Building Augmented Reality Applications for Education: An Overview of Frameworks

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The field of education has always embraced changes and has always searched for ways or methods to improve the pedagogical act. Technology has become an important support for both teachers and students. Therefore, new ways to use technology in education have started to emerge. Augmented reality is one of the promising options for current trends. Thus, this paper has the goal to create an exhaustive overview of how augmented reality can be used in order to create a more qualitative educational act. Firstly, this study will briefly define the term and present a short history of the evolution of the concept, as well as the most important advantages and disadvantages. Secondly, the paper will focus on developing applications based on augmented reality, analyzing the eight most relevant frameworks at the present moment. The frameworks will then be compared based on general and more advanced capabilities. Overall, the contribution of this paper to the literature is based on offering a complete overview of the way that augmented reality can be used to build applications that can be integrated into the educational act.
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1 Introduction

An inclusive definition of the concept of AR is that it represents "a wide spectrum of technologies that project computer generated materials, such as text, images, and video, onto users' perceptions of the real world" [1]. Thus, augmented reality should be easily explained as a combination of reality and virtuality happening in the real environment [2]. Therefore, the user will not leave the real world, but will be enriched with virtual objects suitable to the purpose of the model [3].

This definition sets AR in opposition to other important notions as virtual reality, mixed reality and augmented virtuality, each of them representing new ways in which the reality can be perceived by the user. Virtual reality can be briefly reduced to the simple definition of "human immersion in a synthetic world" [4]. Thus, VR consists of creating a completely new artificial world that will replace reality [5], a so-called "virtual environment", in which the user will emerge through a headset [6]. During this kind of experience, the sense of vision and the sense of hearing will be stimulated [3].

Mixed reality can be defined as "a hybrid reality, where real and virtual worlds combine to create new environments and visualizations that coexist and interact in real time with physical and digital objects" [3]. Thus, mixed reality can be seen either as a combination between augmented reality and virtual reality or as another form of augmented reality at all. However, one must note that there is a slight nuance in the definitions of the concepts. Augmented reality implies an overlap of digital content with the real world, while mixed reality will anchor digital content in the real world [8].

The last notion is augmented virtuality. It represents "the ability to interactively explore a virtual representation obtained from the real world [3]". In fact, it is the opposite operation to the augmented reality: it brings real objects into the virtual world.

Since the position of augmented reality has been established, this paper will focus on creating an overview of the evolution and capabilities of

AR. The first section has the goal of presenting the history and stages of the development of the notion of augmented reality. The second section will provide a brief presentation of the eight most popular frameworks that are currently used in order to develop AR applications. The paper will conclude with a comparison between the analyzed frameworks, based on two criteria: general capabilities and more advanced capabilities.

2 History of AR

The name of augmented reality originated back in 1990 and is linked to the names of Tom Caudell and David Mizell, who were researchers for Boeing Aerospace [6]. They used this term to identify the display that electricians use on their heads to be able to assemble complicated wires. Nonetheless, the history of augmented reality dates even further back to 1990. Figure 1 shows a complete timeline of evolution in AR technology, together with the different generations that emerged over time.

The history begins back in 1955, where Morton Heiling designed the first multisensory theater with the aid of a device that simulated the behavior of a modern headset device used for virtual and augmented reality [4]. Then, almost 15 years later, Ivan Sutherland invented an actual head-mounted display [10]. The usage of that device was extremely like the modern ones, enhancing the senses and creating an altered perception of the reality with the aid of media content. Myron Krueger continued the research in the sphere of augmented reality and, in 1975, created a so-called videoplace that consisted of two rooms that communicated through projected images [10]. NASA also contributed to the development of this emerging technology and created its own virtual environment device, less heavy, where the user could see in a 360-degree view.

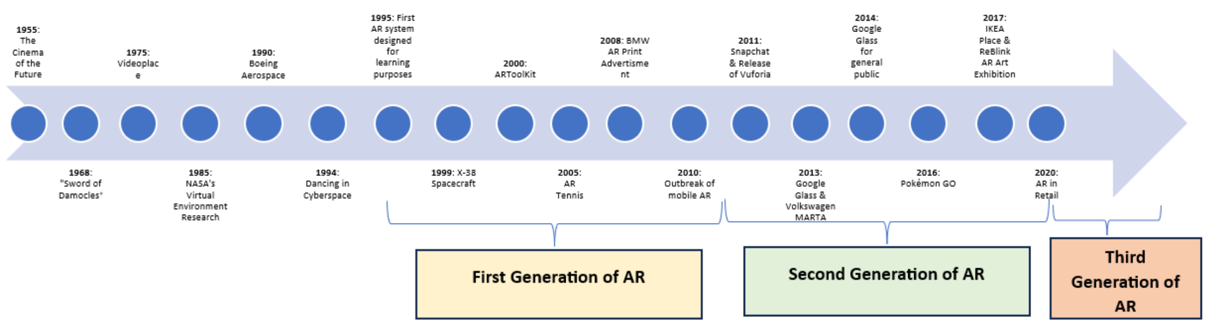

Fig. 1. Timeline of AR evolution

From 1992 on, the first generation of AR emerged [11]. It was characterized by hardware-based AR, meaning that the alteration of reality was mediated by displays, either head-mounted or handheld. This generation is marked by several important milestones such as the head-mounted device created by Boeing Aerospace, the first AR-based theater show entitled *Dancing in Cyberspace*, the AR navigation system designed for the X-38 Spacecraft or the Bluetooth-based tennis game that was developed by Nokia [5]. Also, the first ARToolkit appeared, thus representing the beginning of the software development in the sphere of AR. Probably the most notable event of this generation took place in 1995, when the first completely dedicated AR application was launched at the University of North Carolina [6]. It was an educational tool with the capability of teaching anatomy with the aid of 3D. The students were able to analyze the structure of the bones by wearing a display on their head. The domain in which AR was introduced during this period consisted of

health, engineering, and natural sciences, but there was no encouraged option due to the high costs that were implied [11].
The year 2010 marked the outbreak of mobile AR and thus the beginning of the second generation of AR. [6]. This implied an increase in AR experiences based on applications, mostly mediated by mobile devices. Several steps in the evolutions were made both in the sphere of software development and use cases for augmented reality. Year 2011 was a remarkable one in the history of augmented reality with two relevant events: the release of Vuforia, the most popular SDK for AR developments [6], and that Snapchat started using AR through its filters, being the first application to do this [5]. AR technologies also entered the automobilist world when, in 2013, Volkswagen developed its own AR mobile application that represented a virtual adjuvant for repairing their cars. With a huge increase of the number of applications, the second generation proved that AR could be integrated in different fields such as entertainment (Pokemon Go in 2016), home design (IKEA Place), art (ReBlink Art Exhibition in Canada). Giants, such as Google, have started investing in AR technologies, with Google Glass being released first in 2013 and then in 2014 for the general public [11]. Thus, during the second generation, augmented reality became more available, especially for the public due to the usage of mobile devices that mediated the experience and became more and more common among people. Therefore, the term Mobile Augmented Reality (Mobile AR) should be explained as being a version of augmented reality with additional challenges brought about by the device on which it is used, the mobile phone in the present case [12].
The third generation of AR is thought to have begun in 2020 and marked two important changes. Firstly, immersion in AR in retail was possible as a consequence of the pandemic when great players such as Sephora and Adidas allowed their customers to test the products through an AR experience [10]. Secondly, the MAR took a step further, and a new experience was created in the concept of WebAR. It can be easily defined as being "*an augmented reality experience that can be achieved using a web browser*" [7]. Even if, at first, this definition might be confusing and might seem a regression to the usage of computers instead of mobile phones, the reality is quite different. WebAR actually implies using a mobile web browser and the AR application will not be installed on the device anymore. It is considered an easier experience, both in terms of development and of actual usage. When being intermediated by a web browser, finding a mobile OS-oriented framework is no longer needed. Thus, cross-platform technologies might be the future of augmented reality.
Augmented reality comes with numerous advantages. The next part of this section will focus on the benefits AR can bring to education. As AR means combining the real world with digital content, it can create the environment to display any situation or any concept [12]. In this way, experiments that are either too dangerous (for example learning about nuclear disasters) or too difficult (learning about the insides of the human body) can be thought through AR in a non-theoretical way [14]. Teachers can create digital content with which students can analyze and interact to gain relevant knowledge about each phenomenon in a safe and interactive way. By approaching the educational process in this way, the learning becomes more effective and more relevant, since the students will explore the concepts in a practical way rather than a theoretical one. This approach is based on constructivism learning theory, which claims that students will shift their roles from passive listeners to actively building their knowledge [15]. In this way, AR creates a challenging learning environment in which the student has more control over the learning pace.
AR also means direct interaction with the learning content, even if it is in a digital format [16]. Therefore, the level of motivation and engagement of the students will increase, they are more curious to learn and find out more.

Thus, the success of the educational act is imminent. In this way, the gamification of the learning act will be obtained and the learning performance of a student will undoubtedly increase [17]. In addition, by direct interaction, students will use not only the sense of seeing, but also, first, the sense of touching. Some AR models can also trigger the sense of hearing. Thus, the learning process will become a kinesthetic one [8]. This will have a direct impact on the effectiveness and motivation of the students.

Furthermore, the learning experience will take place in a context, making it even more relevant for the student [15]. This approach is supported by Piaget's learning theory, at least for students in elementary school, but it can unquestionably be extended to any learner at the beginning of a process of gaining knowledge about a subject. According to Piaget, children's cognition is developed in an iterative way, through several stages, similar to a staircase: the sensorimotor stage, the preoperative stage, the concrete operational stage and the formal operational stage [18]. The concrete operational stage is associated with ages 7-11 (so, therefore, around the beginning of the elementary school almost everywhere in the world) and it is the moment when students start to operate with concrete objects, especially in their learning. AR accommodates exactly a similar environment: learners will interact directly with the digital content that is brought into reality, and, by manipulating it, they can create abstractions and references. Moreover, this approach will stimulate better memory retention [15].

However, augmented reality also comes with a series of challenges. These drawbacks can be categorized into three categories: design, implementation, and operation [19]. In terms of design, the most important challenge is represented by the lack of sufficient technical knowledge of the creators [19]. Thus, the application will be limited and will also lack creativity and possibly the usage of more advanced features. There is also the question of accessibility. The way an AR application is developed is based on a set of requirements. However, the design can bring about discrepancies for students with special needs, physical (such as blindness) or intellectual (for example, autism) [11]. Moreover, to create a pleasant experience through an augmented reality application, specialist from multiple disciplines must be gathered [19]. This might result in a serious challenge in regard to the design of the system.

In terms of implementation, the most crucial drawback is usability of the AR solution in relationship with its complexity. The implementation needs to be as simple as possible in order to create a pleasurable experience. Thus, some instructors might feel quite reluctant introducing such technologies in the teaching process [9]. In addition, the fact that the concept of cross-platform is not so popular in the context of developing AR applications [6] can lead to some disadvantages. Thus, multiple versions of the application should be implemented, as well as compatible versions for different operating systems. Thus, creating and developing an AR experience can result in high costs, especially when special equipment is necessary [10].

When one thinks of challenges regarding the operation of AR systems, the most important one is, at the present moment, the lack of digital skills among teachers. Since AR is a quite new discovery for the education system, teachers are not used to make use of it. Moreover, there are not clear regulations and directions or suggestions regarding its implementation in the learning process [6]. So, in this situation, teachers will surely adopt the strategy of trial and error to observe what is the best approach of integrating AR solutions. This might lead to a flip side for students. Instead of having a fun learning environment, the atmosphere will be dominated by confusion. Another drawback is indeed the cost of equipment students and teachers need to use during the class. This is a cost that the school should support and might result in an impossibility for certain educational institutions [9], especially the ones in poor areas.

3 Research Methodology

In order to create AR experiences, one approach will be to develop them from scratch. However, strong programming skills are required in this case.

This paper will provide qualitative research that will consist of an analysis of the most popular AR development frameworks and SDKs that can be used in 2024. Eight frameworks were selected, both from Internet blogs and from research papers. These are Kudan, ARCore, ARKit, ARToolKit, Unreal Engine, Unity, Vuforia and EasyAR. The first motivation behind this choice is their relevance in the current market. They are frameworks that are still available and they are not approaching their end life or support, thus, a developer can still benefit from all the features they offer. Secondly, they represent popular mentions, since they appeared in all the sources that were used to define the collection ([11] [12] [13] [14] [15] [16] [17] [18]). The section will continue with a brief description of each and its capabilities and features, and, afterward, a series of criteria will be established and used for a comparison between the eight solutions. The order in which the solutions will be approached will be alphabetical.

In order to continue through this paper, two notions need to be explained: SDK and framework. According to the Cambridge Dictionary, SDK is an abbreviation for software development kit and refers to "a set of tools and programs that allow developers […] to create software applications […] for particular types of computer systems or mobile phones" [1]. Unlike a framework, which can be defined as "a reusable design of all or part of a system that is represented by a set of abstract classes and the way their instances interact" [2]. Thus, one can clearly understand that the purpose of both SDK and framework is the same, they act as an adjuvant for developers in creating software. But the main difference between them is that the framework already has a design, so it is more structured.

3.1 Analysis of the frameworks

ARCore is the SDK that Google developed to build AR experiences. Even if it is targeted to Android developments (so the programming languages that are used are the ones that run in a JVM – Java or Kotlin), it offers also cross-platform support. It is a very powerful tool, integrating multiple important features related to AR in terms of 3D content, light estimation, motion tracking and understanding the environment [19].

ARKit is the SDK that Apple created for AR development. It targets devices that run iOS as the operating system. At the time of writing this section, the last version of ARKit is 6. It comes with a great deal of features, such as new location anchors, capturing one's movement in real time, and offering the possibility of capturing 4K videos. An interesting improvement of the new version is the capability of ARKit to detect the overall pose of the body by tracking the left and right ear of the user [20].

ARToolKit is an AR SDK that started as an open source in 2001, but was sold in 2015. Therefore, the project that was initially under the ownership of ARToolWorks, took another name, artoolkitX, in order to be able to offer free AR resources in a similar way and in the same community as the former ARToolKit. In terms of functionalities, it covers the main ones of every AR developing system: motion tracking, understanding the environment, and creating a high-quality loyal copy of it or multi-user collaboration. It is available for all platforms (Android, iOS, MacOS, Linux, Windows). Its greatest advantage lies, in fact, in its community that has been nurtured since its first launch [13].

EasyAR is an SDK produced by a Chinese company. It offers two types of solution: EasyAR Mega and EasyAR Sense. EasyAR Mega is targeted for the development of mobile applications, but also for smart glasses software. It is a city-scale spatial solution that is adequate for developing AR experiences that include large spaces such as cities or parks. It can be used to develop applications for a set of industries such as education or tourism. Its key feature is AR navigation, where the user can display content in different locations of the world. The second product is EasyAR Sense and it is dedicated to the implementation of SLAM (Simultaneous Localization and Mapping) capabilities. It targets mobile applications and smart glasses applications. Its key functionality is tracking of motion and objects (in different forms). Even if it is a standalone SDK, it can be integrated into 3D engines such as Unity. The advantage of EasyAR (compared to ARCore) is that it is optimized for older Android phones, making it suitable for the Chinese market [14].

Kudan is another option to develop an application with SLAM capabilities. It provides a proprietary solution, GrandSLAM, to create mobile tracking. It also supports image tracking and location tracking, but also 3D content detection. It has cross-platform capabilities and can be combined with cloud infrastructure or a 5G network. It is aimed at different industries, such as medical or constructions [15].

Unity3D is not an SDK, but, more precisely, a game engine, a framework. Therefore, the main purpose of it is to create games, making it one of the most important choices in the industry. In terms of operating systems, it supports Windows, macOS, iOS, Android and Linux. It offers free and paid versions, depending on the purpose of the developed application (it offers plans for students, for personal use, or a pro version). To create AR experiences through coding and with the aid of Unity3D, C# is the necessary programming language. As features, it provides image tracking and can recognize 2D images and 3D objects [16].

Another game engine that one can use to create AR experiences is Unreal Engine. It is a perfect framework not only for AR but also for VR and MR. The distinctive aspect of this framework is that it is the only one on the list analyzed that offers support for mixed reality. It can be used for both mobile applications (Android and iOS), but also for smart glasses software. The programming language that one needs to master to use this framework is C++. Its key features include 2D and 3D object recognition and tracking of objects.

Vuforia is the last SDK in the list analyzed. Its release dates back to 2011 and marked an important milestone in the development of AR applications. Even in 2024, the relevance of Vuforia in the field cannot be questioned. It is a product of the PTC company and it offers two plans, a free and a premium one. The free plan is quite consisted, but there are a few limitations in number of models one can use, whereas in the premium one, the resources are multiple, as well as the offered functionalities. Moreover, it allows multiple types of hosting such as on-premises, cloud-based, or SaaS. In terms of functionalities, it focuses on accurate object recognition (both 2D and 3D objects) and multiple types of tracking (objects, images, environment) [17].

4 Discussions

The section will continue with two comparisons between the solutions of the list. Comparisons will be based on two tables, Table 1 and Table 2. Table 1 provides general information on each solution such as the target platform, the tracking system for each, and whether the application can be used free of charge or if there is a fee to pay to create an AR experience.

Table 1: General comparison between AR development solutions

Solution	Platform			Marker / Tracking system					General features				
	Android	iOS	Linux	Markerless	3D objects	Geolocation	Text	2D image	Online	Offline	Free	Paid	Open source
ARCore	□	□	x	□	□	□	x	□	x	□	□	x	x
ARKit	x	□	x	x	x	□	x	□	x	□	□	x	x
artoolkitX	□	□	□	□	x	x	□	□	x	□	□	x	□
EasyAR	□	□	x	x	x	x	x	□	x	□	□	□	x
Kudan	□	□	x	x	x	x	x	□	x	□	□	□	x
Unity3D	□	□	□	x	□	x	x	□	x	□	□	□	x
Unreal Engine	□	□	□	x	□	x	x	□	x	□	□	x	x
Vuforia	□	□	x	□	□	□	□	□	□	□	□	□	x

According to Table 1, developing AR experiences bot for Android and iOS is quite easy, almost all analyzed solutions have such capabilities, whereas, when it comes to Linux, it can be rather difficult to create an AR application since only artoolkitX and Vuforia have the necessary capabilities. In terms of tracking system, the most encountered seems to be represented by 2D images, included in all the analyzed solutions, whereas text is the less popular tracking system. All solutions offer support to develop offline applications and only Vuforia has the capability of online applications. They all have free versions that one can use either to test the functionalities or to actually develop a minimal application, but some of them offer a paid version for more resources and more capabilities. In addition, the single open-source option is artoolkitX, all the others being proprietary solutions.

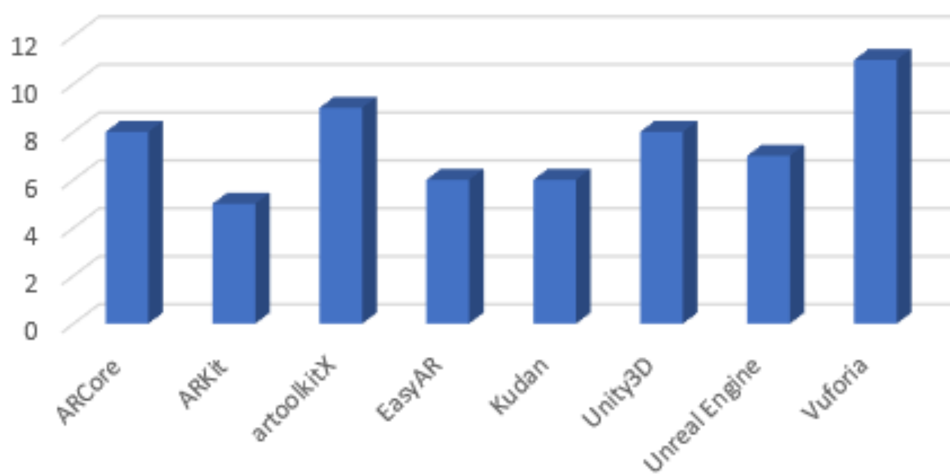

Fig. 2. Distribution of AR solutions based on general capabilities

Figure 2 reveals a graph where the eight solutions were compared based on the general capabilities explained in Table 1. So, according to this distribution, it seems that the most profitable solution for AR development seems to be Vuforia, which has 11 out of 13 general capabilities. This number of capabilities can be explained by the fact that it is the most longevous solution in the field, so, over time, it had time and space to become more and more relevant. On the contrary, the least favorable solution seems to be Apple's ARKit. Nevertheless, this position could be explained by the limitation of platform applications developed with ARKit that can be used. Since this is an Apple solution, it is targeted for iOS devices, so all the capabilities are designed in order to adapt to Apple devices. The second position is occupied by artoolkitX, having 9 capabilities out of 13. This can be explained by the fact that this solution is based on an open-source project. It is even more valuable since the community tried to further sustain this product even after the original project was sold. Unity3D and ARCore occupies the third place, having 8 capabilities, followed shortly by Unreal Engine. The next position is occupied by Kudan and EasyAR, which seem to be quite similar in terms of general capabilities.

One interesting result of this graph is the apparent discrepancy between ARCore and ARKit. Even if they are similar products, they are developed by different competitor companies. An advantage of the solution that Google provides is that it promotes its cross-platform ability, whereas Apple targets its solutions. Apart from that, the two solutions offer similar marking systems, so similar general capabilities.

A deeper analysis of the solutions will be covered in Table 2. A sum of more advanced capabilities was gathered and this table provides an insight on what each solution offers.

Table 2: Comparison between AR development solutions based on features

Solution	Motion Tracking	Environmental Understanding	Depth understanding	Light estimation	User interaction	Oriented points	Anchors	Trackables	4K Video	Scene Geometry
ARCore	□	□	□	□	□	□	□	□	x	□
ARKit	□	□	□	□	□	□	□	□	□	□
artoolkitX	□	□	x	x	□	x	□	x	x	x
EasyAR	□	□	x	□	□	x	□	□	□	x
Kudan	□	□	x	x	x	x	x	□	x	x
Unity3D	□	□	x	□	□	x	□	□	□	□
Unreal Engine	x	x	x	x	□	□	□	□	□	□
Vuforia	□	□	x	□	□	x	□	□	x	x

Figure 3 provides insight on how the solutions analyzed are distributed based on more advanced capabilities. The capabilities that were considered are the most used in the field of AR. Based on the provided chart, the best solution to use is ARKit from Apple, which has 10 out of 10 features. The second place is occupied by ARCore, which has 9 of 10 capabilities. The single feature it lacks is the 4k videos. Then Unity3D is the next on the scale, with 8 capabilities lacking depth understanding and oriented points. EasyAR is the next-best solution, the Unreal Engine and Vuforia, with 6 features out of 10. artoolkitX is the second-last-best option, offering only 4 capabilities, the basic ones that one can include in an AR system. The last solution to be considered according to this chart is Kudan, which provides only motion tracking and environmental understanding.

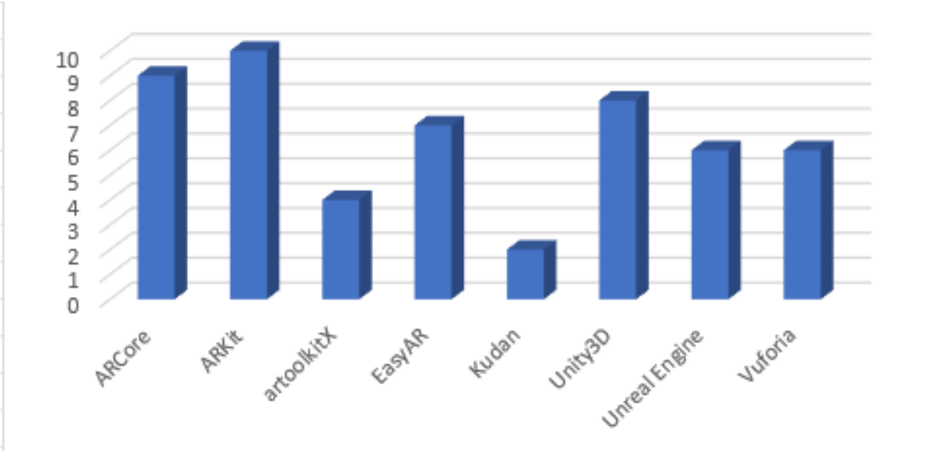

Fig. 3. Distribution of AR solutions based on advanced capabilities

Based on the two distributions, ARCore can be considered one of the best choices for developing AR experiences for multiple platforms since it has the majority of advanced and general capabilities. Even if ARKit is the last best solution in terms of general capabilities, when one wants to develop an AR application for iOS, it will definitely be the best option. Unity3D can also be considered a good option when developing cross-platform solutions, since it has both many general and advanced capabilities. Moreover, Vuforia can also be taken into account.

In contrast, if one wants to develop an AR experience with more features, artoolkitX might not be a good choice, since it lacks the majority of advanced features. Even if it is an open-source solution that has a great community, the products resulting after its usage might not exceed some limits. An even worse case is Kudan, which has really rudimentary options for creating an AR experience.

5 Conclusions

Augmented reality is unquestionably a technology that might enrich the educational act. The whole necessary setup in which students can benefit from an AR experience is valuable and is sustained by learning theories.

This paper firstly attempts to define the concept of augmented reality. The term is defined by itself, but also in relation to other terms of the spectrum. AR is explained as opposed to virtual reality, mixed reality, and augmented reality.

Then, the focus of the researched shifts to providing an overview on the history of augmented reality. The three generations are described with numerous details. The first outburst of AR and the first applications are emphasized. Moreover, the stages of Mobile AR and WebAR are presented. This section concludes with a possible future direction in the development of AR, which consists in the development of cross-platform applications in the context of WebAR. The paper continues with the advantages and disadvantages of AR. They were focused on the educational field since the purpose of this paper is to provide insights on tools that can help building applications for education.

The next section of the paper focuses on the analysis of the eight most relevant frameworks and SDK for building AR applications at the present moment. ARCore, ARKit, artoolkitX, EasyAR, Kudan, Unity3D, UnrealEngine and Vuforia. Then, a comparison between them is provided, based on two criteria: general and advanced capabilities. This paper contributes to the literature by creating an overview of the notion of augmented reality and providing an analysis of the most relevant frameworks for building AR applications.

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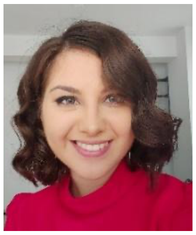

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