A Systematic Review on the use of LEGO® Robotics in Education

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***Abstract*—Educational Robotics (ER) has revealed several benefits in the educational context, not only helping the teaching of disciplines, but also making possible the development of several abilities, such as teamwork, problem-solving, and creativity. Among various robotics kits, LEGO® Robotics has been shown one of the best results considering some evaluated criteria (modularity level, hardware, curriculum, price, etc.). Some studies analyze the teaching practices, some compare technologies, and others evaluate the kits in a pedagogical way. However, it is essential to investigate all these contexts together in order to improve the impact produced by the ER in education and to know the best teaching practices associated with the most powerful technologies. The objective of this Research Full Paper is to identify: a) environments and programming languages adopted in the LEGO® Robotics context, b) educational practices applied during classes based on LEGO® Robotics, and c) the educational levels in which robotics has been applied with positive results. To achieve these goals, we planned and carried out a systematic review of the literature. Our main findings are: a) the most widely used environment and programming language are LabVIEW along with the LEGO®'s block-based programming language, b) we identified LEGO® Robotics is used for teaching programming, interdisciplinary contents, participation in tournaments, robotics, and computational thinking, c) LEGO® Robotics is used with success by students of different levels, such as K-12, undergraduate, and graduated. Finally, we discuss some problems and limitations related to ER and point out that there is no standardization of teaching practices or methodologies for evaluating results, indicating that more research is needed to find the best scenario regarding technologies, methods, and target audience.**

I. Introduction

Educational Robotics (ER) is an educational tool indicated for teaching Science, Technology, Engineering and Mathematics (STEM) and Computer Science in all levels of education [40]. Seymour Papert has pioneered the use of computers and robots as a way of learning. He believed on learning by making, where students were encouraged to discover and build knowledge through practical activities [35]. Besides, several studies have demonstrated that ER is an approach to stimulate the development of various skills, such as teamwork, logical reasoning, critical thinking and creativity [8], [31]. ER is a multidisciplinary approach involving design, assembly and use of robots applying principles of engineering, computing, mathematics, physics, among other sciences.

The educational benefits of ER are provided by robotics kits and software in order to facilitate the programming of constructed robots. Currently, there are several robotics kits available for use, not only open source, such as Arduino but also commercials, such as LEGO® Mindstorms® and Fischertechnik. LEGO® Mindstorms® is widely used in schools around the world. According to Eigner *et al.*, "LEGO Mindstorms is probably the most popular modular robotics kit, building on the famous bricks and with a wide range of applications" [44].

LEGO® Mindstorms® NXT or EV3 promotes education both with its physical part, while building blocks, and in the LabVIEW visual programming environment, while programming the robots. According to Chambers *et al.* [10], activities based on building blocks have helped students to understand the concepts of gears and a vehicles speed, for example. The LabVIEW visual programming environment provides fun and direct programming learning and additionally stimulates the development of Computational Thinking [6].

Several works have analyzed the technological and pedagogical potential that robotics can offer for education. Kunduracolu investigated how to use LabVIEW with LEGO® Mindstorms® EV3 [27]. Hirst *et al.* examined the programming environments for LEGO® Mindstorms® available until 2003 [23], aiming to assist in choosing the environment for teaching LEGO® Robotics. Nevertheless, it was carried out in 2003, fifteen years ago. Eigner *et al.* investigated the development of communities that use robotics kits for educational purpose [44]. They pointed out that LEGO® Robotics is one of the most popular and has the best support for education.

Although previous works have analyzed the pedagogical potential of robotics, there is still very little understanding of the impacts and contributions that ER offer, considering hardware, software, and educational practices in the same context. The existing studies focus on specific criteria and commonly ignore the applied teaching methodology during activities. This fact may interfere in the analysis as a whole. As far as we know, there is no systematic review of literature that analyzed the use of LEGO® Robotics technology as an instrument for teaching, considering the robotics kits and its programming environments as a combination of teaching methodologies and practices.

In this context, it is necessary to know the best teaching practices associated with the most powerful technologies. The objective of this work is to identify: a) environments and programming languages adopted in the LEGO® Robotics context; b) educational practices applied during classes based

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on LEGO® Robotics; c) the educational levels in which robotics has been applied with positive results. To achieve these goals, we planned and carried out a systematic review of the literature (SRL) following the guidelines proposed by Kitchenham *et al.* [26].

This paper is organized as follows. In Section II, we present the related work. We describe the SRL process in Section III. In Section IV, we show the results answering the research questions. We discuss the primary information observed during the SRL in Section V. The threats to validity are presented in Section VI. Finally, in Section VII, we present the conclusions and pointers to further work.

II. Related Work

ER can promote students interest in education and scientific careers [6], [9], [29], [34]. The previous studies discuss teaching practices such as interdisciplinary teaching, teaching programming, and development of Computational Thinking.

Several studies argue over the educational potential of ER, but they only worry about the technological artifacts that support educational practices. Eigner *et al.* evaluated various robotics kits considering some criteria, such as quality of educational materials, development and extension possibilities, target audience, and modularity level [44]. All mentioned criteria are focused on educational resources in several robotics kits. Hirts *et al.* compared the programming environments for LEGO® Mindstorms® available until 2003 in order to assist in choosing the programming environment for teaching [23]. Kunduracoglu aimed at providing detailed information on how to use LabVIEW with LEGO® Mindstorms® EV3 [27].

To the best of our knowledge, there are no literature reviews focused on surveying the programming environments for teaching with LEGO® Robotics that cover pedagogical issues involved in the teaching process. Bers *et al.* [6], Ospennikova *et al.* [34], Rogers *et al.* [9], and Lupetti *et al.* [29] are focused on applied teaching practices, while Eiger *et al.* [44] analyzed some robotic kits. Besides, Eiger *et al.* used the popularity and availability of the manufacturers official materials as criteria to select the robotics kits for evaluation, without following a systematic process. In turn, Hist *et al.* compared the programming environments for LEGO® until 2003, but without obeying a systematic process [23].

In the context of SRL, Cheng *et al.* present an investigation of the characteristics of ER in six different target groups, such as Preschool, Elementary, High School, Higher Education, Adults and Elderly [12]. However, they did not evaluate considering the technological artifacts and pedagogical practices. Both aspects are essential to measure the effectiveness of learning through ER, especially if they are taken together in the same context. However, as far as we know, there is no SRL focused on technological artifacts and pedagogical practices in LEGO® Robotics.

III. Methodology

This section presents the methodology used in our SRL. We planned and executed an SRL following the guidelines proposed by Kitchenham *et al.* [26]. This SRL methodology has been gaining attention in the Software Engineering community because it follows a rigorous and auditable protocol allowing to evaluate available studies relevant to a particular field and answer research questions. In addition, it enables the identification of gaps in current researches, thereby opening possibilities for future work [26]. The detailed procedures are described in the following subsections.

A. Research Questions

The research questions proposed in this SRL aim to gather information about programming environments and educational practices in LEGO® Robotics classes. The research questions (RQ) are:

RQ1: What environments and programming languages have been used for teaching through LEGO® Robotics?

The objective of RQ1 is to identify environments and programming languages adopted in the LEGO® Robotics context.

RQ2: How LEGO® Robotics has been used in education?

The objective of RQ2 is to classify educational practices applied during classes based on LEGO® Robotics.

RQ3: What has been the target audience for the use of LEGO® Robotics?

The objective of RQ3 is to identify the educational levels in which robotics has been applied with positive results.

B. Conducted Search

Planning is an imperative activity for a consistent SRL. After the definition of RQs, the search string was constructed in the direction of supporting the search of the studies in the digital libraries. For this, we followed the guideline defined in the protocol:

- Identify the main keywords of the research questions;
- Identify related words and synonyms for keywords;
- Perform tests in databases and check the quality of the results. If necessary, select the related words and synonyms for the keywords again;
- In the search string, use the keywords, related words, and synonyms that returned the studies aligned with the research questions;
- Use OR Boolean to connect synonyms/related words and AND Boolean to connect keywords;
- Perform tests to evaluate the quality of the results. If necessary, remake the search string to obtain better results.

The main keywords were identified according to the research questions and the objective of the present study. The main keywords chosen were Environments, LEGO® and Robotics. The related words and synonyms for the keywords are shown in Table I.

After following the above-mentioned guideline, the search string was defined as:

((software OR programming OR environment OR package) AND (lego OR mindstorms) AND robotic)

The next step was to perform the search in the ACM, IEEEXplore, ScienceDirect (Elsevier), and Scopus digital libraries. These libraries were chosen because they presented

TABLE I
SYNONYMS FOR THE KEYWORDS

Keywords	Synonyms or related words
Environment	software OR programming OR environment OR package
LEGO®	Mindstorms®
Robotic	-

TABLE II
SUMMARY OF THE STUDIES RETURNED IN EACH DIGITAL LIBRARY

Digital Library	Search Results
ACM	36
IEEE	79
ScienceDirect	224
Scopus	1.024
Total	**1.363**

better results during the pilot test, besides they have been centralized the most publications related to Computer Science and Education. Table II shows the quantity of the studies returned in each digital library.

C. Screening of papers for inclusion and exclusion

The selection of the studies considered inclusion and exclusion criteria. The inclusion criteria defined were:

- Studies that address the use of LEGO® Robotics in teaching;
- Studies accessible electronically.

The exclusion criteria defined were:

- Studies that are outside the field of research;
- Studies that explore LEGO® Robotics for the teaching of any subject, but do not present evaluation, assessment, or validation;
- Studies that use LEGO® Robotics for the teaching of any subject, but do not contemplate robot programming;
- Non-peer reviewed studies, such as abstracts only, tutorials, editorials, slides, lectures, posters, panels, keynotes, and technical reports;
- Peer-reviewed studies, but not published in journals, conferences, or workshops, such as doctoral thesis, books, and patents;
- Studies whose language is not English;
- Studies published before 2013;
- Studies not accessible electronically.
- Duplicated and secondary studies.

Initially, we excluded duplicated and secondary studies. Then, the selection process was performed in two steps. In the first step, we read the titles and abstracts. The studies related to the mechatronics industry, using or not LEGO® Robotics, were excluded. So, we selected 315 studies that may help to answer the research questions. In the second step, the introduction, methodology and conclusion sections of the selected studies in the first step were read and the inclusion and exclusion criteria were applied. Studies which involved the development of LEGO® Robotics laboratories were withdrawn. In this phase, 36 studies fit the context of the research with information capable of answering the research questions. These studies were read and carefully analyzed in order to extract the information.

IV. RESULTS

This section details the results of our SRL. The research was conducted from October 2017 to April 2018. Initially, we will present the general results, including the distribution of publications by years, countries were the research has been done, types of publication vehicles and types of scientific research applied in the studies. Finally, the remaining sections answer each research question.

A. General Results

1) **Publication year:** The absolute number of studies by year of publication are presented in Figure 1. It is possible to note that there is a peak of publications in the years 2015 and 2016, both with 25% of papers each one. The years 2013, 2014, and 2017 presented a distribution of 11.11%, 22%, and 16.7%, respectively. These numbers demonstrate a growing interest of the scientific community in the use of LEGO® Robotics as an instrument for teaching since 2014.
2) **Countries distribution:** We observed that the United States of America is the country with the most significant number of papers involving LEGO® Robotics with eleven studies, followed by Germany with four studies. South Africa, Brazil, and Spain published three studies each one, while the United Kingdom, Italy, and Cyprus published two studies each one. Canada, Chile, Slovenia, Georgia, Greece, India, Japan, Puerto Rico, Portugal, and Saudi Arabia have only one published study each one. The fact that the United States of America leads the research in this area may be related to the country's investment in Computer Education since the first years of school. As robotics is one of the tools used to teach computational concepts, LEGO® Robotics stands out in

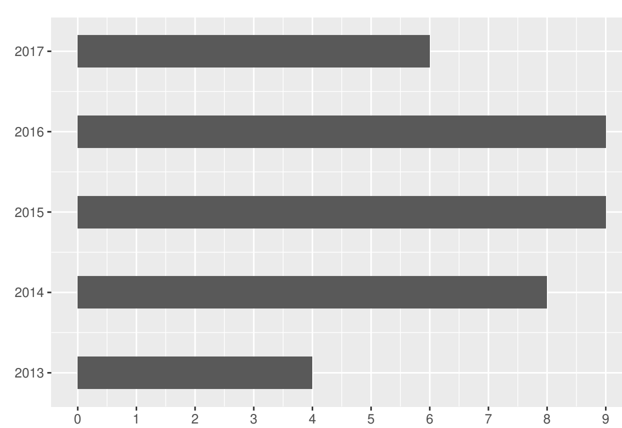

Fig. 1. The absolute number of studies by year of publication

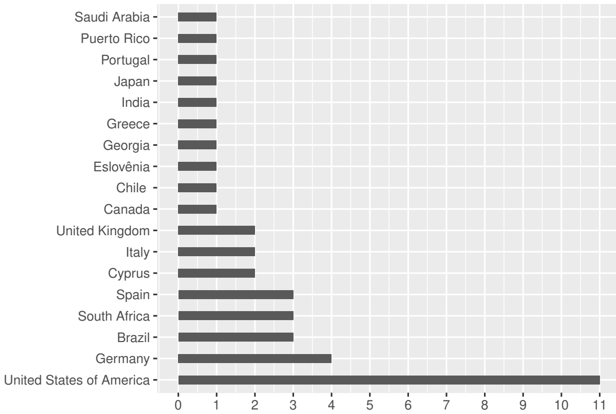

Fig. 2. Countries distribution

schools motivating research involving technology. The countries distribution where researches in this area have been done is shown in Figure 2. Note the number of studies is higher than the total of selected studies because some studies have authors from different countries.

3) **Publication vehicles:** The studies were published in Conferences (twenty-six studies), Symposiums (five studies), Journals (four studies), and Workshops (one study).
4) **Types of studies:** The studies were also classified by the adopted method (Figure 3). Most of selected studies presented the experiences with LEGO® Robotics in teaching some subject. Few studies showed validation, but those who did, showed only a comparative case study. The types of studies found in the selected papers were case study (twenty studies), experience report (fifteen studies), and experimental study (one study). We highlight that the descriptive and comparative case studies were classified only as a case study.

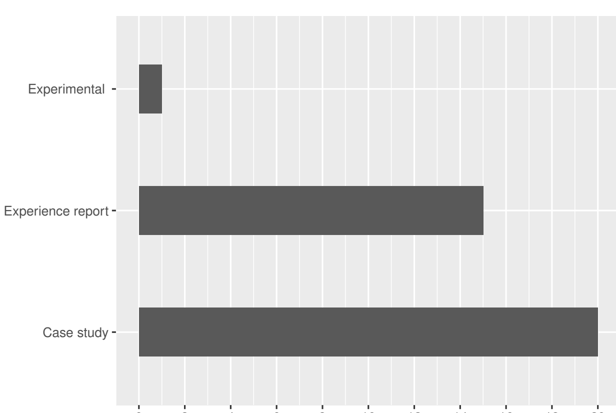

Fig. 3. Types of studies distribution

B. RQ1: What environments and programming languages have been used for teaching through LEGO® Robotics?

According to the selected studies, the programming environment most used for teaching though LEGO® Robotics is LabVIEW (twenty-eight studies), considering the LEGO® Mindstorm® NXT, EV3 or both. The NXT version (NXT-G) was used by nineteen studies, whereas the EV3 by seven studies, but two studies used both versions. LabVIEW is a development environment designed for LEGO® Mindstorm® Education products that allows students and teachers program robots through a specific block-based language.

The Eclipse environment was cited by two studies, while Lejos, Enchanting, BricxCC, AIA, and AdaCore were cited by only one study each one. Besides, the study [13] did not mention which environment was used. Table III summarizes the used environments identified in our SRL.

In Figure 4, we present the programming languages that have been used for teaching through LEGO® Robotics. The most commonly used programming language was block-language (total of thirty studies), out of which twenty-eight studies were related to LabVIEW NXT and/or EV3 ([43], [7], [2], [21], [11], [15], [51], [32], [16], [49], [19], [47], [14], [4], [45], [5], [41], [46], [22], [33], [48], [18], [25], [50], [3], [20], [42], [24]), while only one study was related to App Inventor plus ([1]), and finally, one study was related to Scratch ([30]). ScriptC language was used in two studies ([36], [37]), whereas NXC ([17]), JAVA ([38]), C# ([17]), ADA ([39]) language were used in one study each one.

C. RQ2: How LEGO® Robotics has been used in education?

Our second objective was to identify which teaching practices (approaches) have been applied during classes based on LEGO® Robotics. In addition, we were interested in understanding how these educational practices were applied.

In Figure 5 we show the distribution of the teaching practices described in the selected studies. LEGO® Robotics was applied to teach Programming in seventeen studies and

TABLE III
THE ENVIRONMENTS USED IN THE SELECTED STUDIES

Environments	Study	Frequency
LabVIEW (NXT)	[2], [3], [5], [7], [14], [18], [20], [22], [24], [25], [32], [33], [49], [41], [46], [45], [48], [50], [42]	19
LabVIEW (EV3)	[43], [21], [11], [15], [51], [19], [4]	7
LabVIEW (NXT / EV3)	[16], [47]	2
Eclipse	[36], [37]	2
Lejos	[38]	1
Enchanting	[30]	1
BricxCC	[17]	1
AIA	[1]	1
AdaCore	[39]	1
Not specified	[13]	1

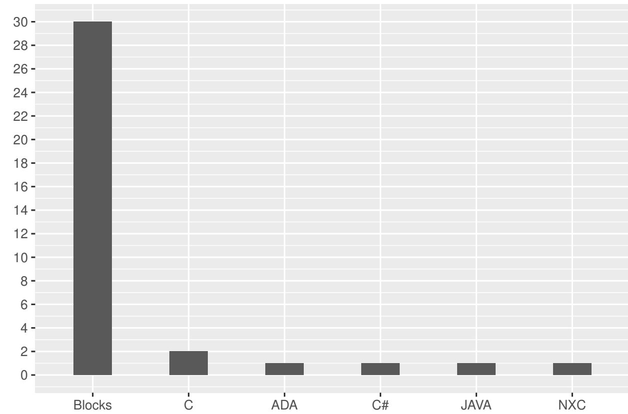

Fig. 4. Programming languages that have been used for teaching through LEGO® Robotics

Sciences through interdisciplinary activities (e.g. Physics, Mathematics, English, among others) in eight studies; the robotics itself as science (e.g. Mechatronics) in seven studies; tournament and Olympiads in two studies; and finally, Computational Thinking in two studies.

We highlight that "participation in tournaments and Olympiads" was classified separately due to its peculiar characteristics. Although this type of practice involves the use of programming strategies, it does not focus on teach programming itself. The culture involved in tournaments and Olympiads transcends the theoretical teaching, covering the social work and human development of students. In addition, we also identified a combination of others teaching practices, but without the same granularity.

Among all studies, two of them have as objective to stimulate Computational Thinking skills through the programming of robots [11], [24]. It is important to highlight the nomenclature "Computational Thinking" in the context of LEGO® robotics because it has gained attention in Computer and Education field, mainly in K-12.

In order to answer how teaching has been done we extracted the approach of the activities carried out. Thus, we obtained an overview of the practices used in classes with LEGO® Robotics. We identified twenty-seven approaches, but six were more common. They are based on: Practice activities, teamwork, theories, tournament and Olympiads challenges, projects, and problems. Table IV shows the frequency of the all identified approaches.

In Figure 6 we show the relation between the teaching proposals described in the selected studies and how they were offered to the target subjects. Considering the teaching of Science (STEM), we observed three studies were based on disciplines of the school curriculum and two studies in extra-curricular disciplines. One study was offered to children with learning disabilities. We decided to classify it as a single category because the methodology was focused on the target audience, not being applied to another group of students. The studies focusing on participation in tournaments and Olympiads (TO) were offered as extra-curricular disciplines (two studies). The proposals based on teaching programming (PRO) had different ways of offering: extra-curricular disciplines (four studies), courses (four studies), based on experiments (three studies), and as a curricular discipline (three studies). The studies focusing on teaching robotics as science (RS) were offered as an elective curricular discipline (two studies), curricular discipline (two studies), camping course (two studies), and course (one study). Finally, the studies focusing on Computational Thinking (CT) were offered as camping course and workshop.

We also identified how the participants were selected for each teaching proposal. The participants could be (i) an exclusive group, (ii) all students in a class, (iii) a random group, or (iv) a free group. In the free group, the students could choose whether or not to participate in the research, while in the random group, the students were randomly chosen from the class. Considering the teaching of Science, an exclusive group were selected by four studies, all students in a class were selected by three studies, and a free group in one study. Studies that focused on tournaments and Olympiads were

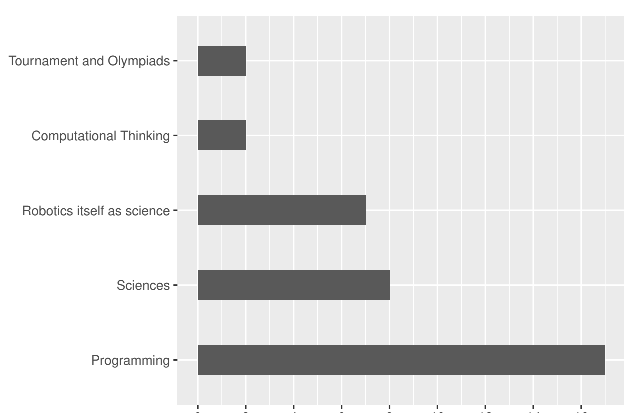

Fig. 5. The teaching proposal of the selected studies

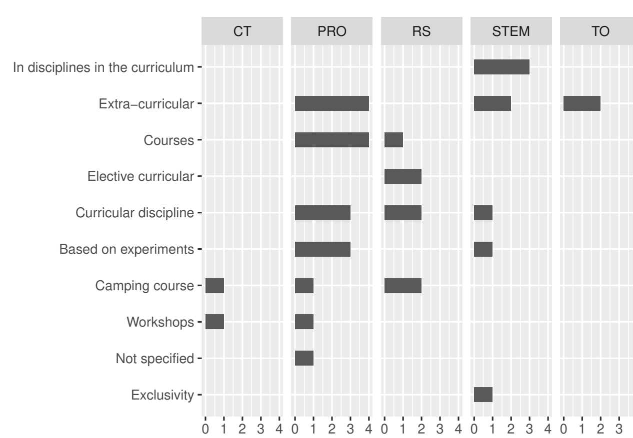

Fig. 6. Teaching proposal and how it was offered

TABLE IV
THE APPROACHES IDENTIFIED IN THE SELECTED STUDIES

Approaches based on	**Study**	**Frequency**
Practice activities	[7], [2], [11], [15], [51], [32], [16], [49], [36], [4], [39], [30], [37], [45], [5], [41], [46], [22], [33], [1], [18], [25], [50], [20], [42], [24]	26
Teamwork	[43], [17], [7], [2], [47], [14], [4], [39], [30], [13], [41], [46], [22], [33], [48], [1], [20], [42], [24]	18
Theory	[7], [11], [15], [51], [32], [16], [49], [39], [37], [45], [5], [41], [46], [22], [33], [18]	16
Tournament and Olympiads challenges	[15], [32], [16], [47], [41], [46], [22], [33], [25], [24]	10
Projects	[47], [47], [41], [46], [22], [1], [20], [42], [24]	9
Problems	[49], [36], [4], [39], [30], [5], [13], [3]	8
Organization and responsibilities	[41], [46], [22], [1]	4
Discussions	[18], [25], [50], [24]	4
Robot design, implementation and programming	[48], [1], [18], [25]	4
Lectures	[20], [42], [24]	3
Robot design and programming activities	[22], [50]	2
Creativity	[24]	1
Digital teaching platforms	[5]	1
Individual work	[4]	1
Read and write activities	[18]	1
Built robots and programming	[21]	1
Knowledge level	[47]	1
Laboratory activities	[51]	1
Game-based learning	[14]	1
Project management	[1]	1
Experimental	[21]	1
Diagnosis	[15]	1
Contextualization	[18]	1
Presentation of seminars	[4]	1
Inquiry	[3]	1
Environment of LEGO® kit	[18]	1
Not specified	[19], [38]	2

restricted to an exclusive group in two studies, while those focusing on teaching programming were exclusive group (four studies), all students in a class (three studies), and random group (one study). Teaching robotics as science was offered to an exclusive group in three studies and all students in a class in four studies. Finally, teaching computational thinking was offered to all students in a class in two studies.

D. RQ3: What has been the target audience for the use of LEGO® Robotics?

The subjects of the selected studies were students at different educational levels (in thirty-three studies), teachers (in two studies), and both (in one study). Considering the students, pupils (from primary and secondary education) were the leading audience (twenty-four studies), followed by undergraduate students (ten studies). Postgraduate students were the audience of one study. We could not identify the target audience in one study. In Figure 7 we summarize the distribution of the target audience.

V. DISCUSSION

A. Programming environments over the years

Figure 8 presents the number of selected studies over the years considering the programming environments. We observed that the use of LabVIEW for the NXT version had an increase and after a decrease. In 2013, four studies were published ([3], [20], [42], [50]), while in 2014, the number increased to seven studies ([18], [22], [24], [25], [33], [46], [48]), followed by four studies ([5], [14], [41], [45]) in 2015, considering only the NXT version. In the following years, the published studies for the NXT version decreased, while the EV3 gained space from 2015 ([11], [15], [16], [19], [47]), considering those who used EV3 and/or both. Finally, in 2017, the EV3 environment had three studies ([21], [43], [51]). This behavior may occur because the EV3 was launched in 2013, while NXT in 2006 (older). Thus, it is possible to observe that after the release of EV3, it took two years for the first study to be published. This time span may be related to the investments necessary to buy the kits and the learning curve required for the teachers to start using the kits.

The LEGO® Mindstorm® EV3 version presented more advanced technology when compared to the NXT version. While the developers have maintained the block-based programming and other functions, the modernization of the

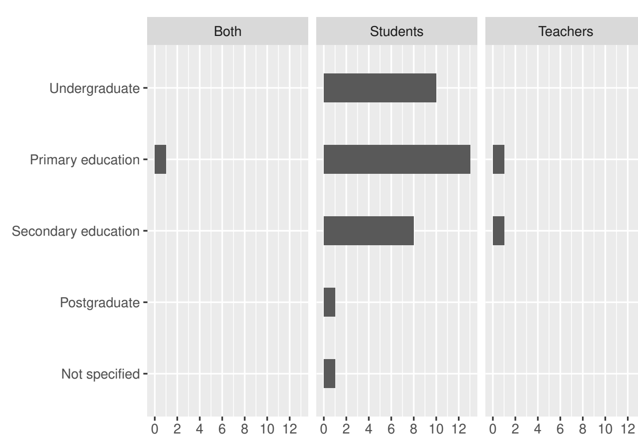

Fig. 7. Summarizes the distribution of the target audience

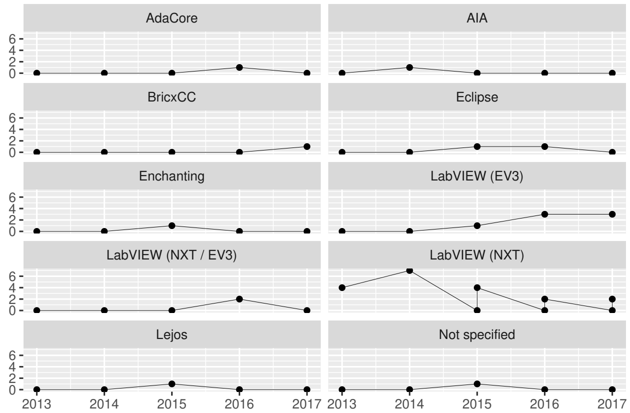

Fig. 8. Number of selected studies over the years, considering the programming environments

LEGO® Mindstorm® EV3 kit has brought new technological possibilities for building and programming robots. Thus, dedication and time for teachers to learn the new possibilities, especially for primary and secondary (K-12) school teachers that had the largest number of publications in this study SRL.

Finally, the years 2015 and 2016 presented a greater variety of development environments, even in small numbers. Lejos ([38]), Enchanting ([30]), and Eclipse ([37]) in 2015 and AdaCore ([39]) in 2016 were used. These environments are free and can be used by changing the firmware of the LEGO® processor. This fact may be related to the popularization of robotics since the publications have grown according to Figure 8. In addition, it is possible that the use of other environments with LEGO® Robotics is a response to the high investments required to use LabVIEW.

B. LEGO® Robotics in K-12

LabVIEW was the leading environment in all the three education levels, but it was more applied in K-12 (twenty-one studies). Among these studies, seven were applied in interdisciplinary teaching sciences ([14], [16], [18], [21], [45], [46], [47]), two focused on tournaments and Olympiads ([43], [48]), seven focused on programming ([3], [4], [5], [7], [15], [25], [33]), three focused on robotics as Science ([2], [19], [32]), followed by Computational Thinking in two studies ([11], [24]).

Several contents have been taught in K-12 using LEGO® Robotics. In [45] and [46] the authors addressed the teaching of physics through practical activities, while in [21], they addressed biology and experiments. The results presented in [16] and [47] were carried out in disciplines of the technological area. However, the methodology of the papers mentioned above involved contents of others sciences, such as mathematics and physics, and participation in tournaments and Olympiads. In [14] the authors addressed robotics concepts and programming for students with learning disabilities and learning difficulties. This study contributed to the inclusive education through playful learning. Finally, in [18] the authors reported robotics classes in language teaching.

In this context, we observed that ER is used as an interdisciplinary science, as explained by Bers et al. [6], Ospennikova et al. [34], Rogers et al. [9] and Lupetti et al. [29]. This diversification may indicate that the activities were carried out by teachers who not necessarily have technological training in block-based programming with LabVIEW. This way of programming may be one of the reasons for the high acceptance of this programming environment in K-12 because block-based programming favors the construction of small programs, even by people without prior knowledge about programming and Computer Science.

The default firmware of LEGO® Mindstorm® kit configured with LabVIEW. Thus, the teachers tend to use the LEGO® kit with factory default settings because changing factory settings requires technical knowledge, which may indicate another reason that can influence the use of LabVIEW in K-12.

Tournaments and Olympiads are also very popular in ER. The studies in [43] and [48] were focused on tournaments and Olympiads using LabVIEW. Both studies referred to the First LEGO® League[1] (FLL) tournament, a worldwide competition that allows students to learn STEM concepts by playing and using the imagination to solve problems. In addition, the competitors can develop critical thinking and team-building skills [28]. In FLL, all equipment used by competing teams, including programming and language environments, must be LEGO® products. However, there are several tournaments and Olympiads that do not restrict the use of equipment and that achieve similar results comparing to those proposed by FLL, such as Robocup[2].

C. LEGO® Robotics in Higher Education

LabVIEW was also the leading environment in Higher Education (six studies), but using non block-based languages, such as JAVA, ADA, C, NXC, and C# (in four studies) focused on teaching programming. The study in [36] was conducted in a Computer Science course using Eclipse, while the study [37] followed the same context but for the Mechatronics course. In [39], the authors used Adacore and ADA languages in a Computer Science course. Finally, the study described in [17] used BricxCC and NCX languages in elective robotics discipline in a Computer Science course. Furthermore, LabVIEW was also used in Engineering courses in six studies ([20], [41], [42], [49], [50], [51]).

D. LEGO® Robotics and teaching practices

Teaching practices have stimulated the students' activities while teachers have been mediators. The selected studies showed that ER promotes learning by making use of programming. In this direction, the students have been encouraged to develop their activities following the ER basic foundation, as Papert's Constructionism says "that learning is most effective when part of an activity the learner experiences as constructing a meaningful product".

[1] www.firstlegoleague.org
[2] www.robocup.org

Teamwork and problem solving have been used as approaches to stimulate some students' skills, such as analyze, manipulate, execute, debug, re-execute, and practice. These skills can assist the learning of theoretical content thought practices activities. Our SRL indicates that when facing problems proposed by the teacher, the students can be able to perform tasks in a more skillful and objective way. Developing those abilities is one of the primary goal in ER. Then, LEGO® Robotics has been recognized by the scientific community as an instrument for teaching.

VI. Threats to Validity

Although our research has followed the protocol, some issues threaten the validity of our SRL. The selected studies have a direct relationship with the search engine of the virtual libraries because each one has specific characteristics. In this way, the search performed in the libraries may not have returned all relevant studies. Besides, we only considered full studies published at scientific events (conference, symposium, workshops) and journals. Considering the objectives of this SRL involve practical activities, it may be presented to the academy in other types of study. Then, it is possible that relevant studies were outside the scope of SRL. Besides, human factors can also influence the data extraction of the selected studies. Although all the selected studies were read more than one time in order to minimize the bias, it is possible that relevant information has not been considered or misinterpreted, since the data extraction is a manual process.

VII. Conclusions and Future Works

Educational robotics is a pedagogical approach that relates social and educational skills and it has increasingly attracted the students' interest. This SRL allowed us to understand that there are several possibilities of applying LEGO Robotics in the educational context. The main positive findings were: a) the main approaches are teamwork and problem solving involving interdisciplinary contents in the K-12 level; b) LabVIEW is the most used environment because programming details are hidden from the students.

We answered three research questions related to environments and programming languages associated with "what" has been taught through LEGO® Robotics, "how" and "for whom". First, we found that the programming environment most used was LabVIEW, using NXT and EV3 versions. The programming language most used was the block-based programming languages. Second, we identified that LEGO® Robotics is used for teaching programming, interdisciplinary contents (STEM), participation in tournaments and Olympiads, and computational thinking. We also observed teamwork and problem solving as main approaches, which stimulated students to analyze, manipulate, execute, debug, re-execute, and practice with robotics kits. Finally, LEGO® Robotics is used with success by students of different levels, such as K-12, undergraduate, and graduated (mainly teachers). The studies were not classified by age group and gender because not all papers presented detail of these topics.

The methodological aspects of the papers considered in this SRL were observed. We noticed that the existing research that addresses the use of LEGO® Robotics did not demonstrate results based on statistical methods to validate the potential of technology for teaching. Furthermore, some of these studies did not present methodological or pedagogical foundations well established. We identified Papert ideas, where students are encouraged to take more responsibility for their learning. However, most studies cannot be replicated because the methodological description, learning objective, or evaluation criteria were not well presented. Another open problem is that the studies only consider the practical application of robotic environments and it is still necessary to investigate which is the most appropriate depending on the level of education. Moreover, several free robotic environments have been proposed as alternatives to LabVIEW. Thus, it is important to define metrics to compare these environments.

Although Computational Thinking has gained attention in Education in the last decade, only two studies were found in our SRL. Those studies which explored Computational Thinking were focused on teaching programming, i.e., algorithmic thinking mainly. Therefore, we highlight the importance of researches focusing on stimulating Computational Thinking skills thought robotics kits, such as LEGO®. Then, future works can be carried out on how to promote and assess Computational Thinking skills using LEGO®.

We hope that this SRL can assist the educational community on how to use LEGO® Robotics in instructional practices. The programming environments, languages, teaching practices, and approaches identified here can help to provide an overview of LEGO® Robotics in education. Finally, we suggest that the educational community should better describe the methodological procedures and evaluative methods in order to allow research replication.

References

[1] S. AlHumoud, H. S. Al-Khalifa, M. Al-Razgan, and A. Alfaries. Using app inventor and lego mindstorm nxt in a summer camp to attract high school girls to computing fields. In *IEEE Global Engineering Education Conference, EDUCON*, pages 173–177, 2014.

[2] I. J. B. Alvarez. Introduction to robotics: Importance of a summer camp as a recruiting tool for future university students. *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, 12(2):71–75, 2017.

[3] J. Arlegui, A. Pina, and M. Moro. A pbl approach using virtual and real robots (with byob and lego nxt) to teaching learning key competences and standard curricula in primary level. In *ACM International Conference Proceeding Series*, pages 323–328, 2013.

[4] O. Asinobi, J. Allison, M. McKinney, S. Flynn, M. Black, and A. Moore. Empirical findings: The use of robotics to engage the youth from lower socio-economic areas. In *ISTAS'16*, 2016.

[5] V. B. Barreto, A. L'Erario, and J. A. Fabri. Teaching programming for high school students using the lego mindstorms robot. In *10th Iberian Conference on Information Systems and Technologies (CISTI'15)*, 2015.

[6] M. U. Bers, L. Flannery, E. R. Kazakoff, and A. Sullivan. Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, 72:145 – 157, 2014.

[7] R. N. Beyers and L. v. d. Merwe. Initiating a pipeline for the computer industry: Using scratch and lego robotics. In *ICTAS'17*, pages 1–7, 2017.

[8] S. Blanchard, V. Freiman, and N. Lirrete-Pitre. Strategies used by elementary schoolchildren solving robotics-based complex tasks: innovative potential of technology. *Procedia - Social and Behavioral Sciences*, 2(2):2851 – 2857, 2010. Innovation and Creativity in Education.

[9] E. Cejka, C. Rogers, and M. Portsmore. Kindergarten robotics: Using robotics to motivate math, science, and engineering literacy in elementary school. *International Journal of Engineering Education*, 22(4):711–722, 2006.

[10] J. Chambers, M. Carbonaro, and H. Murray. Developing conceptual understanding of mechanical advantage through the use of lego robotic technology. *Australasian Journal of Educational Technology*, 24(4), 2008.

[11] V. Chaudhary, V. Agrawal, P. Sureka, and A. Sureka. An experience report on teaching programming and computational thinking to elementary level children using lego robotics education kit. In *Proceedings - IEEE 8th International Conference on Technology for Education, T4E 2016*, pages 38–41, 2017.

[12] Y. W. Cheng, P. C. Sun, and N. S. Chen. An investigation of the needs on educational robots. In *2017 IEEE 17th International Conference on Advanced Learning Technologies (ICALT)*, pages 536–538, July 2017.

[13] J. Chetty. Lego mindstorms: Merely a toy or a powerful pedagogical tool for learning computer programming? In *ACSC*, 2015.

[14] C. Conchinha, P. Osrio, and J. C. De Freitas. Playful learning: Educational robotics applied to students with learning disabilities. In *2015 International Symposium on Computers in Education, SIIE 2015*, pages 167–171, 2016.

[15] S. Davrajh and R. Stopforth. Integrating lego mindstorms and developmental outcomes to address engineering education in previously disadvantaged secondary schools. In *2016 Pattern Recognition Association of South Africa and Robotics and Mechatronics International Conference, PRASA-RobMech 2016*, 2017.

[16] O. L. Dos Santos, D. Cury, J. Rafalski, and P. D. N. Silveira. An iot computational robotics learning laboratory in vila velha, espirito santo. In *Proceedings - 2016 11th Latin American Conference on Learning Objects and Technology, LACLO 2016*, 2016.

[17] F. J. Estrada. Practical robotics in computer science using the lego nxt. In *Annual Conference on Innovation and Technology in Computer Science Education, ITiCSE*, volume Part F128680, pages 329–334, 2017.

[18] N. Eteokleous and D. Ktoridou. Educational robotics as learning tools within the teaching and learning practice. In *2014 IEEE Global Engineering Education Conference (EDUCON)*, pages 1055–1058, April 2014.

[19] M. T. Frye, S. C. Nair, and A. Meyer. Evaluation of minigems 2015 - engineering summer camp for middle school girls. In *ASEE Annual Conference and Exposition, Conference Proceedings*, volume 2016-June, 2016.

[20] D. J. Gail, J. S. Sally, G. T. Tom, and H. Kuang-Ting. Novel program for engineering student retention. In *ASEE Annual Conference and Exposition, Conference Proceedings*, 2013.

[21] L. C. Gerber, A. Calasanz-Kaiser, L. Hyman, K. Voitiuk, U. Patil, and I. H. Riedel-Kruse. Liquid-handling lego robots and experiments for stem education and research. *PLoS Biology*, 15(3), 2017.

[22] R. Grandi, R. Falconi, and C. Melchiorri. Robotic competitions: Teaching robotics and real-time programming with lego mindstorms. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 19, pages 10598–10603, 2014.

[23] A. J. Hirst, J. Johnson, M. Petre, B. A. Price, and M. Richards. What is the best programming environment/language for teaching robotics using lego mindstorms? *Artificial Life and Robotics*, 7(3):124–131, 2003.

[24] S. P. Imberman, D. Sturm, and M. Q. Azhar. Computational thinking: Expanding the toolkit. In *Journal of Computing Sciences in Colleges*, 2014.

[25] J. S. Kay, S. Engelman, J. G. Moss, and T. McKlin. Sneaking in through the back door: Introducing k-12 teachers to robot programming. In *SIGCSE 2014 - Proceedings of the 45th ACM Technical Symposium on Computer Science Education*, pages 499–504, 2014.

[26] B. Kitchenham and S. Charters. Guidelines for performing systematic literature reviews in software engineering. In *Technical report, Ver. 2.3 EBSE Technical Report. EBSE*. sn, 2007.

[27] . Kunduracolu. Examining the interface of lego mindstorms ev3 robot programming, 2018.

[28] F. L. League. What is first lego league?, 2018.

[29] M. L. Lupetti, Y. Yao, H. Mi, and C. Germak. Design for children's playful learning with robots. *Future Internet*, 9(3), 2017.

[30] A. Merkouris and K. Chorianopoulos. Introducing computer programming to children through robotic and wearable devices. In *ACM International Conference Proceeding Series*, volume 09-11-November-2015, pages 69–72, 2015.

[31] D. P. Miller, I. R. Nourbakhsh, and R. Siegwart. *Robots for Education*, pages 1283–1301. Springer Berlin Heidelberg, Berlin, Heidelberg, 2008.

[32] P. Navarrete, C. J. Nettle, C. Oliva, and M. A. Solis. Fostering science and technology interest in chilean children with educational robot kits. In *Proceedings - 13th Latin American Robotics Symposium and 4th Brazilian Symposium on Robotics, LARS/SBR 2016*, pages 121–126, 2016.

[33] Y. Ohnishi and S. Mori. A practical report of programing experiment class for elementary school children. In *Proceedings of the 2014 International Conference on Advanced Mechatronic Systems*, pages 291–294, Aug 2014.

[34] E. Ospennikova, M. Ershov, and I. Iljin. Educational robotics as an inovative educational technology. *Procedia - Social and Behavioral Sciences*, 214:18 – 26, 2015.

[35] S. PAPERT. Constructionism: A new opportunity for elementary science education. 1986.

[36] S. R. Perez, A. Fatoum, and J. Abke. Development of an eclipse plug-in for using the lego mindstorms ev3 in education. In *IEEE Global Engineering Education Conference, EDUCON*, volume 10-13-April-2016, pages 631–636, 2016.

[37] S. R. Perez, C. Gold-Veerkamp, J. Abke, and K. Borgeest. A new didactic method for programming in c for freshmen students using lego mindstorms ev3. In *Proceedings of 2015 International Conference on Interactive Collaborative Learning, ICL 2015*, pages 911–914, 2015.

[38] A. Rao. The application of lejos, lego mindstorms robotics, in an lms environment to teach children java programming and technology at an early age. In *ISEC 2015 - 5th IEEE Integrated STEM Education Conference*, pages 121–122, 2015.

[39] C. Rodrguez, J. L. Guzman, M. Berenguel, and S. Dormido. Teaching real-time programming using mobile robots. *IFAC-PapersOnLine*, 49(6):10–15, 2016.

[40] C. Rogers and M. Portsmore. Bringing engineering to elementary school. In *Journal of STEM Education : Innovations and Research; Auburn*, volume 5, pages 17–28, 2004.

[41] I. Rothe. Work in progress: Starter-project for first semester students to survey their engineering studies. In *IEEE Global Engineering Education Conference, EDUCON*, volume 2015-April, pages 1–4, 2015.

[42] A. L. Sala. Infusing mechatronics and robotics concepts in engineering curriculum. In *ASEE Annual Conference and Exposition, Conference Proceedings*, 2013.

[43] B. Strnad. Programming lego mindstorms for first lego league robot game and technical interview. In *2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, pages 958–960, May 2017.

[44] A. Takacs, G. Eigner, L. Kovacs, I. J. Rudas, and T. Haidegger. Teacher's kit: Development, usability, and communities of modular robotic kits for classroom education. *IEEE Robotics and Automation Magazine*, 23(2):30–39, 2016.

[45] F. Tuluri. Using robotics educational module as an interactive stem learning platform. In *ISEC 2015 - 5th IEEE Integrated STEM Education Conference*, pages 16–20, 2015.

[46] M. Usselman, M. Ryan, J. H. Rosen, J. Koval, S. Grossman, M. N. A. Newsome, and M. N. Moreno. Robotics in the core science classroom: Benefits and challenges for curriculum development and implementation (rtp, strand 4). In *ASEE Annual Conference and Exposition, Conference Proceedings*, volume 122nd ASEE Annual Conference and Exposition: Making Value for Society, 2015.

[47] W. Wang. A mini experiment of offering stem education to several age groups through the use of robots. In *ISEC 2016 - Proceedings of the 6th IEEE Integrated STEM Education Conference*, pages 120–127, 2016.

[48] I. Weissberger, A. Qureshi, and A. Qureshi. Delivering software engineering education through lego robotics. In *Proceedings of the 9th International Conference on Computer Science and Education, ICCCSE 2014*, pages 169–176, 2014.

[49] R. H. Wong and S. Hsieh. Maker: An entry-level robotic system design project for undergraduates and k12. In *ASEE Annual Conference and Exposition, Conference Proceedings*, volume 2016-June, 2016.

[50] A. lvarez and M. Larraaga. Using lego mindstorms to engage students on algorithm design. In *2013 IEEE Frontiers in Education Conference (FIE)*, pages 1346–1351, Oct 2013.

[51] N. . zorun and H. Bicen. Does the inclusion of robots affect engineering students' achievement in computer programming courses? *Eurasia Journal of Mathematics, Science and Technology Education*, 13(8):4779–4787, 2017.