# Using Augmented Reality in programming learning: A systematic mapping study

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***Abstract*—Coding skills have become the new language of communication for the tech world. At an educational level, applying the concepts and logic of programming is a complex task for the student. The investigation of this problem was carried out with the intention of knowing if there are tools that could help the student understand programming by using augmented reality technology. For this purpose, a systematic mapping study was carried out to identify, filter and classify the information through a query applied in different ways of research. As a result, 34 articles were selected and classified. The main results show that: a) programming learning is not limited in terms of the student's age; b) Augmented reality has potential advantages in programming learning; c) Due to the extensive content of the programming, applications focused on specific topics were found according to the level of studies; d) The software used in the development of AR applications, mostly uses Unity with Vuforia; and, e) Augmented reality contributes to different learning techniques and styles that improve the way information is perceived and visualized. In conclusion, augmented reality technology has proven to have positive consequences in the programming learning process, providing a starting point for the development of a tool that contributes to the programming learning based on the characteristics found and analyzed in this document.**

***Keywords— Augmented Reality, programming learning, learning based on gamification, collaborative learning, computational thinking***

## I. Introduction

Computational thinking applied to the traditional educational system helps to enhance the development of skills to solve problems of different kinds[1]. Programming can be ideal to develop this thinking due to the great similarity of the cognitive processes that it integrates. There are different methodologies and environments for programming learning, each one applied within a paradigm and interaction style [2-5]. Currently, among the most popular ones, we have the use of virtual reality and augmented reality, the latter being the one that has shown great potential in educational applications in different areas. The objective of this type of application is to create a comprehensible algorithmic panorama for the student [6,7].

Augmented reality (AR) works through a set of devices that add virtual information in a physical environment of the real world, unlike virtual reality (VR), which immerses the user in a totally virtual world. Augmented reality can technically be used to enhance the five senses, but its most common use today is visual [8].

The objective is to find studies that contribute to the learning process of programming with Augmented Reality to validate how AR is being used to teach programming and to verify whether its use is convenient or not.

To accomplish the bibliographic review, a research was carried out based on a query applied to the most popular searching tools and the snowball effect. The article is structured as follows: Section II indicates the methodology applied, the research questions and the query design for the search of articles; Section III shows the result which answers each of the research questions, that are detailed in its subsections. At the end of the paper, we find Section IV with discussions and the conclusion at Section V.

## II. Research Questions and Methodology

The research questions were asked based on the need to know the main characteristics that influence the use of Augmented Reality technology in programming learning, the levels of education to which they have been applied, the devices used and the learning methodology to determine the teaching method and to design more efficient tools. Taking into account each of these unknowns, the following questions were raised:

RQ1. At what educative levels is Augmented Reality used for programming learning?
RQ2. What advantages does the use of Augmented Reality have in programming learning?
RQ3. What kind of devices do Augmented Reality technologies use to learn to program?
RQ4. What software is used for the construction of Augmented Reality tools for programming learning?
RQ5. What programming concepts are taught with the use of Augmented Reality applications?
RQ6. What type of teaching-learning methodology is used to learn to program with Augmented Reality?

For the review, we represented the procedure in Fig. 1. The work was divided into four stages:

*1) Analysis:* this first stage defines the problem, the research questions and the search method to be used.

*2) Processing:* we worked on obtaining data, for which two search strategies were raised. The first strategy where the terms, phrases and keywords that would result in the design of the query were analyzed in an automated way Fig. 2. The second strategy was Snowballing [9], to minimize the risk of not including some relevant studies that contain keywords other than those selected or because we could have accidentally excluded a relevant study. This second search strategy was based on the references of the documents found in the automated search, applying the same inclusion/exclusion criteria.

*3) Execution:* applying the automated search strategy, we chose the following search engines among the most used and related to the area of science and technology: ACM, Scopus, IEEE, WoS, Google Scholar, Science Direct, Sirius and CiteSeer. The query was executed obtaining a total of 730 papers with the first four search engines, and with the last three engines the result was null.

*4) Results:* in the last stage and after applying the inclusion and exclusion criteria of both strategies (see Table I), we obtained a total of 34 papers referring to the topic: 32 using the automated search strategy and 2 [10],[44] using the snowball method.

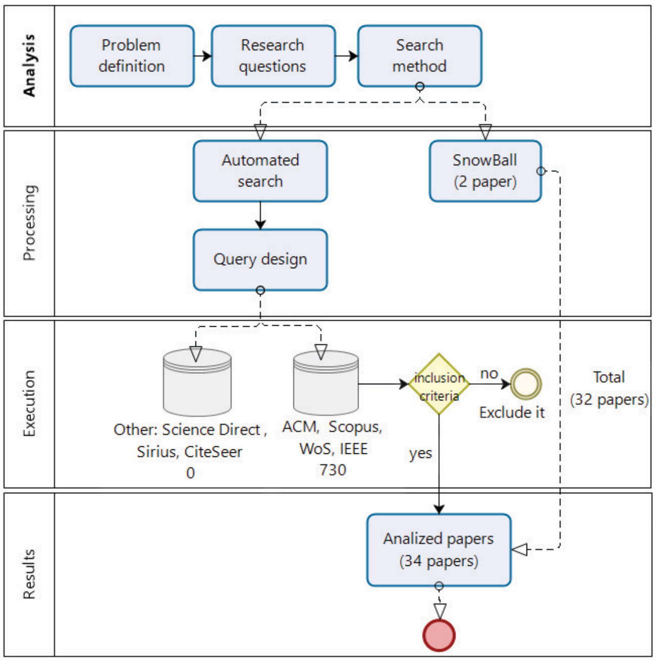


Fig. 1. Survey methodology.

The design of the query was created to obtain the greatest amount of data related to programming learning through the use of Augmented Reality. The main term used was "Augmented Reality in programming learning". Following that, due to the large number of results, a filter by category was added for the field of "computer science" and for the area of programming learning. Finally, the query that was made is as follows.

*(("augmented reality") AND NOT ("linguistic programming")) AND (education OR learning) AND (programming) AND (students)*

Fig. 2. Query design.

Inclusion criteria were applied to the 730 papers which were the result of the consultation in order to obtain unique articles that met the necessary characteristics to be analyzed. Also, exclusion criteria were used in order to reject not relevant information and duplicate papers. The term "linguistic programming" was discarded, because it was one of the most common and was not related to the subject of study (see Table I).

TABLE I. INCLUSION AND EXCLUSION CRITERIA

| Inclusion | Exclusion |
|---|---|
| Education related with the use of augmented reality technology | Excluding all duplicates |
| Related to programming learning | Excluding all gray literature |
| Full text of the papers must be available | "Linguistic programming" term |
| Publications of the last 6 years | |

The following section shows all the studies that were obtained by executing the query in each of the search engines mentioned above

## III. RESULTS

A total of 34 papers were obtained regarding the use of Augmented Reality in programming learning. Below, in Table II, the details about search results are presented regarding the topic.

TABLE II. SEARCH ENGINES AND THEIR CORRESPONDING RESULTS IN NUMBER OF PAPERS

| Search Engine | Number of Search Results | Regarding the Topic |
|---|---|---|
| ACM | 149 | 5 |
| SCOPUS | 246 | 12 |
| IEEE | 101 | 8 |
| WoS | 108 | 7 |
| GOOGLE SCHOLAR | 126 | 2 |
| **Total** | **730** | **34** |

As can be seen, in the column "Search engine" appears the name of each of the search engines used for this review. In the column "Number of Search Results", the total number of resulting papers is detailed after applying the query mentioned in Section II. And finally, in the column "Regarding the Topic," the total number of papers related to the use of AR in the programming learning is indicated. From this last indicator we noted that there is not a large number of papers related to the topic. They have been helpful in carrying out the respective analysis.

### *A. At what educative levels is Augmented Reality used for programming learning?*

To describe the educational levels where the use of augmented reality in programming learning has been experienced, we have classified according to the degree of study (see Table III). This being the case, in the column "Educative level", the levels ranging from elementary school with children aged 8-12 are presented [11-17], primary/secondary for those applications that have been experimented with youth and children 8-18 years of age [18-22]. In secondary school, the ages range from 16 - 22 years [7],[10],[14],[24], it should be noted that the cells with the sign "-" are those for which the data were not available in the reading. At the university level, which represents the highest percentage of jobs, ages were mostly not indicated, but for those studies that did, the range can be observed in the column "Age range" ranging from 18-23 years [25-38]. Applications were also found for postgraduate levels [40] and as for the one that indicates novices in the last row, it is because it did not specify the level of study [40]. On the other hand, the column “Papers” indicates the total of 34 documents divided by each level of study found. Based on the experimentation of some studies reviewed, the total number of students who participated were mostly men, we can see it in the column "Gender".

On the other hand, the applications were aimed at students with different levels of knowledge, for which we classified this detail in the column "PPK" which stands for Previous Programming Knowledge and hence the acronyms: a) NPK (No Programming Knowledge), which indicates a zero level of knowledge. In other words, the student does not know about programming concepts or its logic and, as can be seen, in most cases they are from those applications aimed at children, of which very few detailed basic knowledge and were those who had used similar applications especially through games. Then there is BPK (Basic Programming Knowledge), which corresponds to those students who had a general idea or basic concepts of programming. In some cases they needed to be reinforced, but in other cases new concepts were presented. Hence, IPK (Intermediate Programming Knowledge), is applied for mostly university-level students who had slightly more advanced programming concepts [31] and finally EPK (Expertise Programming Knowledge), applied especially on postgraduate students and other college degrees similar to computer science.

TABLE III. AUGMENTED REALITY ACCORDING TO THE EDUCATIVE LEVEL OF STUDENTS

| Educative level | Papers | Age range | Gender | | PPK |
|---|---|---|---|---|---|
| | | | *M* | *F* | |
| Elementary school | 7 | 8-9 | 3 | 3 | NPK(4)<br>BPK(2) |
| | | 8-9 | - | - | BPK |
| | | 9-10 | - | - | NPK |
| | | 9-11 | 3 | 0 | NPK |
| | | 11-12 | | | NPK |
| | | - | 5 | 3 | BPK |
| | | - | - | - | NPK |
| Elementary /Secondary | 5 | 8-15 | - | - | BPK |
| | | 8-15 | 9 | 3 | NPK |
| | | 12-13 | - | - | BPK |
| | | 10-15 | - | - | NPK |
| | | 14-18 | 8 | 2 | NPK |
| Secondary | 5 | 16-17 | - | - | NPK |
| | | 19-22 | 10 | 2 | NPK |
| | | - | - | - | BPK |
| | | - | - | - | NPK |
| | | - | - | - | NPK |
| University | 15 | 18 | 32 | 13 | BPK |
| | | 18-20 | - | - | NPK |
| | | 18-23 | 11 | 7 | IPK |
| | | - | - | - | IPK |
| | | - | - | - | BPK |
| | | - | - | - | BPK |
| | | - | - | - | EPK |
| | | - | - | - | BPK |
| | | - | - | - | BPK |
| | | - | - | - | IPK |
| | | - | - | - | IPK |
| | | - | - | - | BPK |
| | | - | - | - | IPK |
| | | - | - | - | IPK |
| | | - | - | - | BPK |
| Professional | 1 | 22-47 | - | - | NPK(6)<br>EPK(13) |
| Novices | 1 | - | - | - | NPK |

Summarizing, we can see that AR for programming learning is not limited by the age of the student, learning can start from early ages to adults or to consolidate the knowledge of experts in the area.

### B. *What advantages does the use of Augmented Reality have in programming learning?*

The usefulness of Augmented Reality, like any other technology that aims to be introduced in education, has been shown to improve the learning process through different types of advantages. This review details those advantages upon which the authors concur according to their experience. Fig. 3 shows those advantages and the number of papers in which were identified. Starting with the first advantage named “Usability”, which refers to the student being able to observe the integration of virtual information within a real scene of simple form without having to do any previous analysis, for example by using tangible cards [10], [11], [16], availability of manipulating [40] virtual objects and the adaptability, with characteristics such as ease of use [38]. Besides, student’s with a high degree of “Satisfaction” [27][35][41], or interest in the use of the application. On the other hand, with respect to the cognitive aspect, the use of augmented reality produces that different activities are carried out to decrease the mental demands [40], which was named “Cognitive load reduction”, which helps the student not to try too hard to understand because they are learning in new ways outside of traditional learning. On the other hand, the “Visual feedback”[24], [23]. AR produces this advantage by superimposing information within a real scene [40] or by obtaining an instant response based on the monitoring of user’s activities, even more so when viewing objects in three dimensions or, for example, reviewing the information in code schemas and identifying programming errors [30].

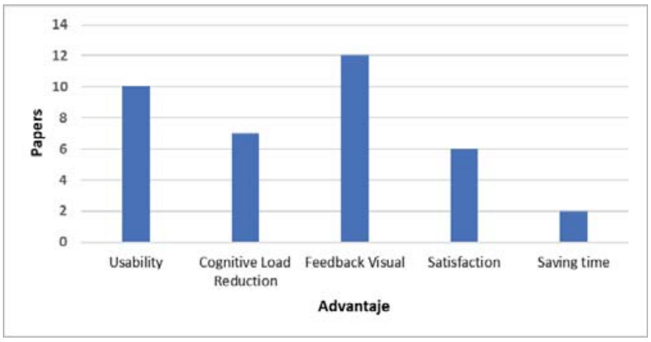


Fig. 3. The matching and relevant advantages of the studies that were analyzed

A very important advantage is “Saving time” while learning. For instance, the teacher does not spend time explaining or repeating programming concepts that the student can observe in real-time, as for example with the use of multimedia [7] in an application with augmented reality: the student can listen, watch videos and review information as many times as necessary according to what he or she needs. This prevents the teacher from having to re-explain certain content that for other students can be repetitive and as a result it becomes boring. There are high percentages of students who prefer to learn how to program autonomously, this being a very interesting feature for the development of applications that support their learning [42].

Summarizing, the main advantage of AR is that it facilitates visual feedback in the learning process, contributes in terms of usability, reduces the student's cognitive load, increases the degree of satisfaction and saves time. As a result, applications that implement the paradigm of augmented reality can raise the motivational level and interest in learning, which can serve to improve algorithmic thinking, the development of intellectual skills and why not apply it in situations where there is a high dropout rate of students [32], [38].

*C. What kind of devices do Augmented Reality technologies use to learn to program?*

[43] proposes a taxonomy of devices used for the development of AR applications organized at various levels. On a first level, there are the "Wearable Devices" (helmets and headsets) and the "No Wearable devices", which are divided into a second level, into two subcategories: 1) stationary devices (televisions, PCs, games, etc.) and 2) Mobile devices (smartphones, tablets, laptops, etc.). Figure 4 shows the number of articles in which the use of different devices was found according to the previous classification.

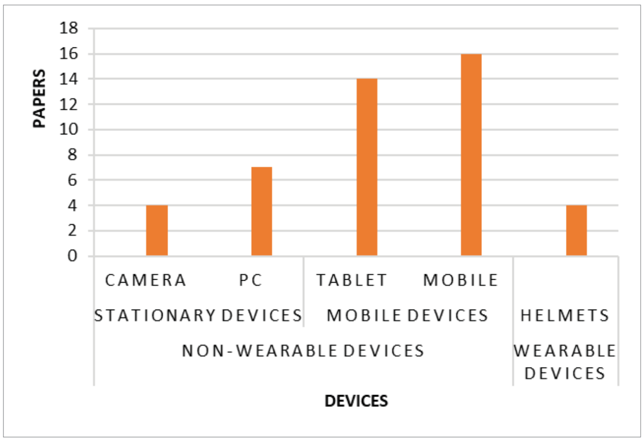


Fig. 4. Devices classified according to the Augmented Reality taxonomy

We can notice that a large percentage of applications use mobile devices. After that, some use a PC and fixed cameras. Regarding wearable devices, the authors found three experiences which used helmet [10].

Augmented reality for its operation requires a device with a camera and an activator, the activator can be through the use of markers. Initially using a QR code, then they switched to the use of labels with black and white or color images, which can be printed on material such as cardboard, sheets, etc. or be captured from a device. On the other hand, there are the objects that can be created or used in the real world and finally through geolocation that works through location. All of them serve as triggers so that when captured or located they superimpose some pattern of information (images, 3D objects, multimedia in general) after being recognized by software.

In Fig. 5 you can see the activators that have been used by the applications based on this review. Some authors present the activators of the QR type, others of Flashcard labels as tangible cards or cubes with images printed on each side. Other applications include scenarios or maps on which the cards or cubes are placed [11], as well as robots that, when identified as an object, can be used in tracking maps [16,17] or physical platforms [19], [21], [22], [35], thus combining electronics with programming, finally by GPS, for example [25] creates digital animated characters placed at three points within a campus and the student, when capturing the character, has to answer questions related to programming concepts.

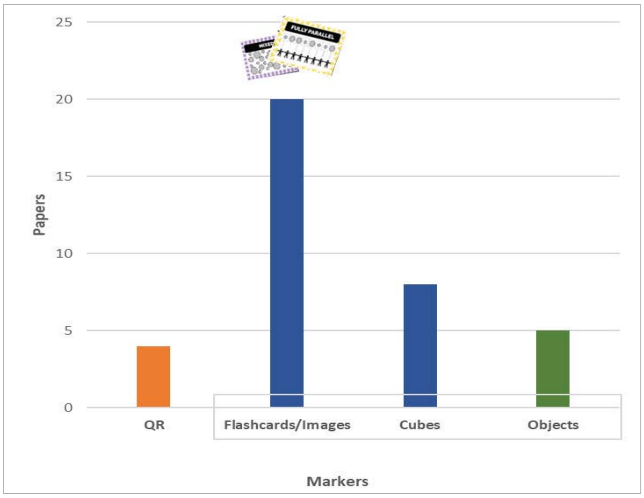


Fig. 5. AR markers

It can be seen that the most commonly used activators are those that handle markers inside which are the flashcards, images inserted in cubes, and objects (electronic boards or robots). Some applications use the markers to manage them in different scenarios such as maps or routes where the flashcards, cubes, or robots move, and the information or components are presented with augmented reality.

*D. What software is used for the construction of Augmented Reality tools for programming learning?*

There are many tools to make apps to integrate Augmented Reality, but some are more visible or are more used in the market than others depending on their characteristics and functionalities. The development platforms found in papers of this review can be seen in Fig. 6.

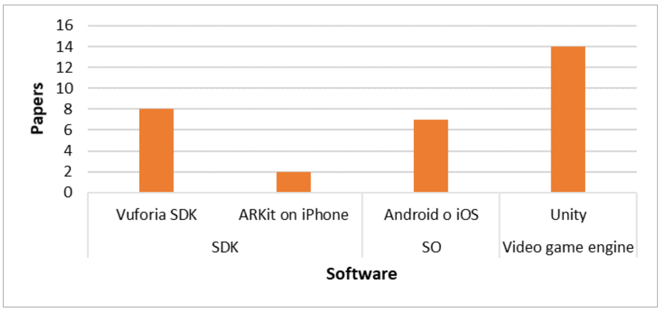


Fig. 6. Development technologies that support AR technology

As we can see, there are several documents that use the iPhone Vuforia SDK and ARKit. On the other hand, Android and iOS are the most used operating systems and Unity is the prominent game engine. There are other tools that are not detailed in Fig. 6 because the number of applications that used them did not exceed one: OpenGL and OpenCV libraries [27], [29], Aseba [23], Swift and C# [10][26], Scratch for Arduino [7], Phyton in the Geany ID [30], Flash Builder [27] and Visual Studio [28], App Inventor with Aurasma Studio [41]. Like IDEs Eclipse [18] and Xcode for iOS [33].

In conclusion, the main SDK for the development of AR is Vuforia and that solutions are developed mainly for Android and iOS. In the case of video game development for learning programming, it is mainly used by Unity.

### E. *What programming concepts are taught with the use of Augmented Reality applications?*

Like other areas, programming begins its learning with basic concepts, and as it progresses some content needs to be reinforced due to its degree of complexity. In this review, each paper has been focused on reinforcing or analyzing a specific topic depending on the level of the student, which were detailed in Section III. Based on this, the conceptual content has been classified into three levels: basic (B), medium (M) and advanced (A). The basic level has the contents which correspond to how to solve algorithms step by step, in real-life problems [20], identification of input and output variables [32], the management of control structures (conditional sentences, loops) and create flowcharts [32,33]. On a medium level, those applications that are within the programming paradigms (Object-Oriented Programming [25], [26], [34], Parallel Programming, Event-driven Programming, Data Structure [31], etc.) were classified. Finally, at the advanced level, the contents of 3D programming have been classified with OpenGL [18], code debuggers [5], [25], optimization algorithms, Dijkstra [31] and applications that integrate the learning of programming with electronics [23], [32], [39]. Fig. 7 shows the number of papers, the type of contents, and the difficulty level for each one of them. We may notice that, most of it, corresponds to the basic programming content

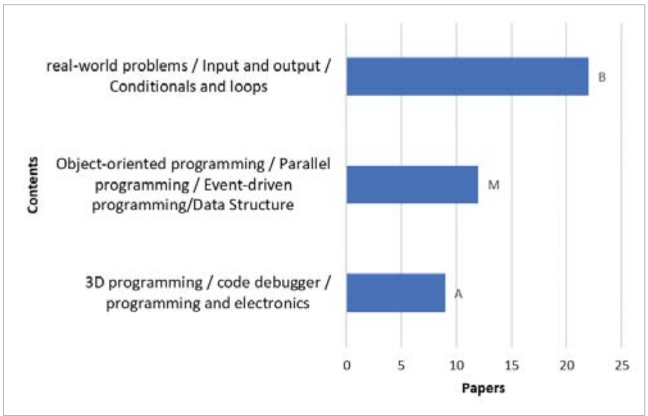


Fig. 7. Type of contents taught with AR applications

### F. *What type of teaching-learning methodology is used to learn to program with Augmented Reality?*

One of the objectives of creating a learning methodology is to improve the development of intelligence. The student has become the centre of the learning process, through the use of the most appropriate methodologies is intended to make their learning more meaningful. Based on Howard Gardner's "Multiple Intelligence Theory" [44] and its focus on one of its components, visual-spatial intelligence, we ascertain that Augmented Reality enhances this approach by using devices that capture an activator and present useful information to the user. This visual approach can be presented in various forms and styles, such as teaching activities that allow the addition of complementary multimedia information [4], or the projection of 3D Models [29], [38]. Our research found out three main teaching-learning methodologies which used Augmented learning:

*a) Learning based on gamification.* The "serious games" represent the 51% of papers reviewed. For instance, ArCat, contain a character (a cat) that performs a search in a maze and, through the use of tags (tangible cards), the students can program a series of combinations from among the set of instructions given to help them find the treasure [11][14]. Other game allows the player to create his own maze marking the paths until he reaches a goal (activity similar to program) and uses a card to expand a virtual avatar with Augmented Reality, while moving the physical avatar across the screen [24]. Similarly, in [10] the student enters instructions and the result program directs an avatar until it reaches its destination depending on those instructions. This helps the student to develop skills in an interactive way, so that a logic is obtained through the set of steps and repetitions that have been performed until it reaches the goal in each game. AR-Maze for example combine the virtual system with physical programming blocks, which helps children to physically program and execute the code generated in virtual environments with a coherent view of the operating space [16]. Through this example, we talk about a type of Kinesthetic learning where the student, interacting with the blocks or cubes, learn with experimentation and therefore, experiment learning as something participatory.

*b) Collaborative learning.* Other applications are based on collaborative learning approach, which represent 28% of paper reviewed. ParallelAR [36] recreates a virtual office to apply concepts of parallel programming in which students work together in small groups towards a common goal. Students are responsible for the learning of others and as well as their own and, based on the method of active participation [32]. Students form work teams and are distributed in a planned way within the classroom. ARQuest, is a game where students collaborate in teams, create challenges and try to solve them through action sequences [10]. CodeCubes allows students to collaboratively create their own mazes by using commands [15] similar to the famous game Scratch. A tangible AR approach has been shown to improve student engagement and collaboration in classroom activities [12]. Augmented reality increases collaboration within the classroom [37], as students share mobile devices, and this improves interactivity allowing them to see educational materials.

*c) Learning by discovery.* Other 13%, when the student uses augmented reality, visualizes, analyses and contextualizes the information, turning this into knowledge, it also develops thinking skills that go beyond memorization [23],[29],[35].

The remaining 8% corresponds to project-based learning methodologies [23][39]. In a general way, the educative methodology to learn to program use multimodal learning approaches that include a combination of several methods.

## IV. DISCUSSIONS

This review may contribute to different aspects that make up the development of applications with augmented reality for programming learning. Regarding research question RQ1 *(At what educative levels is Augmented Reality used for programming learning?)*, most applications are based on introductory programming concepts, for students with or without prior knowledge in the area. This is due to the fact that programming learning and its importance are currently being exploited as a gateway to the work environment. Therefore, the answer to this RQ1 question is that, although the educational level predominates at the university stage, age and cognitive level are not a limitation, learning can start from an early age to adults and professionals. Science seeks to adopt good learning practices and therefore RQ2 *(What advantages does the use of Augmented Reality have in programming learning?)*, indicates that usability is one of the advantages that stand out the most. In addition to the fact that its focus and visual feedback allows to reduce the cognitive load of the student and on the other hand they help the teacher not to spend much time on themes or concepts that can be verified through the tool. As a consequence, the degree of satisfaction is absolute. But the use of these tools requires both HW and SW components, in response to this the RQ3 *(What kind of devices do Augmented Reality technologies use to learn to program?*), indicates that the type of devices most used when we apply AR are mobile, stationary and wearable devices. This is important to analyze to measure the ergonomic point of view, which we think could become an inconvenience because the use of AR requires focusing with a camera from a mobile device or through the use of helmets, which it may cause a certain level of tension or fatigue with prolonged use. In addition, its implementation requires a significant investment and even more so if we talk about a laboratory for an educational institution. But it is worth mentioning that the superposition of virtual elements generates significant savings instead of using physical elements. Regarding the software that is detailed in RQ4 *(What software is used for the construction of Augmented Reality tools for programming learning).* There is a great variety on the market, one of the most used being Unity with Vuforia. The importance of reviewing it is so that developers can take into account the use of the platforms, which in many of the existing tools require important HW features. But, advances in technology present better and varied alternatives for both hardware and software. In relation to RQ5 *(What programming concepts are taught with the use of Augmented Reality applications?)*, most applications are developed for learning introductory concepts, this is attributed to the fact that the beginning of programming learning is to understand logic and develop computational thinking, and then move on to more advanced topics. Lastly, on RQ6 *(What type of teaching-learning methodology is used to learn to program with Augmented Reality?)*, it is detailed that the most popular type of learning is gamification since a large percentage of applications are based on attracting the interest of users through games. On the other hand, the use of tangible activators and device exchanges promote students to work collaboratively, favoring the motivation and construction of their own learning.

## V. CONCLUSIONS

We have presented a thorough systematic review about the main aspects that influence the development of applications with augmented reality for programming learning. The result has been satisfactory. On one hand, knowing the variety of applications that have been developed using this technology, the advantages it offers and ways to implement it. The result of the work indicates that AR for learning programming is used mainly at the university level, with stationary mobile and wearable devices. Besides, instructors using gamification methodologies and collaborative learning, applied in learning basic programming concepts. On the other hand, in terms of the hardware and software components used by students, they need to be analyzed, as well as the relevant type of learning. We're currently working on a deeper review of this research in order to suggest better practices in the development of AR tools for the programming area.

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## REFERENCES

[1] Araújo, Cristiana, Lázaro VO Lima, and Pedro Rangel Henriques. "An Ontology based approach to teach Computational Thinking." 2019 International Symposium on Computers in Education (SIIE). IEEE, pp. 1-6, 2019

[2] Aras, Sefa, Eyup Gedikli, and Ozcan Ozyurt. "A Framework Based on Compiler Design Techniques for Programming Learning Environments." 2018 International Conference on Artificial Intelligence and Data Processing (IDAP). IEEE, pp. 1-6, 2018.

[3] Davy, John, and Tony Jenkins. "led innovation in teaching and learning programming." Proceedings of the 4th annual SIGCSE/SIGCUE ITiCSE conference on Innovation and technology in computer science education, pp 5-8, 1999.

[4] Garner, Stuart. "The use of a code restructuring tool in the learning of programming." Proceedings of the 9th annual SIGCSE conference on Innovation and technology in computer science education, pp. 277-277, 2004.

[5] Kawaguchi, Shota, et al. "Machine Learning Model for Analyzing Learning Situations in Programming Learning." 2018 IEEE Conference on Big Data and Analytics (ICBDA), IEEE, pp 74-79, 2018.

[6] Aparicio, Joao Tiago, and Carlos J. Costa. "A virtual robot solution to support programming learning an open source approach." 2018 13th Iberian Conference on Information Systems and Technologies (CISTI). IEEE, pp. 1-6, 2018..

[7] Figueiredo, Mauro, Maria-Ángeles Cifredo-Chacón, and Vítor Gonçalves. "Learning programming and electronics with augmented reality." International Conference on Universal Access in Human-Computer Interaction. Springer, Cham, pp. 57-64, 2016.

[8] Kipper, Greg, and Joseph Rampolla. Augmented Reality: an emerging technologies guide to AR. Elsevier, pp. 1-5, 2012.

[9] Stevanetic, Srdjan, and Uwe Zdun. "Software metrics for measuring the understandability of architectural structures: a systematic mapping study." Proceedings of the 19th International Conference on Evaluation and Assessment in Software Engineering, pp. 1-14, 2015.

[10] Dass, Nathan, et al. "Augmenting coding: Augmented reality for learning programming." Proceedings of the Sixth International Symposium of Chinese CHI, pp. 156-159,2018.

[11] Deng, Xiaozhou, et al. "ARCat: A Tangible Programming Tool for DFS Algorithm Teaching." Proceedings of the 18th ACM International Conference on Interaction Design and Children, pp. 533-537, 2019.

[12] Gardeli, Anna, and Spyros Vosinakis. "The Effect of Tangible Augmented Reality Interfaces on Teaching Computational Thinking: A Preliminary Study." International Conference on Interactive Collaborative Learning. Springer, Cham, pp. 673-684, 2018.

[13] Gardeli, Anna, and Spyros Vosinakis. "ARQuest: A tangible augmented reality approach to developing computational thinking skills." 2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games). IEEE, pp. 1-8, 2019.

[14] Da Silva Esteves, Adson Marques, André Luiz Maciel Santana, and Rodrigo Lyra. "Use of Augmented Reality for Computational Thinking Stimulation through Virtual." 2019 21st Symposium on Virtual and Augmented Reality (SVR). IEEE, pp. 102-106, 2019.

[15] Cleto, Barbara, et al. "CodeCubes-Playing with Cubes and Learning to Code." Interactivity, Game Creation, Design, Learning, and Innovation. Springer, Cham, pp. 538-543, 2018.

[16] Jin, Qiao, et al. "AR-Maze: a tangible programming tool for children based on AR technology." Proceedings of the 17th ACM Conference on Interaction Design and Children, pp. 611-616, 2018.

[17] Rivera-Loaiza, Cuauhtémoc, María Isabel López-Huerta, and Francisco J. Domínguez-Mota. "Use of augmented reality to teach basic computing concepts." Proceedings of the IX Latin American Conference on Human Computer Interaction, pp. 1-6, 2019.

[18] Schez-Sobrino, Santiago, et al. “An Intelligent Tutoring System to Facilitate the Learning of Programming through the Usage of Dynamic Graphic Visualizations”. Applied Sciences, vol. 10, no 4, p. 1518, 2020

[19] Schez-Sobrino, Santiago, et al. RoboTIC: “A serious game based on augmented reality for learning programming”. Multimedia Tools and Applications, , vol. 79, no 45, p. 34079-34099, 2020.

[20] Sabuncuoğlu, Alpay, et al. "Code notes: designing a low-cost tangible coding tool for/with children." Proceedings of the 17th ACM Conference on Interaction Design and Children, pp. 644-649, 2018.

[21] Johal, Wafa, et al. "Augmented Robotics for Learners: A Case Study on Optics." 2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN). IEEE, pp. 1-6, 2019.

[22] Glenn, Terrell, et al. "StoryMakAR: Bringing Stories to Life With An Augmented Reality & Physical Prototyping Toolkit for Youth." Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1-14, 2020.

[23] Magnenat, Stéphane, et al. "Enhancing robot programming with visual feedback and augmented reality." Proceedings of the 2015 ACM conference on innovation and technology in computer science education, pp. 153-158, 2015.

[24] Kim, Joonyoung, et al. "Mixed Reality for Learning Programming." Proceedings of the 18th ACM International Conference on Interaction Design and Children, pp. 574-579, 2019.

[25] Ibáñez, María Blanca, Jorge Peláez, and Carlos Delgado Kloos. "Using an augmented reality geolocalized quiz game as an incentive to overcome academic procrastination." Interactive Mobile Communication, Technologies and Learning. Springer, Cham, pp. 175-184, 2018.

[26] Ramos, Carmen, and Tania Patino. "Program with Ixquic: Educative Games and Learning in Augmented and Virtual Environments." 2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES). IEEE, pp. 1-2, 2016.

[27] Mesia, Natali Salazar, Cecilia Sanz, and Gladys Gorga. "Augmented reality for programming teaching. Student satisfaction analysis." 2016 international conference on collaboration technologies and systems (cts). IEEE, pp. 165-171, 2016.

[28] Tan, Kelwin Seen Tiong, and Yunli Lee. "An Augmented Reality learning system for programming concepts." International Conference on Information Science and Applications. Springer, Singapore, pp. 179-187, 2017.

[29] Teng, Chin-Hung, Jr-Yi Chen, and Zhi-Hong Chen. "Impact of augmented reality on programming language learning: Efficiency and perception." Journal of Educational Computing Research 56.2, pp. 254-271, 2018.

[30] AlNajdi, Sameer M., Malek Q. Alrashidi, and Khalid S. Almohamadi. "The effectiveness of using augmented reality (AR) on assembling and exploring educational mobile robot in pedagogical virtual machine (PVM)." Interactive Learning Environments 28.8, pp. 964-990, 2020.

[31] Paredes-Velasco, Maximiliano, Mónica Gómez Rios, and Angel Velázquez-Iturbide. "Analysis of the Emotions Experienced by Learning Greedy Algorithms with Augmented Reality", Proceedings of the 22nd International Symposium on Computers in Education, SIIE, 2020.

[32] Toledo, Javier Alejandro Jiménez, et al. "Collaborative strategy with augmented reality for the development of algorithmic thinking." Iberoamerican Workshop on Human-Computer Interaction. Springer, Cham, pp. 70-82, 2018.

[33] Boonbrahm, Salin, et al. "Teaching Fundamental Programming Using Augmented Reality.", pp. 31-43, 2019.

[34] Schez-Sobrino, Santiago, et al. "A modern approach to supporting program visualization: from a 2D notation to 3D representations using augmented reality." Multimedia Tools and Applications, pp. 1-32, 2020.

[35] Guenaga, Mariluz, et al. "Serious Games, Remote Laboratories and Augmented Reality to Develop and Assess Programming Skills." International Simulation and Gaming Association Conference. Springer, Cham, pp. 29-36, 2013.

[36] Abernethy, Marin, et al. "ParallelAR: An augmented reality app and instructional approach for learning parallel programming scheduling concepts." 2018 IEEE International Parallel and Distributed Processing Symposium Workshops (IPDPSW). IEEE, pp. 224-331, 2018.

[37] Teng, Chin-Hung, and Jr-Yi Chen. "An augmented reality environment for learning OpenGL programming." 2012 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing. IEEE, pp. 996-1001, 2012.

[38] Del Bosque, Laura, Raquel Martinez, and Jose Luis Torres. "Decreasing failure in programming subject with augmented reality tool." Procedia Computer Science 75, pp. 221-225, 2015.

[39] Stadler, Susanne, et al. "Augmented reality for industrial robot programmers: Workload analysis for task-based, augmented reality-supported robot control." 2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN). IEEE,, pp. 179-184, 2016.

[40] Melcer, Edward. "Moving to Learn: Exploring the Impact of Physical Embodiment in Educational Programming Games." Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems, pp. 301-306, 2017.

[41] Kazanidis, Ioannis, Avgoustos Tsinakos, and Chris Lytridis. "Teaching mobile programming using augmented reality and collaborative game based learning." Interactive Mobile Communication, Technologies and Learning. Springer, Cham, pp. 850-859, 2017.

[42] Anggrawan, Anthony, et al. "Influence of blended learning on learning result of algorithm and programming." 2018 Third International Conference on Informatics and Computing (ICIC). IEEE, pp. 1-6, 2018.

[43] Peddie, J. "Augmented reality: Where we will all live". Springer, pp. 31, 2017

[44] Gardner, H. Introduction to second paper edition (tenth-anniversary edition). 2011. Frames of mind: The theory of multiple intelligences. New York, 2011.

[45] Klopfenstein, L., Andriy Fedosyeyev, and Alessandro Bogliolo. "Bringing an unplugged coding card game to augmented reality." Proceedings of the 11th International Technology, Education and Development Conference (11th International Technology, Education and Development Conference) IATED, pp. 9800-9805, 2017.