Educational Robotics Applied to Computational Thinking Development: A Systematic Mapping Study

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***Abstract*—Educational Robotics (ER) is a tool that can favor teamwork, stimulate creativity, and the ability to solve students' problems through the process of assembling and programming robots. In this sense, ER has been used to improve educational practices. There are several initiatives that seek to stimulate Computational Thinking (CT) to stand out. Although ER being used to develop CT, there are still no guidelines based on scientific studies that support this use. The objective of this Research Full Paper is to identify: a) the main pedagogical approaches are applied in classes with ER focused on developing students' CT; b) the central difficulties are encountered in classes with ER focused on developing students' CT; c) the CT skills are presents in classes with ER focused on developing students' CT; d) the instruments are used to assess students' CT during classes with ER; e) the students 'profile who participated in classes with ER focused o on developing students' CT; f) the educational robotics technologies are adopted in classes focused on developing students' CT. To achieve these goals, we planned and carried out systematic mapping of the literature. The results show that, through ER, CT is approached through the teaching of programming languages in a collaborative way in Early Childhood and High School. The most CT skills observed are related to programming, such as sequencing, algorithm, loop, generalization, decomposition, and debugging. The main instruments for assessing students are tests, and the most significant difficulty is the limitation of class hours. Finally, LEGO® is the most used technology in class.**

I. Introduction

Educational Robotics (ER) is a tool that, through a process of assembling and programming robots, can favor teamwork, stimulate creativity and the ability to solve students' problems. The ER covers interesting and motivating didactic-pedagogical conditions, that is, it can create situations, make conditions more flexible so that active learning occurs [36], [41].

ER has been widely used in order to improve educational practices at different levels of education. There are several initiatives, among them, those to stimulate Computational Thinking (CT) [14] and [56]. CT is a set of "strategies to understand and solve problems in order to harness the power of technological methods to develop and test solutions" [32]. The CT encompasses mental skills that simplify understanding and problem solving, situations that can be observed when scientists solve problems [34].

Although ER is used to develop CT, there are still no guidelines based on scientific studies that support this use. In this sense, we present a Systematic Mapping Study (SMS), based on Petersen's guidelines [49], to understand how ER has been used to stimulate CT skills in students in the last 11 years (2009 to 2020). For this, we defined the following research questions: RQ1: Which educational strategies have been used to stimulate CT through ER? RQ2: What educational difficulties have been identified during class to stimulate CT through ER? RQ3: Which CT skills have been observed during ER classes? RQ4: What tools or instruments have been used to evaluate the CT during ER classes? RQ5: What has been the target audience for the use of ER to stimulate CT? RQ6: What robotics kits have been used in class to stimulate CT through ER?

The results indicate that ER is most used to work teaching programming, CT, robotics like sciences, STEM, and mathematics collaboratively in Elementary School and High School. The most CT skills observed are related to programming, such as sequencing, algorithm, loop, generalization, decomposition, and debugging. The main research instruments for student CT skills assessment are logical reasoning tests by authors' studies, and the most significant difficulty is the limitation of class hours. Finally, the LEGO ® kit is the most used in classes.

This work is organized as follows: in Section II, we present the related works; in Section III we describe the methodology; in Section IV, we summarize the results obtained from the mapping; in Section V, we discuss some aspects of these results; in Section VI we identify threats to validity; and finally, in Section VII, we show the conclusions and suggestions for future works.

II. Related Work

The ER has been proposed to promote students' interest in education, science, and technology, as in [14], [18], [39]. These works investigate ways to use ER in the classroom and propose some teaching practices such as interdisciplinary, programming, and CT.

For Hsu *et al.* (2018), the CT is an important and necessary competence to adapt to the future. However, there is still no guidance on how to teach it. That said, the authors carried out a literature review to understand how the CT is worked in continuing education courses. The results showed that the CT has been applied, above all, in the context of teaching programming, being the ER observed as one of the educational instruments used [29].

Another review of the literature tries to understand how ER is used in schools. The results of this review suggest that ER generally favors the improvement of learning. However, it cannot be generalized, as studies report cases in which the improvement in learning was not verified [13].

In a previous work, we performed a literature review in order to analyze the use of LEGO® technology in education considering technological and methodological aspects related to teaching practices [54]. In this SMS, we seek to understand how ER is used in the educational field as a whole and not focused only on a specific technology. In addition, it is necessary to understand how ER is used in classes, seeking to stimulate CT in students.

III. Methodology

This study is SMS to help to understand the theme gaps through the categorization of the primary studies. For this, we adopted the systematic mapping protocol for Software Engineering proposed by Petersen *et al.* [49]. The detailed procedures are described in the following subsections.

In this SMS, we adopted the CT definition by Wing (2006) that classifies it as problem-solving skills based on Computer Science concepts that need to incorporate the learning of CT skills at early ages [34].

A. Research Questions

Aiming to obtain a better understanding of the use of ER in the scope of the CT in the last 11 years (from 2009 to 2020), we intended to answer the following research questions (RQ) were defined to guide this SMS:

RQ1: Which educational strategies have been used to stimulate CT through ER? *The aim is to identify the main pedagogical approaches are applied in classes with ER focused on developing CT skills.*

RQ2: What educational difficulties have been identified during class to stimulate CT through ER? *The purpose is to identify the central difficulties are encountered in classes with ER focused on developing CT skills.*

RQ3: Which CT skills have been observed during ER classes? *The purpose is to identify which CT skills are observed in classes with ER focused on developing CT skills.*

RQ4: What tools or technologies have been used to evaluate the CT during ER classes? *The purpose is to identify the instruments are used to assess students' CT during classes with ER.*

RQ5: What has been the target audience for the use of ER to stimulate CT? *The aim is to identify the students 'profile who participated in classes with ER focused on developing CT skills.*

RQ6: What robotics kits have been used in class to stimulate CT through ER? *The purpose is to identify which educational robotics technologies are adopted in classes focused on developing CT skills.*

B. Studies Selection

Promising results from a bibliographic search of the systematic mapping type result from the definition and application of planning. After the description of RQs, we define and follow specific guidelines considering the protocol by Petersen *et al.* [49], they are: 1) Identify the main keywords of the research questions; 2) Identify synonyms/related words for keywords; 3) Perform tests in digital libraries and check the quality of the results. If necessary, redo the previous guideline; 4) Build a search string using the defined synonyms/related words that returned the studies aligned with the research questions; 5) Use the *OR* Boolean to connect synonyms/related words and *AND* Boolean to join keywords in the building of the search string; 6) Conduct tests to assess the quality of the results. If necessary, redo the sequence for the best results.

The main keywords defined were: "Educational Robotics" and "Computational Thinking". Synonyms/related words were defined as "Pedagogical Robotics" and "Programming Teaching" (see Table I)). Considering the prevalence of studies written in English in the most relevant virtual libraries in Computer Science and Education, the keywords, synonyms/related were written in English, generating the following search string:

(((educational robotics) OR (pedagogical robotics)) AND ((computational thinking) OR (programming teaching)))

TABLE I
SYNONYMS FOR THE KEYWORDS

Keywords	Synonyms or related words
Educational Robotics	Pedagogical Robotics
Computational Thinking	Programming Teaching

With the search string defined, we selected the digital libraries *ACM*, *IEEEXplore*, *ScienceDirect (Elsevier)*, *Springer*, and *Scopus*. The libraries were chosen for having relevant results during the test search, as well as for concentrating the most relevant publications in Computer Science and Education. Table II presents the summary of the search returned by each digital library.

TABLE II
SUMMARY OF THE STUDIES RETURNED IN EACH DIGITAL LIBRARY

Digital Library	Search Results	Search Results(%)
Scopus	271	6.9%
IEEEXplore	285	7.3%
ScienceDirect (Elsevier)	461	11.8%
Springer	1.155	29.5%
ACM	1.743	44.5%
Total	**1.915**	**100%**

C. Studies Screening

All inclusion and exclusion criteria applied in this SMS are described below. Inclusion criteria involved full studies that used the ER in classes to stimulate CT skills and studies available electronically.

The Exclusion criteria were:

1) Studies that do not use the ER to developing CT skills in students;
2) Studies that explore robotics in the medicine and industry field;
3) Studies not peer-reviewed;
4) Peer-reviewed studies, but not published in journals, conferences, or workshops;
5) Studies written in languages other than English or Portuguese;
6) Studies published before 2009;
7) Secondary studies[1].

Initially, we excluded duplicate and secondary studies, resulting in 3.722 studies. Then, the selection was performed in two steps. In the first step, we read the titles, abstracts, and keywords when available, obtaining at the end a set of 406 studies. In the second step, we read the introduction, methodology, and conclusion sections of the studies selected in the first step and apply the inclusion and exclusion criteria. Studies related to the mechatronic industry and medicine learning through robotic have been removed. In the end, we selected 38 studies with the potential to answer the RQs, and these were read in full.

IV. Results

This SMS was conducted from July 2019 to October 2020. In this section, we show the results of the selected studies' analysis. Initially, we will present the general data and after, we answer the proposed research questions.

A. General Results

1) **Publication Year:** Figure 1 presents the study's distribution by year of publication. We observed ER use on developing CT skills from 2009 to 2020. However, we did not find any studies before 2010. In 2010, 2012, 2014, and 2015 had 2.6% (1) (each) of the studies were published. From 2016, there was an increase in the number of studies where 7.9% (3) were published in 2016, 13.2% (5) in 2017, 29% (11) in 2018, 29% (11) in 2019, and 10.5% (4) in 2020.
2) **Authors Origin:** Figure 2 shows the distribution by authors' countries. The countries with the most predominance in publications are: Cyprus with 5.3% (2) published studies, Brazil with 7.9% (3), Spain with 13.2% (5), the United States with 15.8% (6), and Greece with 21% (8). The other countries appear, each, with 2.6% (1) of the studies published.
3) **Classification of Research Approaches:** The studies were classified according to the research method adopted. In general, the studies presented experiences with ER to CT development. However, some were limited to show the procedures applied without considering any data analysis (qualitative or quantitative). Few studies have shown validation, even though it was conducted as a comparative case study. The types of studies found in the selected studies were action research 2.6% (1), Quasi experiment in 10.5% (4), a case study in 36.8% (14), and experience report in 50% (19). Figure 3 shows the distribution by research approaches.

[1]Secondary studies are studies that main conclusions from the analysis of primary studies, such as Systematic Reviews and Mappings.

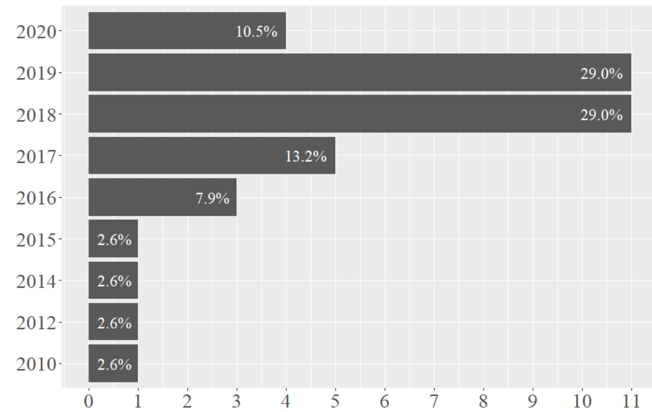

Fig. 1. The absolute number of studies by year of publication

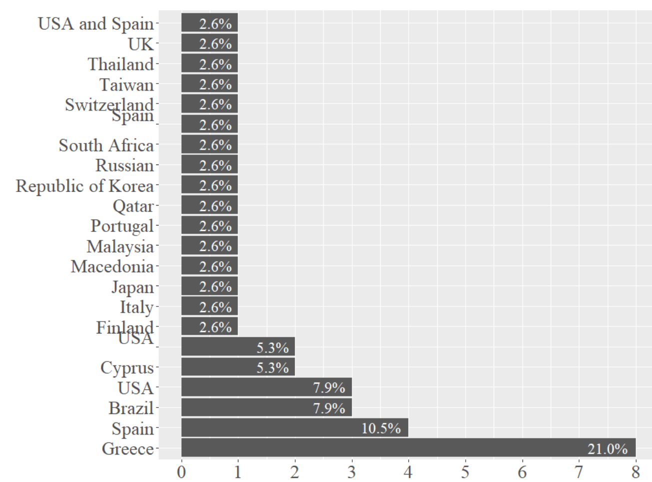

Fig. 2. Origin of studies authors

B. RQ1: Which educational strategies have been used to stimulate CT through ER?

The ER teaching goal focused on CT development identified in this SMS is summarized in Table III. Programming teaching is the most common goal, observed in 16 studies, while CT in 13 studies. Although many studies highlight CT as a goal, they apply programming teaching or logical reasoning activities. So, we categorize these studies as CT following the descriptions presented by the authors and the CT definition by Wing (2011) [60]. The robotics teaching was identified in 9 studies, while the teaching of Science, Technology, Engineering and Mathematics (STEM) in 6 studies. Mathematics and logical

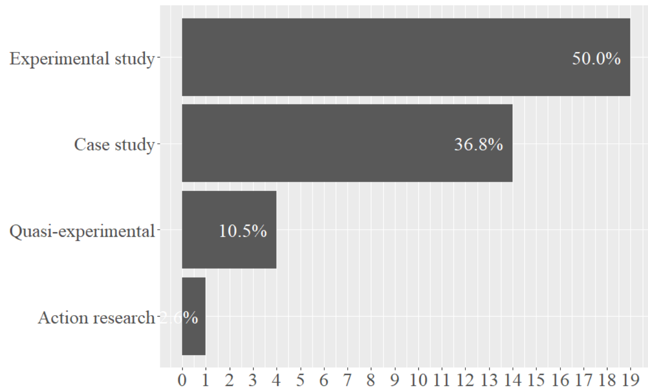

Fig. 3. Classification of Research Approaches

reasoning were verified in 4 studies and, finally, the algorithm thinking in 1 study.

To understand how teaching goals are applied in the classroom, we observed the educational strategies used. The educational strategies were selected based on the author's information about how they highlight their didactic methodology in the classroom and what they sought to develop in students. The educational strategies identified are summarized in Table IV.

Collaborative or teamwork and problem-solving are the most used strategies, being found in 21 studies. We classify in the same categories all studies that mentioned some aspect of the work in group or collaboration. Learning by doing or hands-on was identified in 11 studies, while the use of challenge in 6 studies. The project-based learning was observed in 3 studies and the multimedia activities in 2 studies. The multimedia activities were those activities that involve several media, such as paper, pen, pictures and images, videos, and web. The use of storytelling, were verified in 2 studies, while interdisciplinary motivation, theoretical classes, and workshops in only 1 study. We emphasize that the same studies can present one or more different educational strategies.

TABLE III
TEACHING GOAL AND HOW IT WAS OFFERED

Approaches	Study	Frequency
Algorithmic Thinking	[40]	1
Logical Reasoning	[51], [27], [11], [50]	4
Computer Science	[17], [43], [28], [3]	4
Mathematics	[57], [22], [52], [35]	4
STEM	[16], [42], [22], [52], [35], [38]	6
Robotics	[17], [16], [43], [42], [27], [9], [52], [35], [31]	9
Computational Thinking	[30], [26], [23], [25], [11], [9], [20], [7], [45], [31], [1], [10], [21]	13
Programming Teaching	[47], [57], [33], [30], [26], [8], [28], [19], [52], [35], [46], [37], [2], [58], [15], [44]	16

TABLE IV
EDUCATIONAL STRATEGIES USED IN TEACHING WITH RE

Educational Strategies	Study	Frequency
Workshops	[10]	1
Theoretical classes	[47]	1
Interdisciplinary Activities	[26]	1
Storytelling	[16], [25]	2
Student protagonism	[3], [38]	1
Multimedia activities	[25], [28]	2
Project-based learning	[17], [16], [37]	3
Challenge	[27], [57], [11], [35], [2], [50]	6
Hands-on	[51], [17], [42], [57], [30], [28], [52], [58], [40], [15], [3]	11
Problem-solving	[43], [33], [22], [8], [11], [9], [19], [52], [35], [38], [20], [7], [46], [45], [31], [40], [1], [10], [21], [44], [3]	21
Collaborative learning/Teamwork	[51], [16], [57], [33], [22], [23], [25], [8], [11], [28], [9], [19], [35], [38], [20], [7], [46], [45], [31], [10], [3]	21

C. RQ2: What educational difficulties have been identified during class to stimulate CT through ER?

Our SMS showed that 68.4% (26) of the studies do not mention difficulties during the teaching with ER, and 31.6% (12) highlight one or more difficulties. Figure 4 summarizes the educational difficulties identified in this SMS. The difficulty most identified is related to the limited workload verified in 4 studies [16], [43], [10], [15].

The difficulties in programming language were observed in 3 studies [17], [43], [30]; and the students' background limitation in 2 studies [43], [23]. The problems with programming language are related to understanding the syntax and restriction of the available programming resources. The other difficulties were identified in only 1 of the studies as follows: tools or technologies for CT evaluation unavailable [31], teachers' methodology absence [15], robotics kits with low usability [16], robotics kits number limited [28], robotics kit limited [38], programming language ID with low usability [20], non consenting parents [51], lack of assembly manual [16], and frequent absences [51].

D. RQ3: Which CT skills have been observed during ER classes?

Although the studies analyzed are supposed to develop CT through ER, our SMS demonstrated that only 50% (19) of them develop one or more CT skills during classes. When considering the studies that mention the skills, they are mainly related to programming concepts and practices. However, we identified that there is no consensus among researchers about CT skills. Some authors do not use definitions proposed in the literature and create their own. We classified the CT skills based on definitions from two works: Barr and Stephenson

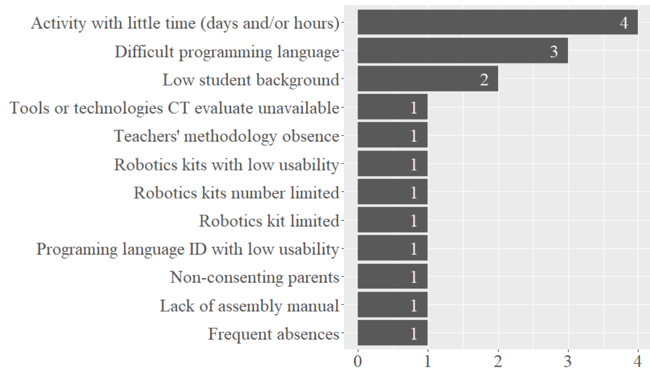

Fig. 4. Classification of educational difficulties

[12] and CSTA [59]. Studies mentioning computer subjects as CT skills were categorized as Computer Science Concepts. Table V summarizes the CT skills shown in this SMS.

TABLE V
CT SKILLS IDENTIFY

CT Skills	Study	Frequency
Automation	[46]	1
Simulation	[7]	1
Pattern recognition	[23]	1
Data representation	[21]	1
Parallelism	[43], [42], [52]	3
Data collection	[43], [42], [46], [21]	4
Generalization	[11], [9], [38], [46], [10]	5
Abstraction	[23], [11], [9], [38], [10]	5
Data analysis	[35], [38], [46], [21], [22], [7]	6
Decomposition	[23], [11], [9], [46], [1], [10]	6
Computer Science Concepts	[51], [16], [27], [7], [43], [42], [16], [52], [51], [15]	10
Algorithms and Procedures	[51], [16], [15], [22], [23], [11], [9], [35], [38], [46], [40], [1], [10], [21], [43], [42]	16
Not specified	[17], [47], [57], [33], [30], [26], [25], [8], [28], [19], [20], [37], [2], [45], [58], [31], [50], [44], [3]	19

E. RQ4: What tools or instruments have been used to evaluate the CT during ER classes?

Our SMS demonstrated that there is no standard research instrument used to evaluate CT in ER classes. The most identified were tests and questionnaires involving logical reasoning created by the authors, presented in 20 studies. Then, semi-structured interviews were observed in 17 studies, qualitative observational assessment in 17, and Bebras Challenge in 3 studies. The other instruments were shown in only 1 study. Tables VI summarizes the tools or instruments to CT evaluate shown in this SMS.

We mapped the Bebras, Román-González, Lippman tests, and Brennan's and Resnick's framework separately because they were applied by institutions and researchers outside the context of their creators. Besides, these tests are concerned with methodological and validation aspects. It is essential to highlight that there is no consensus on how to evaluate CT skills. Also, there are no widely accepted instruments and tools. Several authors propose their instruments and tools. So, this SMS categorized the tools and instruments used to evaluate CT skills according to what the authors mentioned in their studies.

TABLE VI
TOOLS OR INSTRUMENTS CT EVALUATE

Evaluate tools	Study	Frequency
Brennan's and Resnick's framework	[42]	1
Lippman test	[40]	1
Román-González CT test	[23]	1
Scoring protocol	[15], [21]	1
Academic peformance	[47], [52], [21]	1
Bebras Challenge	[46], [31], [21]	3
Qualitative observational assessment	[16], [27], [22], [30], [25], [8], [11], [9], [19], [35], [20], [7], [1], [15], [21], [3]	17
Semi-Structured Interviews	[51], [17], [16], [47], [43], [27], [22], [26], [25], [11], [9], [37], [2], [45], [10], [50], [3]	17
Author's test	[51], [17], [16], [43], [27], [57], [33], [22], [30], [25], [11], [28], [9], [52], [38], [58], [1], [10], [44], [42]	20

F. RQ5: What has been the target audience for the use of ER to stimulate CT?

Only 58% (22) of the studies mentioned the student's age.Table VII summarizes the age range identified in these studies. Of the 32 studies considered, 5% (2) did not specify which level of education the study was applied to.The educational levels with the most significant number of initiatives to stimulate the CT through ER are the Middle school in 13 studies distributed among Brazil ([31]), Japan ([47]), Macedonia ([37]), Malaysia ([33]), Qatar ([50]), Thailand ([22]), USA ([7], [45]), and Greece ([43], [42], [9], [10]). We emphasize that the same study can work with one or more different teaching levels.

G. RQ6: What robotics kits have been used in class to stimulate CT through ER?

We identified that the LEGO® is the most used in classes to stimulate the CT, being verified in 19 studies. Then, Arduino is used in 7 studies, Bee-Bot in 5, and Thymio in 3 studies. The remaining robotics kits were verified in only 1 of the studies analyzed. We emphasize that in each study one or more robotics kits can be used. Table IX summarizes the robotics kits shown in this SMS.

TABLE VII
AGE RANGE

Study	Age range	Study	Age range
[17], [50]	From 10 to 12	[35]	From 8 to 13
[43], [42]	From 14 to 15	[20]	From 9 to 10
[57], [58]	From 14 to 17	[45]	From 6 to 10
[9], [10]	From 15 to 18	[31]	From 14 to 28
[51]	From 4.5 to 6	[1]	From 5 to 6
[16]	From 3 to 5	[15]	From 4 to 6
[33]	From 13 to 18	[21]	From 8 to 10
[23]	From 5 to 14	[3]	From 18 to 40
[8]	From 9 to 12	[47], [27], [22], [30], [26], [25], [11], [28], [19], [52], [38], [7], [46], [37], [2], [40]	Not specified

TABLE VIII
TEACHING LEVELS

Teaching Levels	Study	Frequency
Primary School	[21]	1
Vocational	[58]	1
Others	[57], [8]	2
Postgraduate	[2], [3]	2
Undergraduate	[28], [19], [2], [10]	4
Preschool	[51], [16], [26], [25], [1], [15]	6
Elementary school	[17], [27], [30], [23], [11], [52], [35], [20], [46]	9
Middle school	[47], [43], [42], [33], [22], [9], [7], [37], [45], [31], [10], [50], [44]	13
Not specified	[38], [40]	2

TABLE IX
ROBOTICS KITS

Robotics Kits	Study	Frequency
Code & Go Robot Mouse	[51]	1
Dash	[30]	1
Fischertechnik	[31]	1
Hamster robot	[46]	1
KIBO	[16]	1
Micro Robots Citizen	[47]	
Robot arm (Free Robotics)	[45]	1
Thymio	[23], [28], [20]	3
Bee-Bot	[27], [26], [25], [8], [1]	5
Arduino	[17], [57], [33], [22], [52], [2], [58]	7
LEGO®	[47], [43], [42], [30], [8], [11], [9], [19], [35], [38], [7], [37], [40], [10], [50], [15], [21], [44], [3]	19

V. DISCUSSION

In this section we present the main points extracted from the studies and which we consider important to carry out further studies on them.

A. Robotics in the Learning Process

We realized that the studies considered in this study assume that ER is an effective resource for learning problems and do not consider external factors that can interfere with this effectiveness. Many studies justify the validity of the ER by presenting the learning theories of [48], theories that underlie the creation of the ER. Nevertheless, in a previous study [55], [53] we observed that the use of ER depends on physical and methodological factors. These can impact on student's motivation and learning. Thus, its effectiveness cannot be seen as a generalizable factor.

We recognize that ER can favor teaching at various educational levels, especially by favoring skills that we consider articulated to the CT: teamwork, logical reasoning and creativity. However, reflections on its use in the classroom are necessary: what are the most suitable teaching objects to be worked on ER? What aspects differentiate ER from other tools used to stimulate CT in students?

B. Computational Thinking Skills

The CT evaluation can be performed using high granularity, when the final performance in a test is weighted, and using fine granularity when observing the skills separately [4]. We found that although 50% of the studies mentioned the skills, they are not assessed individually, that is, when there was an assessment of CT in teaching with ER, it was of high granularity.

This reality may arise from the complexity of evaluating CT skills separately, as they are grouped by the skills in common [5]. Although assessing skills is a challenge, there may be those that can be further stimulated during teaching with ER. Thus, we consider important studies that investigate which CT skills can be better worked through ER.

C. Instruments to assess the Computational Thinking

We realized that there is no standard instrument for evaluating CT in students during classes with ER. The authors of the studies commonly propose a new instrument. Of the 32 studies, only 6.2% (2) applied referenced in the literature with support from the scientific community. The first is Bebras [2] which, although it has questions related to CT skills, does not require mastery of computing concepts to answer them [24]. The second is the Computational Thinking Test by Román-González (2015) which follows the same principles as Bebras. Both have guidelines on how they should be applied, and marks are given to the participants. However, as far as we know, there is no scientific evidence that they can actually assess the CT, as well as its skills [6].

In this sense, it is possible that instruments proposed by the authors of the studies do not actually "measure" the CT in students during classes with ER. With that, we consider reflections on the CT evaluation instruments necessary, they are: What are the types of instruments that best verify the CT

[2]Bebras: https://www.bebras.org

in students? Is it necessary to think about specific instruments to evaluate CT in the context of teaching with ER?

VI. Threats to Validity

This SMS has threats to its validity. The analyzed studies are directly related to the search engines of the virtual libraries, thus, the search performed may not have returned all relevant studies. We only consider complete studies published in scientific and periodical events, considering that the objectives of this SMS involve practical activities, they may have been presented to the academy in other types of studies. Finally, human factors may have influenced data extraction since it is a manual process.

VII. Conclusions and Future Works

The use of ER in the classroom has been widespread in recent years to improve educational practices. Among the initiatives, those that seek to stimulate the CT skills stand out. In this sense, this work presented a SMS that aims at understanding how ER is used in the educational field to stimulate CT skills in students.

The results show that the most used approaches are teaching programming languages and Computational Thinking applying educational strategies of collaboratives and problem-solving. The most faced difficulty is related to the class load. We identified a variety of CT skills, mainly related to the practice of programming, with algorithms and sequencing being the most observed. Concerning the research instruments for CT assessment, we found that the most used are tests proposed by the studies' authors, followed by semi-structured interviews. We observed that the target audience of classes with ER is, above all, students from High School and Elementary school, aged between 0 and 17 years old. Finally, we find that LEGO® technology is the most widely used.

As future work, we consider it is necessary to investigate how teaching approaches are related to ER and to understand how ER is distinguished from other tools used to stimulate CT. We also consider it important to understand which CT skills can be better worked through ER and investigate CT assessment tools applied to teaching with ER.

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