Mindstorms EV3 is the third generation robotic kit in Lego's Mindstorms line, following the two previous versions of the programmable LEGO brick, the RCX released in 1998 and NXT released in 2007 [140]. It includes elements from the Lego Technic series, three servo motors, five Sensors (Gyro, Ultrasonic, Color, and 2 Touch), and a programmable brick through which all the parts can be controlled. Along with the kit, Lego offers a set of lesson plans separated into five segments, Coding, Engineering, Technology, Science, and Maker, with exercises of different difficulty levels. This curriculum aims to prepare students for higher education and future jobs by building skills such as creativity, critical thinking, collaboration, and communication.

The EV3 intelligent brick can be programmed through different platforms offering different age groups and different learning level learners to use the robotic kit. The first option is the intuitive Lego official software, where students can drag and drop visual programming tiles to compose different instructions and specify a program flow. Students also have the opportunity to program their Ev3 brick through other programming environments like Swift Playgrounds, CoderZ, Microsoft MakeCode, Scratch 3.0, ROBOTC, Open Roberta, and Python. Swift Playgrounds uses Apple's programming language Swift and is suitable for beginner programmers. CoderZ offers an online 3D simulation environment and the two programming options, Blocky for beginners and Java code for more experienced programmers. Microsoft MakeCode and Open Roberta combine a 2D simulator and different programming environments, making it easier for teachers to integrate coding in their classrooms. Through Microsoft MakeCode, students can use a drag and drop workspace or a JavaScript editor for novice and expert programmers, respectively, while Open Roberta is based on NEPO language. Students can also use Ev3 brick with Scratch 3.0 to create their own interactive stories, games, and animations based on the drag and drop programming. RobotC is based on the C programming language, offering learners the opportunity to work with text-based programming. Finally, Ev3 Micro Python programming language lets high school students learn Python programming language using the Visual Studio Code from Microsoft coding editor.

Engino is a versatile three-dimensional construction system that proposes a new modular connector system to simultaneously connect up to 6 sides or extend at any length. Through its Engino STEM and Robotics education series, Engino offers robotics kits for all levels of education, based on STEM and robotics principles. Starting from preschool, students aged 3-6 can use the STEM Qboidz to develop fundamental cognitive abilities, social and sufficient motor skills. Through a set of activities, Qboidz helps students learn about animals, vehicles, technology, airplanes, and sea exploration. For Kindergarten and Early Primary, school Engino proposes the starter robotic set Junior Robotics. It includes Engino and Qboids connecting parts, a mini controller, a touch sensor, one motor, and one LED. Students can build the proposed models through instructions or make their builds, and program the mini controller either manually, using onboard buttons, or through its official programming software KEIRO. Based on the Scratch idea of drag and drop programming, KEIRO has action blocks combined by the student to create the program and learn about inputs/outputs, sensors, and flow diagrams. For primary students (6-9 years old) STEM and Robotics Mini is the most suitable solution.

Along with the Engino constructional parts, the students can also find in the box the mini controller, 2 Infrared sensors, 1 Touch sensor, 1 LED, and two motors. As for the previous set, students can use the mini controllers' buttons for manual programming or KEIRO software with more advanced features such as functions and live readings. Late Primary and Secondary students can use the STEM and Robotics PRO kit, including Engino and robotics parts such as the PRO controller, 1 Touch sensor, 2 Infrared sensors, 3 Motors, and 5 LED lights. Instructions for creating up to 34 models are given with the set, while students can learn more complex programming concepts like conditional statements, variables, and operators by using KEIRO software. Finally, STEM and Robotics Produino is designed for students of ages 14 and up. Produino is the most advanced educational solution of Engino. It includes the Produino controller, which has Bluetooth and Wi-Fi wireless connectivity, a USB port, a Display with six programming buttons, and a Rechargeable battery. The set also includes a touch sensor, a color sensor, infrared sensors, an ultrasonic sensor, a Compass/Magnetometer, DC motors, and a servo motor. The Produino controller integrates the open-source Arduino platforms, connecting and using more sensors and shields. The Scratch-like environment of KEIRO is available for programming, while students can switch to Arduino mode for textual programming in C++.

Thymio is a white, small shaped, and differential wheeled robot, suitable all students' ages. Thymio's shape can be expanded with Lego components, as it has compatible fits on its surface and wheels. The robot has a lot of built-in sensors and actuators. There are nine infrared proximity sensors, 7 of them on the front and the back of the robot to detect obstacles and two on the bottom to help the robot detect the ground. It also has a 3-axis accelerometer, a microphone, a temperature sensor, and an IR sensor for remote control. Thymio also holds five capacitive touch buttons on the top, a secure-digital SD card slot, two motors, a loudspeaker, and 39 RGB LEDs. Thymio can be programmed with Aseba open-source programming environment using a VPL or a scripting language. Users may also program Thymio with Blockly, which offers a combination of a VPL and a TPL [141], [142].

C. 'Advanced CODE' ROBOTICS

A more flexible solution to education is Arduino, an open-source electronic platform mainly used to construct and programming electronics. The boards have a set of digital and analog pins configured as either inputs or outputs. The boards' capabilities can be extended by plugging in various expansion shields (boards), breadboards, or other circuits. Thus it can use many sensors to sense the environment and affect its surroundings by controlling a set of actuators like lights and motors. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). It uses a simplified version of the C++ programming language, making it easier to learn to program [143]. This flexibility of the Arduino board made it widely used in computer programming and in creating custom educational robots with different behaviors [144].

Students of different ages and intellectual levels can choose between the official Arduino kit, and a series of custom made robotic kits based on the Arduino board. Arduino Education offers a series of different kits, covering students from middle school to university, covering different subjects such as programming, physics, electronics, engineering, and mechatronics [145], [146]. With the increasing complexity of the kits, students can develop their critical thinking, collaborative learning, and problem-solving skills. All kits include Arduino programmable boards, sensors, accessories, and mechanical parts while being programmed with open-source software. Apart from the official Arduino kits, many third-party companies created Arduino based educational robots like Makeblock and Pololu, allowing younger students to work with the Arduino board.

Makeblock uses the Arduino board on its Mbot series, including Mbot, Mbot Ranger, and Ultimate 2.0. Mbot is an entry-level educational robotic kit suitable for elementary and secondary education students, starting from 8 years and up. It consists of the mainboard mCore based on Arduino Uno, which can connect with various onboard sensors, such as a buzzer, a light sensor, an RGB led, a button, an IR Receiver, an ultrasonic sensor, and a line follower sensor. Moreover, when working with this robot, students have all the advantages of working with the Arduino board [147]. This robot can easily be assembled or modified to create robots of different shapes, and it can be programmed with software -like mBlock, Makeblock app, and mBlock [148]. mBlock is both a block-based and text-based programming language developed after Scratch 3.0 and Arduino code. This offers users the opportunity to see and edit the code with Arduino IDE with the C++ language. Using the mBot series, students can learn basic programming concepts such as loops, conditions structure, functions, procedures, variables, lists, and sequences. At the same time, they can develop their critical thinking and problem-solving skills [148]. Students of 11 years and older can go further with Halocode Board, a small-sized programmable computer board with many sensors. They can start with graphical programming using the mBlock software and move to textual programming with Python. Makeblok also offers educational robotics for students from early childhood to primary education. Young learners at the age group 4-7 years old can work with mTiny, a programmable robot with a screen-free coding tool. In contrast, students of the next level age group can use Codey Rocky to learn more about computer science concepts and programming skills.

Pololu 3pi platform is a small size robot, commonly used for line-following. The robot core is a C-programmable ATmega328 AVR microcontroller, where two micro gear motors, five IR reflectance sensors, an 8×2 character LCD, a buzzer, and three user push-buttons are connected. The robot can also expand its abilities by adding accessories, such as avoiding obstacles, following walls, solving a maze, or turning into radio-controlled [149]. Pololu 3pi can be programmed using the Pololu AVR C/C++ Studio is combined with many libraries for controlling the integrated hardware [150]. Users can also use Arduino IDE for programming, as Pololu 3pi is compatible with the Arduino platform [149].

BBC micro: bit is another educational board that can be used to create different robotics projects. It is a pocket-sized programmable computer, consisting of 25 red LEDs, two pushbuttons, an accelerometer, a compass, a radio, and a Bluetooth antenna. Besides the on board features, it's possible to connect various accessories like a joystick and color display board to advance it. Microbit can be used with different age groups and educational levels as it can be programmed with various software and programming languages. Starting with blocks and JavaScript, students can proceed with MakeCode editor or Scratch and then go further with more advanced programming with Python editor [151].

A more advanced option when using boards in educational robotics is Raspberry Pi, a fully-featured credit-card sized computer. Today they are several models of Raspberry Pi, from the Raspberry Pi Zero, a single board computer to the 4^{th} generation dual-display desktop computer Raspberry Pi 4 Model B. All boards include a processor, a graphics chip and a RAM, HDMI, and USB ports. Users can add peripherals through USB or using the discrete input and output connector ports. Raspberry Pi's initial purpose was to help students of all ages learn programming by using Scratch and Python. However, Raspberry Pi is now used as a universal programmable control unit for many machines and applications, including robotics.

Tetrix robotics system from Pitsco Education consists of two robotics kits, Tetrix Prime for middle school and Tetrix Max for high school. They both have aluminum and plastic pieces, including structural elements, connectors, hubs, brackets, wheels, gears, and sensors. They also include robotics controllers called TETRIX PULSE for Tetrix Prime and TETRIX PRIZM for Tetrix Max, both Arduino compatible. Thus students can use Arduino Software (IDE) to control their robots. Tetrix Prime and its Tetrix pulse controller can be programmed with the drag-and-drop block-based graphic coding software TETRIX Ardublockly developed using the Google interface called Blockly. Tetrix also offers a connection with Lego education robots. Today there is a TETRIX PRIME Robotics Set for EV3 that allows students to build larger, more powerful, and more complex robots. This set includes a module attached to a sensor port on the EV3 brick and connects up to six TETRIX PRIME servo motors and two TETRIX PRIME DC Motors.

Nao and Pepper are two autonomous and programmable humanoid robots offered by SoftBank robotics. They can be used on various occasions like entertainment, therapy, human assistance, and education. Nao is 58cm in height, and it has 25 degrees of freedom, allowing it to perform various motor actions. Nao can interact with humans through a friendly voice in 20 languages and proper vocabulary and grammar using its four directional microphones and speakers. It also has two 2D cameras for image recognition. Pepper is a 120 cm tall, humanoid robot that moves on three multi-dimensional wheels, enabling it to move around 360 degrees. It also has two arms for object handling and a touch screen for users to control the robot through various applications. It can communicate with users in 15 languages, through its four directional microphones [152]. Pepper is equipped with sensors like infrared sensors, an inertial unit, 2D and 3D cameras, and sonars for omnidirectional and autonomous navigation. Both Nao and Pepper can be programmed with Choregraphe IDE or the Software Development Kit (SDK). With Choregraphe IDE, students can program Nao and Pepper with a graphic-based programming software using drag and drop blocks or using Python. More access to robot features can be achieved using SDK, which is available in Python and C++ [153]. Pepper users can also use the Pepper SDK plugin for Android Studio and program in Java or Kotlin. Both robots can be used in education and assist educators in different aspects of teaching. They can help students develop problem-solving and analytical skills while at the same time, they improve self-motivation in learning STEAM. Nao is suitable for primary to higher education, while Pepper is suitable for higher education. Their friendly appearance and ability to detect human emotions make them suitable for students with disabilities and emotional or behavioral disorders. They can help develop social communication skills, self-esteem, reduce shyness, reluctance, un-confidence, and frustration in individuals in special education [154].

E-puck is a small-scale robotic platform based on open-source hardware/software. It has a straightforward structure consisting of plastic parts, including the main body, the light ring, and two wheels. E-puck uses an STM32F4 microcontroller and is equipped with a wide range of sensors for communicating with its environment. More precisely, on the robot body are 8 IR proximity sensors, 9 IMU sensors, a 3D accelerometer, a CMOS camera, a ToF distance sensor, an SD storage, and four digital microphones. Also, the e-puck supports Bluetooth, WiFi, and USB connectivity. E-puck actuators consist of two stepper motors, a speaker, and a ring of 8 LEDs. Users can also extend e-puck possibilities with additional sensors and actuators. As an open-source project, besides its embedded bootloader, many software and libraries are available for programming the e-puck platform, including the ASEBA tool, Matlab, Python, and C++ libraries, and the Player driver. Additionally, simulation programs like Webots and Enki are available to test and verify users' theoretical concepts for e-puck [155].

Table 1 presents the number of articles that appear in the Google Scholar web scientific indexing service when specific and relevant keywords are used. As one can easily observe, in the case of 'No Code Robotics' category, the vast majority of the articles utilise the Edison robot. In the case of 'Basic Code Robotics' category, most of the scientific community adopts Lego Mindstorms - EV3. Its ease of programming,

TABLE 1. Number of articles that appear in Google Scholar when specific queries are used. [Data Last Accessed on 2020 November 1st].

Platform	Query	Results
Bee-Bot	("Bee-Bot" OR "BeeBot") AND "Robot" AND "Education"	1120
Blue-Bot	("Blue-Bot" OR "BlueBot") AND "Robot" AND "Education"	294
Pro-Bot	("Pro-Bot" OR "ProBot") AND "Robot" AND "Education"	401
KIBO	"KIBO" AND "Robot" AND "Education"	573
Cubelets	"Cubelets" AND "Robot" AND "Education"	243
Ozobot	"Ozobot" AND "Robot" AND "Education"	384
Edison	"Edison" AND "Robot" AND "Education"	6550
InO-Bot	("InO-Bot" OR "InOBot") AND "Robot" AND "Education"	7
Dash	("Dash" AND "Wonder Workshop") AND "Robot" AND "Education"	138
Dot	("Dot" AND "Wonder Workshop") AND "Robot" AND "Education"	107
Cue	("Cue" AND "Wonder Workshop") AND "Robot" AND "Education"	23
WeDo	("Lego" AND "WeDo") AND "Robot" AND "Education"	953
Spike	("Lego" AND "Spike" AND "Robot" AND "Education"	375
EV3	("MINDSTORMS" OR "EV3" OR "EV-3") AND "Robot" AND "Education"	4350
Engino	"Engino" AND "Robot" AND "Education"	46
Thymio	"Thymio" AND "Robot" AND "Education"	455
Arduino	"Arduino" AND "Robot" AND "Education"	13700
Pololu 3pi	"Pololu 3pi" AND "Robot" AND "Education"	58
BBC micro	"BBC Micro" AND "Robot" AND "Education"	321
Raspberry	"Raspberry" AND "Robot" AND "Education"	6870
Tetrix	"Tetrix" AND "Robot" AND "Education"	225
Nao	"Nao" AND "Robot" AND "Education"	6470
Pepper	"Pepper" AND "Robot" AND "Education"	7460
E-puck	"E-puck" AND "Robot" AND "Education"	1260

low cost, and scalability make Arduino-based robots the most common choice in 'Advanced Code Robotics' category and the preferred microcontroller for teaching.

V. EVENTS AND COMPETITIONS

This section briefly describes some of the most noted educational robotics competitions today. Robotics competitions consist of various challenges, including project-based tasks, team games, fighting challenges or solving a generic task. In addition to the different challenges, most of the competitions engage a variety of robotic platforms. Thus, the presented competitions are not classified based on the robotic platforms' categories of the previous section. Robotic competitions are aimed at a national or international audience. In this section, we categorize the competitions by continent, based on the countries in which they are allowed to participate in the competition.

A. INTERNATIONAL COMPETITIONS

The Robotics Education & Competition Foundation offers VEX IQ Challenge, VEX Robotics Competition, and VEX U events to inspire and motivate students in STEAM education. Participants in all VEX events are able to use only VEX Robotics and use components from the VEX product line. Moreover, as all VEX events require alliances between the teams, students develop essential skills like teamwork, leadership, and communication. VEX IQ Challenge is a competition for elementary and middle school students. Students use the VEX IQ robotic kit to build their robotic solutions and compete in 3 challenges, Teamwork, Driving Skills, and Programming Skills. In a Teamwork challenge, two teams must cooperate to maximize their score. Scoring objects of different colors are randomly placed inside a field, and teams must place those objects inside the predefined positions to earn points. For the other two challenges, teams work individually to collect points. In the Programming skills challenge, the robot is in the autonomous driving mode, while in the Driving Skills challenge, the robot is remotely controlled by a team member. In the VEX Robotics Competition, two teams ally and compete against other alliances. Each alliance tries to score the most points by accomplishing a variety of tasks. Every game has two periods, the autonomous driving period, followed by the driver control period. The teams of the alliance with the top-scoring points win the tournament championship [156]. The VEX U event follows the same rules and objectives of the VEX Robotics Competition but is dedicated only to college and university students. In this level, more customization and flexibility is allowed for the teams. Besides the winning teams, in VEX competitions, special awards are given to the teams based on their performance in a particular aspect of the competition, such as programming.

World Robot Olympiad (WRO) is a global robotics competition for students aged 6 - 25 years old. It was founded in 2004 and aimed to develop students' creativity, design, and problem-solving skills through original robotic structures. Each country organizes a local WRO tournament. The winners of each category, except the WeDo age group, can participate in the final international competition hosted by a different country every year.

Each year WRO has a new theme drawn from essential aspects such as 'Smart Cities', 'Food Matters', 'Robots for sustainability', and 'Robots for life improvement'. WRO consists of 4 categories with different age group competitions: Regular Category, Open Category, WRO Football, and Advanced Robotics Challenge (ARC).

The Regular category is a challenge-based competition. The competition is separated into four subcategories based on students' age, WeDo for younger students up to ten years old, Elementary for students ten up to twelve years old, Junior for students thirteen up to fifteen years old, and Senior for students sixteen up to nineteen years old. For the WeDo category, only the Lego WeDo kit can be used, and teams must bring their robots assembled to the competition. All other age group teams can use one of the Lego Education Robotics platforms; Mindstorms sets NXT or EV3 and Spike Prime, while beside the HiTechnic Color Sensor, no other third-party elements are allowed. All age groups can use any compatible software or firmware to program their robots. The aim is to assemble and program their robots on the competition day, without any instructions. On some occasions, a surprise rule or task is revealed on the competition day to boost creativity. The teams achieving the surprise task are awarded extra points.

The Open Category is a project-based competition where participants can create an innovative robotic solution based on the season's theme and present it to the judges. The project is supported by a short video demonstrating the robot's functionalities and a written and illustrated report, summarizing what the robot can do. According to this category regulations, there are specific criteria (e.g. quality of the solution, programming, engineering design, presentation and teamkork) which groups must meet to collects points. The Open Category is divided - like the Regular Category- into four subcategories according to age: WeDo, Elementary, Junior, and Senior. For mechanical construction, a Lego WeDo kit can be used by the WeDo group. Simultaneously, there is no restriction on the robot's size and the use of controllers, elements, and materials for all the other age groups. They are also free to use any software they prefer to program their solution.

The WRO Football Category is a gameplay competition inspired by human soccer. Two teams compete using two autonomous robots: either a goalie and a forward player or two forward players. The two robots chase an infra-red transmitting ball, aiming to score the most goals and win the game. To encourages students to develop their robots, the game differentiates a little every year by the organizers. Unlike the other two categories, only one age group can participate in this category: the student 10-19 years old. The controller, the motors, and the sensors used to assemble the robot must be from LEGO MINDSTORMS sets and HiTechnic, and only Lego brand pieces are allowed. Robots are assembled on the assigned assembly time on the day of the competition.

The program can be prepared in advance in any software and any firmware on NXT / EV3 controllers. The participants must also explain their robots' operation and answer questions for their construction and programming procedure.

Robotex is an international robotics competition organized since 2001 in Tallinn, Estonia. Teams selected as the 1st to 3rd place winners of each category at the national competition have the right to participate in the International Robotex tournament. During the international competition, various expositions, technology exhibitions, and workshops for young people to take place, making Robotex a technology festival. The International Robotex's competitions are separated into five categories, including Beginners, Intermediate, Advances, Entrepreneurial challenge, and Girls, reflecting the age and degree of difficulty of the tasks.

The Beginners' category consists of four competitions with two main subjects, the line-following (line-following and the Makeblock line-following) and the Lego Sumo (Lego Sumo and 3kg Lego Sumo). It also includes a non-competitive robotics exhibition called 'Insplay Robo League'. The Intermediate category includes two Sumo challenges (Micro and Mini Sumo), two line-following challenges (Enhanced and Arduino line-following), a Maze Solving challenge, and two race challenges (Folkrace and Water Rally). The Advanced category consists of 6 challenges, three of which invite contestants to build robotic solutions for a given problem (City Kratt, Animal Rescue, and Robotics Drone Race). The other three challenges are Mega Sumo, Basketball, and Mind Control, where the challenge is to solve a problem by controlling the robot's movement with your mind.

The Insplay Robo League, the non-competitive exhibition for the Beginners category, is a themed based challenge for kindergarten and elementary school students. Each year, participants are invited to build a robotic project based on the given theme and present it to the mentors on the competition day. Following the project's presentation, teams get feedback from the mentors on the idea and its execution, the program, and the teamwork.

For the line-following challenge, teams must construct and program a robot that will autonomously drive through a track, marked with a black line on a white surface, as fast as possible. Line-following has various versions as a contest in the Robotex tournament, based on the robotics platforms allowed or variations in the rules. Lego line-following, Makeblock line-following, and Line-following correspond to the use of Lego, Makeblock, and Arduino based robotic platforms, respectively. The Makeblock challenge increases difficulty as the robot must also avoid obstacles and compete with various challenges as it follows the track. The Enhanced line-following is another variation with increased difficulty, introduced by the addition of obstacles or changes of the line thickness or coherence of the track that the robot must traverse to complete the race. The line-following challenge is exceptionally competitive and attracts the interest of schools and universities around the world [157].

The Sumo challenge in Robotex resembles the human sumo wrestle where a wrestler attempts to force his opponent out of a circular ring. In the robotic competition, a sumo robot competes against a robot opponent, aiming to push its opponent out of the ring. Teams must develop a robot and program it to locate the opponent, attack or resist an attack, and avoid falling out of the game field. The Sumo challenge has four versions in Robotex. Lego Sumo and 3kg Lego Sumo challenges are organized only for the Lego Education Mindstorms EV3/NXT and Spike robotic platforms. In the Mini Sumo and Micro Sumo challenges of the Intermediate level, participants must build their robotic solutions using Arduino based platforms. The Mega Sumo challenge found on the advanced category, allows teams to use any robotic platform for their solution.

For the Maze Solving challenge, an autonomous robot drives through a maze, starting at a predefined corner and moving towards its center in the shortest possible time. For the robot construction, teams can choose between Arduino, Raspberry, Pi, ARM, ESP, Engino, Lego EV3, or Lego Spike robotics platforms. The robot cannot jump over, fly over, or climb the maze walls to reach the destination square; it can only drive through the paths. The maze map remains secret until the day of the competition, and each team has to prepare by developing a generic code that can perform successfully in any maze. Robots are ranked based on the minimum official time taken to reach their final position and the minimum distance of this final position from the target.

Folkrace simulates rallycross, where up to five robots compete against each other on the same track. The objective is to complete the field in the correct direction as many times as possible. The winner is the robot that earns the most points within a three-minute time frame. Teams are free to choose between the available platforms and adjust their robots based on the competition's needs. Extra features might be introduced to make the race more enjoyable, including simple obstacles like hills, holes and loose materials. Water Rally is similar to Folkrace with the track placed in the water. More precisely, autonomous robot boats must complete laps in a small pool filled with obstacles.

In addition to the ground and water races, Robotex also offers an air race called the Robotics Drone Race challenge. This race is considered to be more advanced than the other two. The goal is to build an unmanned aerial robot (drone) that flies an eight shaped figure around two poles. The fastest robot to complete the task and reach the landing point wins the competition.

The Animal Rescue and the City Kratt are two advanced challenges aiming to inspire teams to create autonomous robots for specific purposes. In the Animal Rescue challenge, the robots must find and rescue animals lost in the city. To develop the required robots, the participants apply machine learning and object recognition skills. Unlike the other Robotex games, the focus of the Animal Rescue challenge is on software development. Thus the participants are entitled to use prebuild hardware platforms for their project.

For the City Kratt competition, teams must create an interactive Kratt, a character of Estonian legends, a house servant built from hay or old household items. Inspired by the myth, each team has the task of building an artificially intelligent house manager who can welcome visitors, direct people around the building, and entertain them while they wait for the host. The winning teams are encouraged to enter the market with their product.

The Basketball competition imitates a real basketball game. Two robots compete against each other, trying to score as many balls into the opponent's basket as possible within 60 seconds. Robots must be programmed to be autonomous, recognize the green squash balls randomly placed on the floor, collect them, and put them into the baskets. To win, a robot must throw more baskets than its opponent.

For the Entrepreneurial Challenge, the participating individuals or teams have to create an innovative working robotic prototype. The robotic product can be applied in any area, such as health or engineering. The prototype must include electronic components and solve a real-world problem. The teams must present their prototype during the competition, to the visitors, other participants, potential investors, and the press. They will receive real-world feedback, and at the same time, they will compete with each other to get the most votes from the visitors of Robotex and win.

The Girls firefighting challenge was founded to encourage girls from all over the world to participate and engage with the world of technology and engineering. The competition's objective is to create and program a firefighter robot to locate and extinguish four randomly placed candles, without touching them. All the four candles stand at the center of a white circle, and 3 of them are blocked by walls. Teams can use any Arduino, Engino ERP, Engino Produino, Lego EV3, and Lego SPIKE platforms to create their solution. Points are given based on the number of candles extinguished by each team.

FIRST (For Inspiration and Recognition of Science and Technology) is a STEAM engagement organization aiming to encourage kids to engage with engineering, science, and technology. It consists of three programs, the FIRST Lego League, the FIRST Tech Challenge, and the FIRST Robotics Challenge. Through these programs, FIRST also aims to help children build self-confidence, knowledge, and life skills.

The FIRST Robotics Competition (FRC) is an international high school robotics competition. FRC is the final event of the season where the winners of each regional FRC competition can participate. FRC allows students to work on a real-world like engineering projects through engaging challenges while volunteer professional mentors guide them. This procedure inspires students to pursue careers in science and technology. The robot challenge changes every season. Students must create teams of 10 or more, raise funds to support their effort, and build and program an industrial-size robot, using a standard 'kit of parts', to play a sophisticated field game against their competitors. In addition to on-field competition winners, there are other awards for the participating teams recognizing the critical features for designing, building, and programming a robotic solution and teamwork skills, such as Digital Animation Award,Engineering Inspiration Award, e.t.c.

FIRST LEGO League (FLL) is a partnership between FIRST and Lego Corporation. The FLL extends the FIRST concept to promote young people's interest in STEAM by using Lego Robotics to children ages 4-16. FLL has three divisions based on students' age, including the FLL Discover for ages 4-6, the FLL Explore for ages 6-10, and the FLL Challenge for ages 9-10. Every year, FLL releases a new Season Topic based on a real-world theme like, e.g., City Shaper for 2019. In all divisions, besides completing their project, the students are expected to familiarise themselves with the Core Values of the FLL. Those are Teamwork, Inclusion, Discovery, Innovation, Fun, and Impact.

The FLL Discover and FLL Explore are non-competitive events. In the FLL Discover, students work in teams of 4 with an exclusive LEGO Education DUPLO set to create solutions for the given challenge. While they explore the given theme, they are introduced to the fundamentals of STEAM. Participants in the Explore category work in teams of 2 to 6 children, with LEGO Education WeDo 2.0 kit to design, build and program robots based on the seasons' challenge. They must also create a team poster to present their findings and their learning journey through this process. In both divisions, teams meet up to present their projects, meet other teams, and celebrate what they have learned during the season at a celebration event. The FLL Challenge has three aspects: the Robot Game, the Innovation Project, and the FIRST Core Values. Teams may have up to 10 children, and they must use the Lego Mindstorms set to build and program a robot that will complete specific missions in the Robot Game table. The aim is to collect as many points as possible in the allotted time. Besides completing the challenge, teams must also present to the judges the innovation of their solution, answer questions about their code and robot, and present their knowledge from the preparation phase.

FIRST Tech Challenge is addressed to grades 7-12, and team members can be up to 15 students. In this challenge, the team's goal is to design, build, and code robots to compete in an alliance format against other teams. Along with the robotic game, teams must also create, promote, and raise funds for their team brand. FLL offers a specific robotic kit to the members to create a remotely operated vehicle. The FLL is controlled by an Android-based platform. The robot can be programmed with a variety of levels of Java-based programming. In addition to the Robot Game, teams can also win judges' awards line FIRST Dean's List, Inspire Award and Think Award e.t.c.

The Robot World Cup (RoboCup) is an annual event created to promote robotics and AI research by setting a common challenge. The main task of RoboCup is robot soccer, where autonomous robots play soccer in a dynamic environment. This task was chosen as soccer is a popular, beloved activity and a complex, real-world problem that raises researchers' interest. Starting from 1997, researchers worldwide meet in RoboCup competitions and scientific meetings to integrate, test, present, and discuss their solutions, theories, and algorithms [158]. RoboCup ambition is by the middle of the 21st century, a team of fully autonomous soccer robots to win a soccer game against the World Cup's latest winner, according to FIFA rules [43]. RoboCup has continuously evolved through the progression of research and technology. Today, robot soccer remains RoboCup's main event, while four more research-oriented leagues were added: RoboCup Rescue League, RoboCup@Home, RoboCup Industrial Leagues, and RoboCupJunior [43].

RoboCup Soccer is divided into five robotic challenges: the Soccer Simulation League, Small-Size League, the Middle-Size League, the Standard Platform League, and the Humanoid League. Simulation League addresses research questions in high-level decision making and team coordination. The games may be played in a 2D or a 3D virtual soccer pitch, constructed within a computer. In the 2D environment, physics rules and agent representation are simplified [159], [160]. The 2D simulator is a useful research tool for autonomous decision making, formulating team strategies and opponent modeling and adaptation [43], [160]. Extra realism and more complex rules and physics are included in the 3D League. In the 3D field, players are simulated as NAO robots with articulated bodies. The 3D simulation environment is built with SimSpark, a multi-agent system simulator [159]. Unlike 2D League, the research interest in 3D simulation is not the design of the agents' strategic behaviors when playing soccer. For 3D League, the aim is the low-level control of the simulated humanoid robots and the realistic simulation of robot behaviors like walking, kicking, turning, and standing up [43], [160]. For both Leagues, the team's simulators and binaries are publicly available, making it easier for the community to expand its solutions [160]. In the Small-Size League (SSL), a fast-paced robot game takes place between teams of semi-autonomous robots. Players are cylinder-shaped robots of maximum 180 mm diameter and 15cm height that move omni-directionally [43], [161]. Robots also have a single kicker and spinning dribbler bars for controlling the ball [160], [161]. The players' position is tracked by a global overhead vision system that helps teams focus on software algorithms, hardware, and control engineering instead of a ball and robot localization and mapping [161]. Teams use an off-site computer to create and send commands to the agents/robots according to the information received from the vision system [43], [161]. Middle-Size League (MSL) is the closest League to the real soccer while it encloses mechatronics design and multi-agent coordination. In MSL, five fully autonomous robots play soccer with a regular size FIFA soccer ball on an 18m*12m field. Teams can design and build their robot, ensuring that all the sensors and computing power on-board. The most challenging task for a robot in MLS is to pass the ball to its team players while passing through the defense on the opponent team [43], [162]. In both SSL and MSL participating teams are free to design their own custom-made robots that satisfy each challenge rules. In the Humanoid League (HL), soccer players are autonomous robots with human-like bodies and senses. Teams must build the mechanical and electronic parts of the robot and develop its software. While playing soccer, robots must walk steadily, visually perceive the ball, the players, and the field limits, kick the ball, and self-locate in a spatial environment [163]. In the HL, there are 3 different size categories: KidSize, TeenSize and AdultSize [164]. For KidSize and TeenSize leagues, every match is played by two teams, each consisting of field players and a goalkeeper. In an AdultSize league, a team consists only of one field player. To meet the official FIFA rules, the game rules of the HL are adapted every year [165]. Standard Platform League Unlike HL, in Standard Platform League (SPL), all teams use the same humanoid robot platform, the Nao robot. Teams are not allowed to modify NAO's hardware; thus, they focus on designing software solutions and improving robot movements. Robots must play completely autonomously, while they can communicate with their team players [166].

RoboCup Rescue League comprises two Leagues: the Rescue Robot League and the Rescue Simulation League. In the RoboCup Rescue Robot League, participants must develop and demonstrate advanced robotic capabilities for emergency responders in a hostile environment [167]. The League uses realistic scenarios such as an earthquake, a flood, or a fire [166]. In the rescue missions, robots face various challenges, including mobility, mapping, sensing, manipulation, communications, and confined space operations. Teams may use standardized robot platforms or create their rescue robots. The League also created the Open Academic Robot Kit, a set of open-source licensed resources online, where teams can find instructions of robot designs created by 3D printable mechanical parts and source code [167]. Teams are allowed to use teleoperated robots with some autonomous capabilities as assistance functions for the operator [43], [166]. Rescue Simulation League's objective is to develop simulators to realistically represent natural disaster scenarios and develop virtual emergency response robots or agents. This League is separated into two sub-leagues, the Virtual Robot Simulation competition, and the Agent Simulation competition [167]. RoboCup@Home intends to develop service and assistive robots that can perform everyday tasks in dynamic home environments [160], [166]. This category's domestic service robot has to cope with challenging tasks such as localization, speech recognition, or grabbing and manipulating objects. The robot abilities and performance are evaluated based on a set of benchmark tests in a dynamic home environment setting [160]. Therefore, League's researcher interest focus on a combination of domains: human-robot-interaction and cooperation, navigation and mapping in dynamic environments, computer vision and object recognition under natural light conditions, object manipulation, adaptive behaviors, behavior integration, ambient intelligence, standardization, and system integration. RoboCup@Home is separated into three categories based on the allowed platforms. The open Platform category use custom platforms and two standard platforms the Toyota Human Support Robot (HSR) and Pepper from SoftBank Robotics are used for the Domestic Standard Platform League and the Social Standard Platform League, respectively [166].

RoboCupIndustrial focuses on the industrial domain, where mobile robots are deployed to perform several industrially-relevant tasks. Two sub leagues, the RoboCup@ Work and the RoboCupLogistics League (RCLL) are available from the RoboCupIndustrial [166], [168]. RoboCup@ Work, robots equipped with advanced manipulators and sensors, cooperate with human workers for complex tasks in work-related scenarios [168]. RCLL is inspired by the industrial scenario of a smart factory. According to dynamic orders, multiple mobile robots must plan, create, and adjust a production plan. In RCLL, a mobile robot from Festo, the Robotino is used as the standard platform of the competition [169]. RoboCup Junior (RCJ) is an entry-level League for the international RoboCup initiative, where young students under 19 years old are introduced to STEM education. Students in the RCJ have to design, build, and program autonomous robots in a team setting. They are free to develop their robotics platforms using any robotic kit or material to create custom-made 3D printed or laser cut parts. Three Leagues are available in RoboCup Junior: Soccer, Rescue, and Dance. Two of the activities were created after the RoboCup main events, the RoboCup Soccer and the RoboCup Rescue. The third competition, RCJ Dance, was created to integrate arts and edutainment into STEM [31]. While the final goal remains the same as the significant events, in junior versions of the soccer and rescue leagues, rules and regulations are slightly simplified. In the dance competition, teams dance on stage with their robots, a creative choreography they have developed, and compete against other teams [166]. A lot of researchers highlight the benefits that students gain from participating in RCJ. Most of them emphasize social teamwork, programming, involving in technology and robotics, developing problem-solving skills, and having the opportunity for a possible career in STEM fields [31], [43].

The Federation of International Sports Association (FIRA) is a robotic competition, which uses sports as benchmarks for AI and robotics research. FIRA consists of 4 main categories FIRA Sports, FIRA Youth, FIRA Challenges, and FIRA AIR and encourages students to create their own custom-made robotic solutions, avoiding the use of any commercially available ER platform.

FIRA Sports focuses on soccer, a robotic challenge ideal for finding solutions to the multi-agent automated system's problems. FIRA Sports has four sub-leagues: HuroCup, RoboSot, SimuroSot, and AndroSot. HuroCup is a humanoid robot competition, emphasizing the development of flexible, robust, and versatile robots that can perform several tasks in complex environments. HuroCup encourages research into relevant areas of humanoid robotics, especially active balancing, complex motion planning, and human-robot interaction with the use of humanoid robots. HuroCup includes seven events Basketball, Climbing, Lift and carry, Long jump, Marathon, Obstacle run, and Sprint focusing on object manipulation, complex motion planning, hand-eye coordination, navigation skills or endurance [170]. Students and researchers can participate in the corresponding categories HuroCup Kid and HuroCup Adults of the HuroCup competition. In the RoboSot match, two autonomous intelligent wheeled mobile robots play soccer against each other in a specific game field. Robots must be fully autonomous, while they can only communicate and interact with their team's other robots. Except for the main soccer game, RoboSot consists of a series of additional challenges like vision challenge, motion challenge, and race challenge [171]. The SimuroSot competition is a simulation league where teams of simulated robots play soccer. This category aims to help researchers and students focus on developing control algorithms and team strategies without the need for complicated and costly hardware setup [172]. Finally, in the AdroSot challenge, humanoid robots play soccer while controlled by a global vision system. In AndroSot, research is concentrated on advancing the abilities of attack and defense in androids. In AndroSot soccer, game robots must perform tasks like dribbling, obstacle avoidance, shooting, trajectory detection, goalkeeping, role arrangement, and positioning control.

The FIRA Youth League is a student-oriented (under 19 years old) event, offering a set of challenging events including Sports Robots, Innovation and Business, HuroCup Junior, CityRacer, DCR-Explorer, Cliff Hanger, and Mission Impossible. The Youth category aims to allow the younger researchers to develop their ideas and learn about robotics inside an attractive environment. In Sports Robots, teams must build and program a robot that will perform tasks relevant to the sports field, like weightlifting, kicking the ball, or pushing obstacles. The Innovation and Business League is a call for inventors and students who want to better understand starting a startup company. Teams must solve a real-life problem through a project and demonstrate it to investors and industry executives, medium and professional professors in the exhibition venue. For a project to be complete, students must create both the robot's hardware and software and create a business and marketing plan. The CityRacer is deigned to challenge junior and high school students' problem-solving skills. Teams must create a robot able to track and follow a line on the floor and traverse the uneven terrain. The robot must also lift and manipulate small items that are randomly placed in the field. Students participating in the DCR-Explorer league must create an autonomous explorer robot to surpass obstacles in a disaster area, to deliver rescue packs to victims. The Cliff Hanger challenge is a sumo fight, where two robot opponents fight in a circular playing surface with a cylinder fixed at the center. Based on the robot size, there are two categories, Lightweight (<= 1Kg) and Heavyweight (1Kg - 3Kg), while robots in both categories must be autonomous. Through the Mission Impossible league, students use their imagination and creativity to solve challenging tasks, such as collecting treasures. Teams must create their robots with a limited set of materials during the construction phase and compete in the game field.

To stimulate researchers' interest, FIRA created 3 Challenges. One of those corresponds to the Innovation and Business challenges in the FIRA Youth League. The goal and objectives of this challenge are the same as the student's version. The other two Challenges are Autonomous Cars and Warehouse Robots. With these challenges, FIRA encourages researchers to develop robots for autonomous driving and storage for two real-life tasks.

With FIRA AIR competitions, FIRA encourages students and researchers to work with autonomous flying robots in commercial and industrial applications. In all four events included in FIRA AIR, Autonomous Race, Autonomous Race U19, and Emergency Services Indoor and Outdoor, participants have to develop efficient, robust, and autonomous drones and cope with challenging tasks as localization, exploration, and intelligent navigation in dynamic environments.

RoboGames (previously known as ROBOlympics) is an annual robot contest with various challenges mimicking the human Olympics. It is held in the United States, and competitors from all over the world can participate. It is known as the world's largest open robot competition [173]. Over 70 different events are to participate, divided into ten categories: Humanoid, Autonomous Humanoid Challenges, Sumo, Combat, Robot Soccer, Open, Jr. League, Autonomous Autos, Art Bots, and BEAM. Thus, RoboGames engages both custom robots and commercially available ER kits, like Lego Mindstorms series. Most of the robots in the events are autonomous, while only some are remotely operated by the teams. RoboGames was founded to bring together robot builders from different areas of interest and professional formation to collaborate and exchange ideas. Moreover, RoboGames is open to everyone, and thus participants may be students, professionals, researchers, and hobbyists, regardless of their age, affiliation, country of origin, or gender [173], [174].

RoboMaster is a relatively new competition, started only in 2015 from China, and expanded to International competition. It is powered by Da-Jiang Innovations (DJI) and is addressed to college students and young engineers. RoboMaster is a fighting robot competition divided into four events, the Robotics Competition, the Technical Challenge, the AI Challenge, and the RoboMaster Youth Tournament. Participants can use only the official DJI RoboMaster robotic kits, including the RoboMaster EP, the RoboMaster S1, and the AI Robot. In the Robotics Competition, university students must develop different robots, such as vehicles or aerial robots that will cooperate in fighting an opponent team. Robots can be fully-automated or remotely operated while they will attack the opposing team's robots with projectiles to destroy their base. The Technical Challenge aims to attract researchers' interest in a specific filed of robotics. Like in the Robotics Competition, participants should be from higher education. Teams in this competition must develop one robot for one challenge. This challenge aims to motivate participants to research a specific technical field in robotics and seek in-depth solutions to perfect their robots. The AI Challenge is co-sponsored by the DJI RoboMaster Organizing Committee (RMOC) and the IEEE International Conference on Robotics and Automation. In this event, university students must develop algorithms for a given robotic platform to enable robots to make independent decisions, move, and fire in the field.

MakeX started in 2017 and is a global robotics competition for students of different ages. The competition is driven by the spirit of creativity, teamwork, fun, and sharing and aims to introduce young learners in the STEAM fields. It provides four challenges: Spark, Starter, Challenge, and Premier, and participants are allowed to use only official MakeBlock robotics kits like mBot. The Spark program invites 6 to 13 years old students to create teams of 2-4 people and participate in a project-based event. Participants must construct and program their project within a specific time and present it to the audience and the judges. Based on their demonstration, teams will get feedback from the judges. Spark event aims to promote students' creativity, imagination and advance their problem-solving and logical thinking skills. The Starter event focuses on improving the social skills of students between 6-16 years old. Teams of a maximum of 2 students must design and program a robot, to work both automatically and manually. The competition requires a corporation between two teams to complete several independent and alliance missions. Young students between 11 to 18 years old can participate in the MakeX Challenge program. In this program, the competition is held between two unions. Each alliance consists of two teams, and they must work together to complete specific tasks. Following the Starter program, the Challenge event is divided into the automatic face and the remote-control face. Teams of 2-8 people have to use their engineering knowledge to construct their robotic solutions and employ their logical thinking skills and decision-making ability in the game field. The Premier program encourages students over the age of 14 to participate in an aggressive robotics competition. Two alliances, each consisting of two teams, play against each other to collect points and win the game. Every coalition must pass through the four stages of a match: Automatic, Manual, Modification, and Final. For this program, participants build and modified their robots during the game, making decisions about their strategy and cooperating with their alliance team.

B. EUROPE

RoboParty is a robotic three-day camp, organized at the University of Minho in Portugal. This non-competitive event aims to teach electronics, mechanical engineering, and programming to school-age children [175]. Participants create teams of 4 people, consisting of 3 students and one adult. The educational event includes lectures, speeches, hands-on classes, and robotic demonstrations. Lectures teach participants how to build the electronics, assemble the mechanics, and program their robot. Moreover, two speakers present their research area expertise to increase the students' knowledge of robotics and relevant scientific fields. Students build their robot during the workshop using the Bot'n Roll One A robotic kit, which was developed especially for this event. The construction face includes soldering the electronic components on the electronic board, assembling the mechanical components, and programming the robot. As Bot'n Roll One A platform is Arduino based, students use C language to create their code. Finally, three challenges including avoiding obstacles, following a line and dancing, are given to the students to test their robots and algorithms [176].

C. ASIA

The Asia-Pacific Broadcast Union Robot Contest (ABU Robocon) is a themed based robotic competition for higher education. Since 2002, ABU Robocon is held among associated member countries of the ABU. The host country, inspired by its culture, defines the theme and the rules of the competition [177]. The ABU contest's main objective is to develop multidisciplinary and multi-professional knowledge, creativity, collaboration, and innovation among university students. Participants must analyze the contest challenges and work as a team to solve the given problems. They have to design and build both the hardware and the software of their robotic solution. ABU Robocon is characterized as a high-level robot contest. Thus participants must have a strong academic background to be competitive [177], [178].

ROBO-ONE is a robot fighting competition in Japan, where two small-size humanoid robots do battle in a fighting arena. The competition is open to public participation and is favored mainly among armature hobbyists [179], [180]. Participants may be young students, university researchers, hobbyists, or adults with engineering backgrounds and families. Five tournaments are included under the ROBO-ONE umbrella. The primary ROBO-ONE game features two bipedal walking robots that are remote-controlled by the participants. The objective of the game is to take their opponents down or force them outside the ring. Robots are built with parts from hobby robot kits and are programmed to walk, run, and perform gymnastics, dance routines, or combat movements. Participants may dress up their robots as mechanical warriors, animal-like characters, or fantasy figures. The Light version of the competition follows the same rules as the main game but is addressed to beginners. Participants are allowed to use commercial robot kits certified by the ROBO-ONE Committee.

In comparison to the original version of the competition, robots are fully autonomous anthropomorphized robots in the ROBO-ONE auto challenge. ROBO-ONE Kendo and ROBO-Ken Arm are two contests: bipedal robots and one-armed robots perform 'Kendo' swordsmanship, a traditional Japanese martial art. Even though ROBO-ONE showcases humanoid combats, there is no sense of aggression in the events [179]. Besides the competitions, participants usually create local groups and meetings to exchange information [180].

D. USA

Boosting Engineering, Science, and Technology (BEST) is a national competition in the United States, where middle and high school students can participate. BEST aims to increase students' interest in pursuing a degree or a career in STEM fields. The competition lasts for 6-weeks, starting from the Kick-Off Day where the game theme, the playing field, and an overview of the game is revealed [47]. Every team receives a kit of parts for their projects. The kit includes construction materials such as plywood, fiberglass board, metal sheet, and a box which is filled with raw materials, such as PVC pipes, screws, valve cover, piano wire, aluminum paint grid, a bicycle inner tube, rollerblade rollers, duck tapes, and a micro-energy chain system. It also includes electrical components such as the brain, controller, servers, DC motors, and sensors [47], [181]. Teams can choose any software they wish.

BEST, among other software, propose MathWorks, EasyC, Robot C, Computer-Aided Drafting software of SolidWorks, and HSMWorks; Training programs offered by InspirTech; Computational Tool of Wolfram Mathematica; Control System provided by VEX. With the components, teams must design and build a remote-controlled robot and complete a set of tasks within a specific time. Before creating their robots, teams can also create a 3D platform simulation to test their ideas. Furthermore, teams can also participate in additional events about their oral presentations, technical writing, web design, or video production. This motivates students with different interests to work in smaller groups focusing on a specific task. For example, a team may consist of smaller groups, including an engineering group, a marketing group, and a creative design group. However, teams are not required to participate in all the events. Except for the Engineering Notebook and the Robotic Game, all the other events are mandatory. When a team succeeds at a local hub Game Day, it can participate in the regional competition and then proceed to the National Championship [47].

Table 2 presents the competitions in relation to the platforms that the participants are allowed to use. International competitions offer the participants the opportunity to use and experiment with a variety of robotic kits. It is observed that most of the competitions use the ER kits presented in Section IV. Some challenges, in specific competitions also allow the use of custom-made solutions, while only a small number of the robotic events prohibit the use of commercially available robotic kits. In their majority, competitions engage platforms from the 'Basic Code' and 'Advanced code' category. Although tangible programming is suitable for learning basic programming concepts using 'No Code' robots is not compelling in a competition setting.

TABLE 2. Approved ER Platforms in Competitions.

Competition	ER Platforms
VEX IQ Challenge	VEX IQ robotic kit
VEX Robotics Competition	VEX V5 or Cortex system
VEX U	VEX V5 or Cortex system
ABU Robocon	Custom-made robots
RoboParty	Bot'n Roll One A robotic kit
WRO	Lego WeDo Lego Spike Prime Lego Mindstorms NXT or Ev3
Robotex	Lego WeDo, Lego Spike Prime, Lego Mindstorms NXT or Ev3, Engino Mini, Engino Produino, Engino ERP, Makeblock, Edison
FIRST Robotics Competition	Custom -made robots
FLL	Lego Duplo, Lego WeDo, Lego Mindstorms NXT or Ev3, Arduino - based robotic platforms
FIRST Tech Challenge	Arduino based robots
Robocup	NAO, Pepper, Custom-made robots, Toyota Human Support Robot, Robotino
BEST	Custom-made robots
FIRA	Custom-made robots, Android robots
RoboGames	Custom-made robots, Lego Mindstorms EV3 or NXT, Android robots
RoboMaster	DJI RoboMaster robotic platforms
ROBO-ONE	Robot kits certified by the ROBO-ONE Committee
MakeX	MakeBlock robotics kits

VI. MAPPING EXPECTED LEARNING OUTCOMES WITH EVENTS AND COMPETITIONS

In the current section, we correlate the learning outcomes of Section III with the competitions presented in Section V. More precisely, we identify each competition's six proposed learning outcomes based on its characteristics, rules, and goals. The efficacy of each expected learning outcome is presented in Table 3, as Limited, Moderate, or Strong.

LO1: Problem-solving skills

Participants in robotics competitions face a problem-solving process, during which they must define, examine, and find solutions to scientific problems. In most competitions, this process takes place before the day of the match as the challenges of the contest, the rules, and the game fields are given to the teams before the competition. Even though participants develop problem-solving skills, those competitions' efficacy is considered to be Moderate (Table 3). The problem-solving process occurs before the competition day, and participants can only prove their skills through their ready-made solutions. Teams in these competitions have guidance from their coaches, wide availability of resources, and sufficient time to work and prepare their robotic solution in advance.

On the other hand, competitions that offer extra challenges on the day of the event, such as hidden parameters, additional rules or restrictions, and secret fields, are evaluated as Strong. These competitions allow the participants to implement and demonstrate their problem-solving skills. For instance, the WRO Regular Category is characterized as Strong in Table 3 since, although most of the challenge rules are known, a surprise rule or task is given to the participants on the competition day. Teams must solve the extra problem by adapting their robotic solution, without help from their coach within a specific time. In this way, teams evidence their problem-solving ability. Finally, since all robotics competitions involve applying problem-solving strategies to different contexts, none of the competition appears as Limited.

LO2: Self-Efficacy

According to Banduras' work, there are four self-efficacy sources, including enactive mastery experiences, vicarious experience, verbal/social persuasions, and emotional arousal [182]. Mastery experience is considered the most effective way of enhancing self-efficacy, and it has the most significant correlation with robotic competitions. This means that a person's sense of efficacy is boost by successful accomplishments. Besides, the difficulty of a task and the required amount of effort affects a person's perceived effectiveness. Students participating in robotics camps and competitions increase their self-confidence in performing robotics tasks as they experience designing and programming their robots. To achieve this, they must have specific roles and responsibilities while working in a team. Based on the above, we classify as Moderate the competitions that even though they require the contestants to work in small groups, their role is not clearly defined. For example, in the Sumo Robotex competition, teams consist of 2-5 students, with one member acting as the leader who is the robot's operator during the game. Accordingly, a bigger group that would be unable to offer sufficient time and space for its members to build their self-efficacy would be categorized as Limited, even though such a case has not been observed. Additionally, some of the competitions are Strong, like RoboCup Rescue League, FLL, or WRO. This category requires the participants to have defined roles and prove their work by presenting their robotic solution, answering clarifying questions, creating their robotic solution on the day of the competition, or effectively control their robot's action to perform specific robotic tasks.

LO3: Computational thinking

Decomposition, abstraction, algorithms, debugging, iteration, and generalization are the most common components of Computational Thinking based on the various definitions found in the research literature [183]–[185]. This means that participants in robotic competitions must systematically approach problems through a series of ordered steps. They must break down the problem into smaller parts of particular functionality and sequence the parts (decompositions), extract the most relevant information from a problem (abstraction), represent their solution as ordered instructions (algorithm), detect and fix possible errors in an incorrect answer (debugging), systematically test and modify the solution to achieve the most efficient solution (iteration) and quickly solve new problems based on previous solutions to problems (generalization). These Computational thinking facets are expected to be applied by the participants in robotics competitions' challenges. Since those facets are used in all competitors, none of them appears as Limited in Table 3. Focusing on the lack of generalization on the Project-based competitions, such as MakeX Spark, we categorize them

TABLE 3. Correlating the proposed learning outcomes with the competitions: • • • Strong, • • Moderate, • Limited.

	Problem Solving	Self-efficacy	Comp. Thinking	Creativity	Motivation	Collaboration
VEX IQ Challenge	• •	• •	• • •	• •	• • •	• • •
VEX Robotics Competition	• •	• •	• • •	• •	• • •	• • •
VEX U	• •	• •	• • •	• •	• • •	• • •
ABU Robocon	• •	• •	• • •	• •	• • •	• •
RoboParty	• •	• • •	• • •	• •	• •	• •
WRO - Regular Category	• • •	• • •	• • •	• •	• • •	• • •
WRO - Open Category	• •	• • •	• •	• • •	• • •	• • •
WRO - Football	• •	• • •	• • •	• •	• • •	• • •
Robotex - line-following	• •	• •	• • •	• •	• • •	• •
Robotex - Sumo	• •	• •	• • •	• •	• • •	• •
Robotex - Insplay Robo League	• •	• • •	• •	• • •	• • •	• • •
Robotex - Maze	• •	• •	• • •	• •	• • •	• •
Robotex - Race Challenges	• •	• •	• • •	• •	• • •	• •
Robotex - Advanced category	• •	• •	• • •	• •	• • •	• •
Robotex - Entrepreneurial Challenge	• •	• • •	• •	• • •	• • •	• • •
Robotex Girls Firefighting	• •	• •	• • •	• •	• • •	• •
FIRST Robotics Competition	• •	• •	• • •	• •	• • •	• • •
FLL Discover	• •	• • •	• •	• • •	• •	• • •
FLL Explore	• •	• • •	• •	• • •	• •	• • •
FLL Challenge	• •	• • •	• • •	• •	• • •	• • •
FIRST Tech Challenge	• •	• •	• • •	• •	• • •	• •
Robocup Soccer	• •	• •	• • •	• •	• • •	• •
RoboCup Rescue League	• •	• • •	• • •	• •	• •	• • •
RoboCup@Home	• •	• • •	• • •	•	• •	• • •
RoboCup Industrial Logistics	• •	• •	• • •	•	• •	• •
RoboCup@Work	• •	• • •	• • •	• •	• •	• • •
RoboCupJunior	• •	• • •	• • •	• •	• • •	• •
BEST	• •	• • •	• • •	• • •	• • •	• • •
FIRA Sports	• •	• •	• • •	• •	• • •	• •
FIRA Youth	• •	• •	• • •	• •	• •	• •
FIRA Challenges	• •	• •	• • •	• •	• • •	• •
FIRA AIR	• •	• •	• • •	• •	• •	• •
RoboGames	• •	• •	• • •	• •	• • •	• •
RoboMaster Robotic Competition	• •	• •	• • •	• •	• • •	• •
RoboMaster Technical Challenge	• •	• •	• • •	• •	• • •	• •
RoboMaster AIChallenge	• •	• •	• • •	•	• • •	• •
RoboMaster Youth Tournament	• •	• •	• • •	• •	• • •	• •
ROBO-ONE	• •	• •	• • •	• •	• • •	• •
MakeX - Spark	• •	• • •	• •	• •	• •	• • •
MakeX - Starter	• •	• •	• • •	• •	• • •	• • •
MakeX - Challenge	• •	• •	• • •	• •	• • •	• • •
MakeX - Premier	• •	• •	• • •	• •	• • •	• • •

as Moderate. On the contrary, on challenges like maze and line-following, students are expected to develop a generic code to perform successfully in any field. For instance, in a maze competition, students need to decompose the problem to understand how to exit the maze, grasp the major concepts that define the problem, and work on an algorithm applied to all mazes. In that sense, these competitions are Strongly enhancing the Computational Thinking skills of the participants.

LO4: Creativity

Building and programming a robot to do a specific mission is an intriguing task for the students' creativity. Robotics competitions promote students' creativity by challenging them to think of new solutions or recreate the existing ones using an innovative method. Our evaluation argues that games that use a standard ready to use the platform inhibit team creativity. An example is the RoboCup@Home Social Standard Platform League, where the team's invention is limited to developing their algorithms. As the students cannot design and construct their novel robotic structures, these competitions are classified as Limited. The rest of the matches are differentiated to Strong and Moderate based on the freedoms and constraints of the creative process. Research on creativity has revealed that putting limitations on the set of possible methods or recourses available to an innovative team can provide helpful boundaries to provoke and structure the collective creative process [186]. From this perspective, BEST competition is described as Strong since it allows for participants with specific and limited materials to construct their robotic structures. On the contrary, in a VEX challenge, the participating teams may use any number of parts, as long as they pick them exclusively from the original licensed parts.

L5: Motivation

Robotics competitions are motivational because they offer an exciting and fun learning environment, thus among 40 Challenges, there is no Limited evaluation in Table 3.

The nature of a challenge and the opportunities that competition can offer to the participants are the criteria that differentiate the Strong and Moderate effectiveness of games on participants' motivation. Competitiveness, demonstrated by the desire to defeat others, is an essential aspect of competition. Fighting robot challenges, like sumo, and robot games, like soccer, tend to attract and retain participants' interest and enjoyment. Two representative examples are the ROBO-ONE and FIRA Sports competitions, characterized as Strong based on the above criteria. Besides, prizes, travel grants, and the opportunity to participate in worldwide contests increase participants' motivation. In this way, the Robotex line-following challenge, which is neither fighting nor a gameplay challenge, is also evaluated as Strong, as it offers the winners of the regional competitions the opportunity to participate in the International Robotex contest.

L6: Collaboration

Collaboration allows individuals to work together to achieve bigger goals. However, the team's collaboration quality can affect its performance in a robotic competition. Also, teamwork requires shared accountability between individuals, the interdependence between them, and clarity of roles and goals. Thus, the absence of a team and the acceptance of individual participation in a robotic competition is characterized as Limited. Notably, for all of the matches presented in this paper, individuals are only allowed to participate as team members. However, having team-based participation is not the only criterion for a competition to be ranked as Strong for promoting participants' collaboration. Games without clearly defined roles are evaluated as Moderate, while the opposite leads to a Strong evaluation. Moreover, competitions like VEX or MakeX are also characterized as Strong, since they require participating teams to join forces and compete against other alliances. In this way, participants demonstrate their collaboration skills, as they must communicate, share knowledge, and exchange ideas with strangers to accomplish a common goal.

By observing the evaluation results presented in Table 3, one concludes that all competitions contribute to every learning outcome. It is observed that some competitions promote specific learning outcomes more than others. However, none of the competitions seems to contribute to all of the defined learning outcomes 'Strongly'. Only the Regular category of the WRO event and the BEST competition receive a 'Strong' rating in 5 out of 6 learning outcomes. The former has a 'Moderate' evaluation for the Creativity skill and the latter receiving a 'Moderate' evaluation for the Problem-Solving skill.

In regards to Problem Solving, all of the competitions except for one were classified as 'Moderate'. On the contrary, most of the competitions reveal a 'Strong' enhancement of the participants' Computational Thinking skills. Even though there is a 'Strong' link between Problem Solving and Computational Thinking, the different approaches to the evaluation criteria, including extra challenges and generalization, led to this result. The existence of a small team with defined roles and responsibilities played a significant role in both learning outcomes of Self-efficacy and Collaboration. Thus, these two learning outcomes display related results. The only difference is that the latter has an additional criterion for promoting the participants' Collaboration skills. The competitions that require alliances between stranger teams encourage more social interaction between them, as described above. It is noteworthy that 'Moderate' evaluation prevails in the Creativity's column, although it is considered one of the most common skills a student earns from activities involving robotics. Besides, Creativity is the only learning outcome where 'Limited' evaluation appears. Limitations on methods or recourses are the point of comparison that stretches participants' Creativity. Concerning the Motivation factors set on this paper, almost all of the competitions achieve to 'Strong'ly stimulate students' interest, with few exceptions achieving it to a lesser extent.

Overall, 'Strong' is the most frequent rating in both Computational Thinking and Motivation. This implies that, in general, competitions achieve to promote those skills. 'Moderate' assessment dominates in the Problem-Solving column, while in the rest of the learning outcomes, the results vary.

VII. CONCLUSION

The principal aim of this paper is to investigate the potential learning outcomes that a student is expected to develop by engaging in an educational robotics-related activity. We conclude a set of six key learning outcomes through a combination of the literature findings and the data taken from the 'Educational Robotics'-related index term bibliographic map (Figure 2). The proposed learning gains were adequately analyzed in Section III.

Also, driven by the ever-increasing ER platforms, the paper offers a thorough study of the commercially available ER kits. Each ER platform has an advisable age group that defines the difficulties an age group will face when using it. However, we consider the age criterion not efficient, as students' interest in learning is affected by their prior knowledge and programming skills. Based on these criteria, we propose three new categories for the ER platforms: No Code, Basic Code, and Advanced Code. Educators can consult this categorization to select the most appropriate teaching tool based on their educational background and interests. Similarly, new ER platforms may follow the proposed categories to help users choose the one that fits them best, based on their unique profile.

As robotics is developing, more complicated and sophisticated competitions are appearing. The most common robotics competitions are described in this paper. Contrary to the ER platforms, we do not classify the ER competition in the proposed categories as all competitions offer various challenges and allow the participation of various ER platforms. The final section explores the correlation between the six proposed learning outcomes with the described ER competitions. We identify the expected learning outcomes of each competition based on its characteristics, rules, and goals.

The competition's efficacy on the six learning outcomes was rated as Limited, Moderate, and Strong. In regards to Problem-Solving, the nearly unanimous results in favor of 'Moderate' show that there is room for improvement. For instance, based on our criteria, a competition that wishes to promote this skill can trigger the problem-solving process by offering extra challenges to participants on the competition day.

Furthermore, having team-based participation is not the most effective way to develop Self-efficacy. Clearly defined roles and responsibilities help participants to enhance their sense of efficacy. Results also show that, in their majority, competitions promote 'Strong' Computational-thinking and Motivation. Robotic challenges that employ generalization are more likely to boost Computational-thinking. In contrast, the nature of the robotic challenge, the award type, and the opportunity to participate in worldwide contests increase students' Motivation. Moreover, for a competition that wants to spark students' creativity, rules must introduce some limitations on the set of possible methods or recourses available. Finally, to support Collaboration among peers, besides encouraging team-working, a competition may include the concept of alliances between stranger teams.

From a pedagogical perspective, this paper aims at supporting robotic educators to design new or modify current robotic activities to help students develop the proposed skills. Also, we argue that the criteria set for evaluating each learning outcome can be used as guidelines to design new competitions that foster a more robust development of each skill.

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