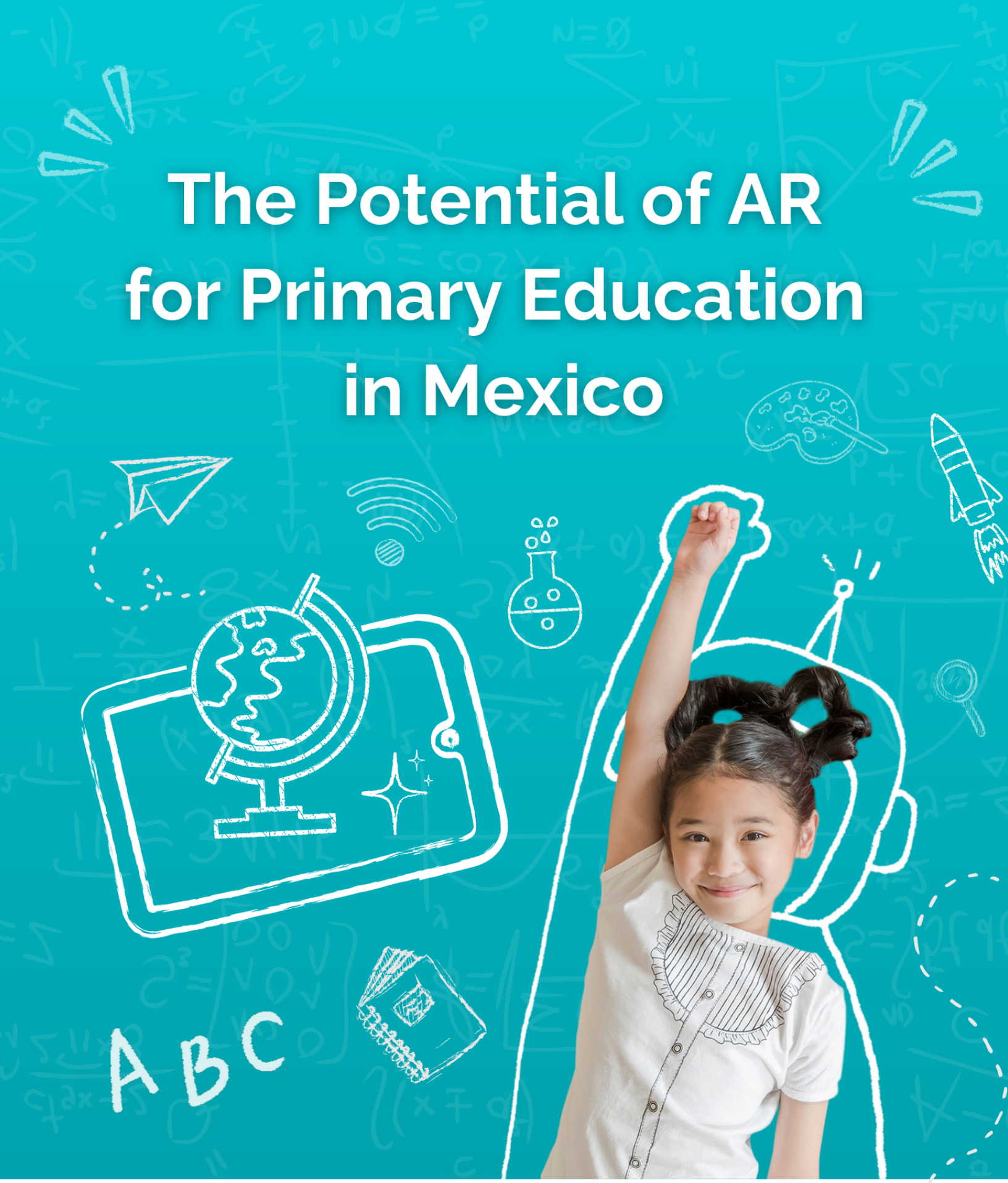
The Potential of AR for Primary Education in Mexico



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The Potential of Augmented Reality for Primary Education in Mexico

March 2023

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For their valuable time and shared inputs from their different perspectives and experiences, we thank the following experts:

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2. Introduction

Mexico infamously ranks last among the Organizacion for Economic Cooperation and Development's (OECD) 35 member nations in education. As the 2017 PISA scores showed, Mexican children left school with the worst literacy, maths, and science skills in the OECD, and approximately 50% did not meet the most basic standards. The Guardian even posed that the poorest children in Vietnam outperform the most privileged in Mexico, based on an analysis of global PISA results (Lakhani, 2017). These challenges have been further exacerbated by the advent of the pandemic in March of 2020, which led the country to close its schools and attempt alternative paths to education during confinement, many of which have been qualified as inadequate or insufficient by experts. Not only did the pandemic directly and indirectly lead to the dropping out of 2% of primary education students during the 2019-2020 school year and a subsequent 5% the following year, it also severely impacted children who stayed in school, with some estimated to have up to a 3 year delay in their education.

In light of this ever increasing education crisis, the topic of technology's potential for educational impact is something the country cannot afford to ignore. In this sense, the recent boost in interest of the Metaverse has unleashed a number of questions with regard to the potential of Extended Reality (XR), composed of Augmented Reality (AR) and Virtual Reality (VR), for attending the world's toughest challenges, including education. Particular interest has been raised within educational spheres about the specific potential of AR—defined by the Oxford Dictionary as "a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view"—for education considering its seeming ease of adoption. Users only require a smartphone and an internet connection to use AR-based applications. While the positive impact of technologies like Artificial Intelligence for education has been well documented, the potential of AR has yet to be fully explored, especially considering the quasi inexistence of applications for primary education for the classroom.

Throughout this report, the authors explore the potential of AR to address Mexico's main educational challenges, namely "quality and inequality", as posed by Sylvia Schmelkes, ex-Director of the National Institute for the Evaluation of Education in Mexico (Lakhani, 2017), focusing on primary education. The report is guided by two specific questions: to what extent can AR improve educational outcomes by improving children's engagement and interest? To what extent can AR-based education solutions be scaled in Mexico?

To answer these questions, the British Embassy in Mexico and C Minds' Eon Resilience Lab held a series of conversations with 19 experts, practitioners, and professionals in the field. Specifically, the organisations carried out a) five interviews, b) an online roundtable discussion with five participants on the technical challenges for scaling an AR education solution, and c) an in-person roundtable conversation with ten participants to discuss AR's potential to impact primary education.

The following report draws on the learnings from these conversations and desk research. This analysis is not exhaustive and is limited by the scope of the analysis. It begins by providing an overview of Mexico's primary education sector and the specific challenges it faces, followed by a

deep dive into AR and its potential for positively impacting primary education, including a presentation of local, regional, and international applications. The authors then explore the specific challenges of an AR-based education solution in Mexico before moving on to the opportunities and recommendations that would need to be followed to successfully design and implement such a solution.

3. Overview of the challenges in primary education in Mexico

Mexico's primary education system

The General Education Law establishes three types of education: primary, upper secondary, and higher education. The first type comprises four levels: initial, preschool, primary, and secondary. According to the reform of Article 3 of the Political Constitution of the United Mexican States, it is compulsory (SEP, 2022).

Primary education covers ages 6 to 11, where the first approaches to science knowledge are made, and habits are formed. According to data from the Ministry of Public Education (SEP), primary education has the highest coverage, reaching almost 91% of the population (SEP, 2022). Although the Mexican education system includes public and private education, 91% of children in primary education attend schools administered by the state or federal government (SEP, 2022).

According to the OECD (2019), Mexico has been facing two main education challenges since before the pandemic:

- **high dropout rates**: from 2015 to 2020, the dropout rate increased to 6% among the 6-14 years old population, representing an overall increase of 74% (Animal Político, 2020).
- **poor learning outcomes**: the 2018 results of the "Planea" standardised test showed that 80% of primary school students did not reach the expected knowledge in mathematics, reading, and writing (Maldonado, 2021). Likewise, according to the OECD in 2018, the proportion of socioeconomically disadvantaged children who reached at least PISA level 2 in reading was 53% lower than those of more advantaged students. For comparison, the OECD average is 29% (OECD, 2021). With the advent of COVID-19 in 2020, these challenges were magnified, mainly due to the abrupt transfer to digital media due to the closure of schools, which lasted up to 53 weeks. This closure led to a further increase in dropouts. According to figures from the National Institute of Statistics, Geography, and Informatics (INEGI), around 2% of primary education students did not return to the classroom during the 2019-2020 school year, and 5% did not enrol for the following school year (INEGI, 2020).

According to INEGI's Survey for Measuring the Impact of COVID-19 in Education, the main reasons for the 2.5 million dropouts in 2021 were directly or indirectly linked to the pandemic. About 27% of the repondents said that *"distance classes were not very functional for learning"* and 22% said it was because they did not have the means to take online classes (either because they did not have individual access to a computer, cell phone, or other devices, or sufficient Internet connection) (Soto Espinosa, 2021). The United Nations Development Programme (UNDP) demonstrates in its report *"COVID-19 and Education in Mexico"* from 2022 that access to the Internet, smartphones, tablets, or computers in the home significantly

reduced the likelihood of dropping out. As only 4 out of 10 schools were connected to the Internet and 3 out of 10 had computers before the pandemic, as reported by the National Institute for the Evaluation of Education (INEE) before its demise, this disadvantaged a large part of the population (UNDP, 2022). The private school system adapted to the new reality with more agility, but both the public and private systems struggled to transition to a digital modality (UNDP, 2022).

Moreover, even though part of the student body had the possibility to continue their studies digitally, a survey conducted by INEGI (2021) showed that 58% of people said that online classes or home studies were not functional because *"they do not learn or learn less than in person"* and 27% said they felt a lack of follow-up.

This links to another of the challenges faced by the education system during the pandemic: the lack of digital skills among teachers, which further complicated the transition to online classes. César Loeza, Director of Education at UNETE, explained that the low levels of digital skills among teachers before the pandemic was, in part, due of being overtaken by technology, leading to a substantial resistance to approach and learn digital skills. This reality meant that many teachers did not have the necessary tools to swiftly (and safely) move to online teaching.

Despite these challenges, as mentioned by the experts at the round table, many teachers tried to face this scenario, which needed to be supported either by their schools and the government to facilitate this work. The government's response was the creation of booklets developed by teachers so that children could learn independently at home (IMCO, 2023). However, this was a challenge for students who needed to adjust to independent, self-learning modalities. In addition, parents and guardians were required to help facilitate the teaching process, which in many cases could not be achieved.

With these challenges in mind, the Mexican government promoted the "Learn at Home" strategy, an alliance with the most important television stations in the country in order to transmit school content through television. This medium was chosen considering it would provide the widest reach, with 91% of households having one (INEGI & IFT, 2021). Nonetheless, Ana Cecilia Pérez, Co-Founder of Capa 8, a cybersecurity consulting firm with specialised programs for cybersecure schools and families, disclosed that the strategy turned out to be an insufficient policy for children since there was no interaction or engagement with the knowledge or teacher. She explained that the unidirectional approach, via television or even computers in some cases, led many children to become disinterested or even leave the education system.

Much as the challenges presented above reflect the known impact of the pandemic on the Mexican educational system, the complete impact is yet to be grasped, as there is no official data, nor have standardised evaluations been carried out since 2019, which makes it impossible to understand the current state of education (IMCO, 2023). Still, some estimates have been made by international and civil society organisations. The UNDP estimates an average lag of 1.3 years in children's school trajectory in the country. In the southern regions, which tend to be the poorest and least well-connected, it is estimated that the impact was even more severe,

which could translate into a loss of up to three years of learning (Monroy-Gómez-Franco, López Calva, et. al, 2021).

Despite the seemingly endless list of challenges mentioned above, Elena Arias, Senior Education Specialist at the Inter-American Development Bank (IADB) called attention to two significant changes that were achieved from 2020 onwards for schools and teachers:

- The strengthening of teacher's digital skills via the massive digitalisation and adoption of technology;
- A change of perspective among the teaching staff, whereby they no longer perceive digital devices as their competition but as an ally.

Policies focused on improving the education system

During the last decade, strategies have been promoted to transform the educational system in Mexico; however, for this document, we will focus on the policies pushed by the 2018-2024 administration since they are the ones that define the current scenario:

- In 2019, the General Education Law (LGE) was modified, creating the New Mexican School (NEM), a pedagogical project that seeks *"the integral human development of the learner, to reorient the National Education System, to influence the educational culture through co-responsibility and to promote social transformations within the school and in the community"* (LGE, 2019).

- Likewise, the National Commission for the Continuous Improvement of Education (Mejoredu) was created, replacing the National Institute for the Evaluation of Education (INEE). However, Mejoredu does not have constitutional autonomy, nor can it carry out the evaluations directly. It is only responsible for generating the evaluation criteria and materials (IMCO, 2023). It is also important to mention that since 2019 there has yet to be a standardised test to measure primary education outcomes.

- In 2021, an initiative was promoted to propose amendments to articles 18, 84, and 85 of the General Law of Education aimed:
    - to strengthen critical and informed thinking when consuming digital content and information,
    - to guarantee a full insertion of girls, boys, and young people into the digital society to close the digital gap and inequalities in the population and,
    - to add to the Digital Education Agenda the axis of attention and the development of Digital Intelligence in the educational system.

- In 2022, the Mexican government presented a new curriculum for primary education focused on four formative axes: Languages; Knowledge and Scientific Thinking; Ethics, Nature and Society; and Humanity and Community. These modifications

seek to rethink the way of learning by adapting knowledge depending on the context of each school, thus recognizing the country's social, cultural, and economic differences (Díaz-Barriga, 2022). A pilot test was planned for October of 2022 with 960 schools but it was stopped due to a lack of clarity of content, subjects, evaluation material, and training for teachers (IMCO, 2023).

4. The potential of new technologies for primary education

The potential of digital and technological tools to improve primary education has been demonstrated through numerous academic studies, pilot projects, and school implementations. Many studies, including one dating back to 2015, showed that the use of technology in the classroom incorporates vertical and lateral thinking, allowing for more creativity in problem-solving and establishing more connections between the learning subject and real life, in addition to promoting information retention and children's autonomy. The report finds that education with technology drives students to have more responsible practices and strengthens their technical skills, contributing directly to their future education and career (Holt, 2015).

That being said, much of the research and pilots that have been carried out to date focus on the potential of Artificial Intelligence[1] (AI) due to its earlier mass adoption among sectors. In light of the increasing conversations around the Metaverse, the question of extended reality's (composed by Virtual Reality (VR)[2] and Augmented Reality (AR)[3] potential for education is increasingly relevant, but there are very few applications. In fact, among the 187 EdTech startups mapped in Mexico by Traxcn in 2023, none use AR and only one uses VR. As VR devices are not recommended for children under 11 or 13, depending on the provider, and considering the sale and distribution limitations in Mexico, this research project focused specifically on AR. Its specific potential for primary education via classroom applications has yet to be explored, but the impact shown by its application for higher education and museum experiences shows promise.

a. What is Augmented Reality?

Augmented Reality (AR) is a technology that superposes digital elements to the physical world. According to Microsoft *"AR incorporates three characteristics: a combination of digital and physical worlds, real-time interactions, and precise 3D identification of virtual and real objects."* This technology tends to be confused with Virtual Reality (VR), but they are not the same. The main difference between these technologies is that AR relies on the physical world, while VR is entirely virtual, and accessing VR content requires devices like headsets or goggles are

[1] "general-purpose technology that has the potential to improve the welfare and well-being of people, to contribute to positive sustainable global economic activity, to increase innovation and productivity, and to help respond to key global challenges" (OCDE, 2019).
[2] "real-time use of information in the form of text, graphics, audio and other virtual enhancements integrated with real-world objects" (Gartner, 2022).
[3] "Augmented reality is an enhanced, interactive version of a real-world environment achieved through digital visual elements, sounds, and other sensory stimuli via holographic technology" (Microsoft, 2023).

needed. In contrast, AR content also can be viewed via a person's smartphone. As mentioned by more than one expert, the main way to understand AR is to think of Pokemon Go.

As Nohemí Vilchis, EdTech Specialist at the Observatory of the Institute for the Future of Education commented, although AR was born in the early 1990s (Interaction Design Foundation, 2021), its applications in different sectors has increased in recent years and will continue to do so thanks its role in the development and deployment of the Metaverse. According to Statista's estimates, the size of the AR market will grow from $3.5 billion to over $198 billion by 2025 (Garibay, 2019).

b. Benefits of AR for education

Most AR applications exist mainly in the entertainment and video games sector and other specific sectors such as health, tourism, e-commerce, and security, primarily used for capacity building. AR is also being designed for and implemented in educational settings, chiefly for independent use as opposed to a classroom setting use. With each new application showing potential in the field by facilitating students' learning process, the number of applications in the field is growing. During the interviews and the roundtables, the experts mentioned the benefits that AR could bring for primary education. These are reported below:

- Increased student engagement and interest:

It has been found that integrating AR solutions into the learning process in the classroom promotes hands-on learning that generates more interest, commitment, and involvement on the part of students (Maryville University, n.d.). Various resources and papers also reveal that AR can increase motivation, engagement, and satisfaction when performing a learning activity. Moreover, considering that one of the essential elements for measuring engagement is the attention dimension—which refers to the mental ability to concentrate on a single action (Herpich, Fabrício, et al., 2018)—it has been found that AR helps students maintain high levels of attention and interest in a particular topic (Herpich, Fabrício, et al., 2018), improving their results in learning assessments. Furthermore, a meta-analysis of 10 years of research on experimental studies on AR and education (Hsin-Yi, Theerapong, et al., 2022) concluded that 1) students who learned through AR generally performed[4] better; 2) it serves as a support tool for strengthening knowledge and other skills, such as collaboration, and 3) it improves more positive responses in terms of motivation and attitude. This impact generated by the integration of AR into learning processes was confirmed by all of the experts consulted for the project, including Roberto Rogel, General Director of Learny, a Mexican company that uses video games and XR to create learning tools. He shared that, in addition to their observations, his company had compiled a number of teacher testimonials speaking to the benefit of AR technology.

Furthermore, research has shown an increased correlation between the use of AR, improved educational achievement and student learning skills, in contrast to traditional methodologies. Among the benefits of this type of technology is that it can help children understand complex

[4] Performance can be defined as a measure of the level of student learning in terms of knowledge and skill development (IGI, n.d.)

and abstract concepts and elements by providing visual and interactive experiences (Herpich, Fabrício, et al., 2018).

The potential of AR can be further improved for education by integrating gamification elements, which consists of using elements and principles of games to make the learning process more interactive and fun. This may involve including rewards, levels, points, badges, and feedback, all of which have been shown to support attention and learning retention (Galvin, 2021). This has been found further to increase students' interest (Dinia, 2023). A number of experts also pointed to gamification as one of the key elements to unlocking AR's potential for education, as shared by Katty Beltrán, General Director of Dibujando un mañana, who is in charge of an educational site for children who live and work on a landfill near Mexico City.

The impact of AR's use on children in learning environments found in the studies above can be found summarised here: improved attitude, interest, attention, engagement, involvement, commitment, motivation, knowledge, collaboration skills, overall skills, satisfaction, performance, and educational achievement.

- Personalised learning

Personalised learning, which means meeting the specific needs of each student, is considered one of the most effective ways to accelerate academic and cognitive growth. According to a Microsoft (n.D) survey of 2,000 students and 2,000 teachers, students perceive that they learn more when they have a greater voice and choice and receive personalised feedback. The same report finds that 98% of students who received personalised instructions perform better than those with traditional learning. In practice, personalised learning is very complex for teachers due to the nature of the task that requires identifying individual needs and the additional workload involved, as mentioned by Francisco Silva, Co-founder and Director of Educational Technology at Tecduverso. This is especially true when they are faced with classes of up to 45 individuals, which is common in Mexico's public sector.

As shared by Elena Arias, Senior Education Specialist at the Inter-American Development Bank (IADB) and Nohemí Vilchis, EdTech Specialist at the Observatory of the Institute for the Future of Education, the combination of AR with other technologies such as AI can facilitate the identification of each student's type of learning (visual, auditive, kinesthetic, or verbal) and of their specific gaps. This identification allows teachers to redirect their efforts to where they are most needed and adapt them to each individual child. For example, if a child learns best visually, 3D elements can be used, or if the child learns kinesthetically, they can play and discover elements in AR. Francisco Silva also mentioned that these tools make it easier to identify students' interests and thus offer resources targeted to each of them. This same idea is shared by Joseph South, ex-Director of the Office of Educational Technology at the U.S. Department of Education in an article dating back to 2017.

Following this point, Diana Alfaro, Director at Itera Inclusión, mentioned that the use of AI+AR tools in learning spaces could help promote inclusion by freeing up teachers' time to attend the

needs of special-needs children, “who typically require five times the attention of an average-capability child.”

- Strengthened soft skills:

According to the World Bank (2021), cognitive, socio-emotional, and technical skills must be prioritised to cope with today’s sociocultural changes, globalisation, climate change, and the future labor market. Among the critical thinking skills, the most important ones are problem-solving and creativity; within the socio-emotional ones, leadership and teamwork are the most important.

Among these capabilities, the use of AR in education processes can strengthen creativity, problem-solving, and collaboration through the gamification of experiences, especifically with experiences where real-time feedback performance is provided, which helps children learn from their mistakes and improve their problem-solving skills (Invelon, 2020). In addition, gamification often involves creative problem-solving, which drives the user to think creatively and develop innovative solutions.

On this same topic, Francisco Silva, Co-founder and Director of Educational Technology at Tecduverso, commented that AR activities, where each student plays a key role in solving a situation, could lead to collaborative learning and teamwork, positively impacting the skills mentioned above. In addition, it has been shown how collaboration is strongly linked to social engagement, community building, and cultural understanding, which in turn can benefit academic performance (Hirsh-Pasek, M. Zosh et al. 2022).

- Comparatively modest investment:

When asked about Mexico’s connectivity, the participants, agreed that it varied greatly depending on the region, and that strong broadband connectivity was not a given. That being said, she did not consider this a deterrent to the development and adoption of AR-based solutions in Mexico because most Mexicans already possess the tools required to use them.

Part of AR's popularity is due to the fact that it does not necessary require sophisticated hardware or equipment, in contrast to VR. It only required a good internet connection, smartphones, or tablets. According to a survey from the Federal Telecommunications Institute (IFT) (2022) composed of people who use fixed internet and mobile telephony and have children between 6 and 17 years of age, 51% mentioned that their child owns a cell phone with internet access and social networks. The Competitive Intelligence Unit (Alamilla, 2022) also posed that 26% of people aged five years or older have an active device. In addition, more and more schools are implementing digital tablets.

While Internet connection may seem to be a significant impediment to the mass adoption of this technology in education, this challenge can be solved by creating solutions that can be used offline, as shared by Edgar Tapia, Regional Manager of Caligrafix Mexico. He explains that in the case of his organisation, five minutes of internet connection is sufficient for someone to download and store new content onto the device. Naturally, the speed of the download will

depend on the quality of the internet connection and the size of the content, the latter of which can be optimised for offline use. Francisco Silva, Co-founder and Director of Educational Technology at Tecduverso, in turn, mentioned that technological advances keep making AR-based content easier to access. Moreover, it is estimated that AR content is only 25% virtual, as it only augments real-world scenes (TeamViewer, 2022), as opposed to VR which creates an entirely immersive virtual environment, meaning AR requires lower levels of connectivity and is thus more suited to Mexico's context.

- Other:

This technology can be beneficial for schools that do not have the resources to conduct field trips or have the infrastructure to conduct experiments or hands-on activities, making it possible to acquire this knowledge through an authentic experience without the need to leave the classroom, as shared by a number of experts.

c. Current uses cases and trends of AR for education

i. Cases of AR solutions for primary education worldwide

Although AR applications for education are being implemented mainly in higher secondary education, some tools have begun to be created to facilitate and improve the results in the learning process of children. Some of these applications are presented below. The usage refers to whether they are intended for children to learn at home (individual) or are to be used in school (classroom).

CoSpaces

Country: Germany
Usage: Individual

The company is dedicated to creating interactive tools with Augmented Reality (AR) for children, where they can create their immersive worlds and 3D objects and learn to programs to bring their creations to life. One of its most outstanding resources is the MERGE cube, a smart cube that allows them to create interactive experiences about literature, vocabulary, and science and create holograms. The cube works as hardware and synchronises with an application to visualize the 3D elements created through a smartphone or tablet.

PleIQ

Country: Chile, Mexico, and Colombia
Usage: Individual and in the classroom

This Chilean company focuses on developing immersive AR educational experiences for preschool and elementary school children. Its offer includes immersive children's books that support the learning process. These tools are aligned with the curricula where they are currently operating and promote children's curiosity and commitment. In addition, it has an artificial intelligence algorithm for guided accompaniment. The platform works through a free app that allows the activation of AR functions on a smartphone or tablet.

Orboot Earth

Country: India
Usage: Individual

This is an interactive learning globe for children aged 4-10 years and offers an immersive AR experience. It aims to support early learning, spark imagination and curiosity, and strengthen geographical, scientific, environmental, social, and cultural skills. Currently, the globe activities focus on animals, cultures, gastronomy, inventions, maps, and monuments, and it is available in 9 different languages. It works with an application for tablets or smartphones that allows children to explore all the applications and activities on the globe.

Launch to the moon with AR

Country: USA
Usage: Individual

This AR app was created to commemorate the 50th anniversary of the moon landing. The app allows children to immerse themselves in NASA missions from the 1960s, such as landing on the moon, launching their own Saturn V rocket, sitting inside the Apollo 11 command module, and exploring the lunar landscape through an AR-powered portal. The goal of this app is to encourage interest in space-related topics. The application runs on a cell phone and offers a real-time simulation with 3D photographs and objects.

WWF forests

Country: USA
Usage: Individual

This application uses augmented reality technology to offer an immersive experience that allows children to explore the forest ecosystem. The objective of the application is to raise awareness about the importance of forest care and sustainability in an interactive way. In addition, the tool also informs about actions to repair and care for threatened forests. The application works through an interface that allows for the visualizing of the forest and observation ofhow different animals react to the presence of people.

ii. Current AR for education solutions in Mexico

Mexico is still in its early stages as a developing market for AR but has shown significant growth in recent years, especially in advertising, commerce, and entertainment. Several startups and established companies are working on projects to drive AR development in the country in the field of education. Featured below are the use cases mentioned by the experts spoken to - it is interesting to note there are very few applications:

AR in museums

The Regional Museum of Cholula, in collaboration with the company Visualma, created AR-powered spaces where one can visualize the construction process of the pyramid and learn about the Aztec culture and mythical figures such as Quetzalcoatl (León, 2022).

AR in classrooms

The company Learny whose applications have created a chemistry lab powered by AR so that students can put their knowledge into practice and perform experiments without the need to invest in the infrastructure of a physical laboratory.

They also worked hand in hand with Larousse dictionaries to include AR content in their most recent edition to support the understanding of words, concepts, and sentences (Larousse Editions, 2023).

AR in public school

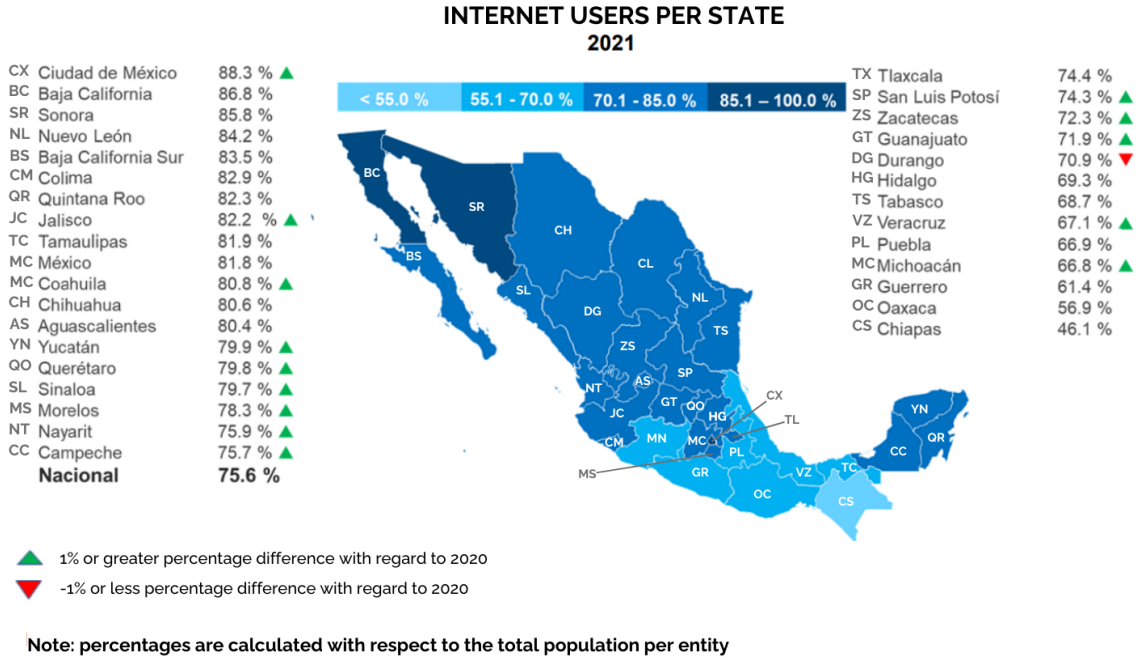
The Institution of Education of Aguascalientes designed a free textbook for students in the third grade of primary school in response to the new guidelines that require adjusting teaching materials to the context of each state. The books work through cell phones, where students can interact with images and 3D graphics presenting the culture and traditions of Aguascalientes.

5. Challenges of implementing AR solutions for primary education

The implementation of AR in primary education in Mexico poses several challenges that should be considered when creating AR experiences and solutions for primary education. During the interviews and roundtables conducted for this research, several challenges were identified, such as connectivity and infrastructure, the digital divide linked to the country's socioeconomic context, the lack of capacity building for teachers in these areas, and the limited resources available. Each of these challenges is discussed in more detail below.

a. Connectivity and infrastructure

Universal coverage in Mexico has been challenging, even though it is in the government's plans. Standard metrics to represent the coverage and availability of these services usually include subscriptions or users (The CIU, 2019). Since the pandemic, there has been an increase in the number of Internet users in Mexico. According to INEGI data, in 2021, there were 88.6 million users, equivalent to 76% of the population, an increase of 4.1 percentage points compared to 2020 (INEGI, 2021). It is estimated that 50% of children between 6 and 11 years of age use the Internet (Montiel, 2022). However, it is estimated that three out of every ten people are still not Internet users (Calderón, 2022). In addition, there are significant disparities in coverage depending on the state, as shown by graph 1 below.

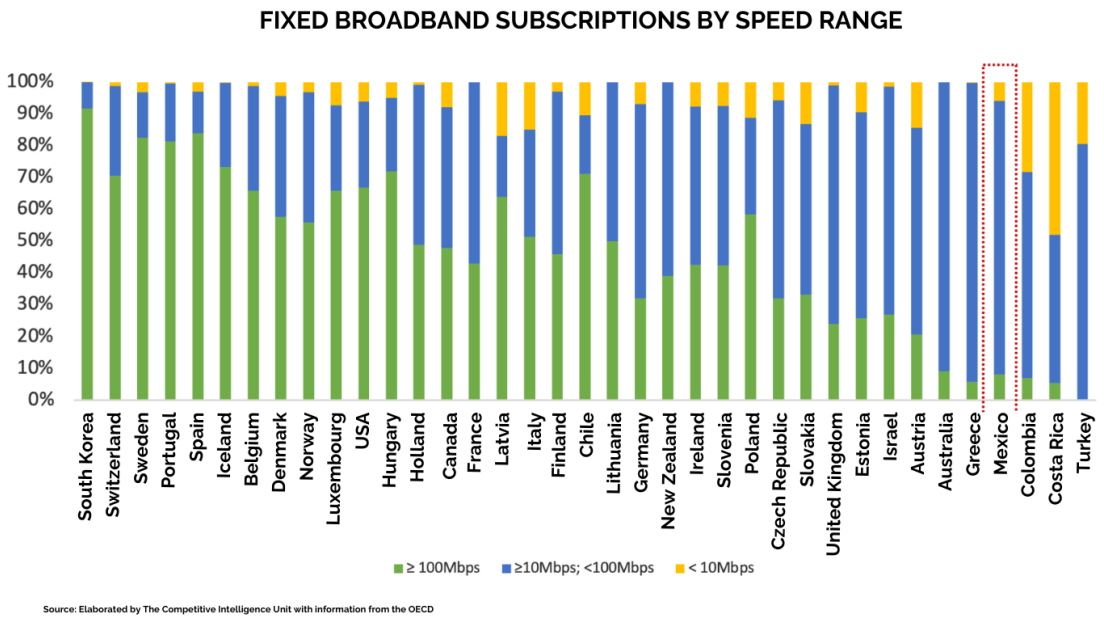


Graph 1: Internet users per State (INEGI, 2021)

While the states of Mexico City, Sonora, and Baja California have a coverage of more than 85% of the population, Guerrero has 61%, Oaxaca 57%, and Chiapas 46% (INEGI, 2021) - these are traditionally the least developed states.

This disparity is also present at the level of schools. Of the 154,580 schools identified in the country at different educational levels, only 37% (equivalent to 57,675) have internet services for pedagogical purposes in their facilities (Solano, 2022). In reality, César Loeza, Director of Education at UNETE, mentions *"this data is much lower. 90% do not have connectivity for academic use. Despite the Ministry of Public Education's (SEP) claims that 70% of schools have internet access, most of them reserve this access for the management office and for administrative processes, not for children's academic use".*

According to information from the OECD in 2021, Mexico had the lowest number of fixed broadband subscribers, with 18.2 per 100 inhabitants, well below the OECD countries' average of 33.8. Furthermore, regarding Internet speed and quality, Mexico ranked 33rd out of 35 in average download speed with 44 Mbps, again well below the average of 119 Mbps (Vargas, 2022), as shown by the graph below.



Graph 2: Fixed Broadband Subscriptions by Speed Range (Vargas, 2022)

According to the IFT, based on OECD data, Mexico is the member country with the highest growth in broadband service penetration from 2013 to 2020, going from 23 lines per 100 inhabitants to 77, representing a growth of 227%.

While the current situation may seem bleak, connectivity is one of the country's main priorities. It is part of the federal government's plans to provide internet access to the 4.8 million people who currently do not have access (Forbes, 2021), demonstrating the government's interest in this

matter. In 2021, the largest telecommunications companies in Mexico announced the launch of their 5G networks. These fifth-generation networks will be critical to take advantage of technologies such as AR and VR. Among the main benefits of this new network are: higher speed (10x faster navigation), the possibility to connect more devices, and less latency (network response time) (Santillán, 2022). Coverage of this network began in 18 cities in the country, focusing on the northern and central states including Mexico City, Guadalajara, Monterrey, and Querétaro.

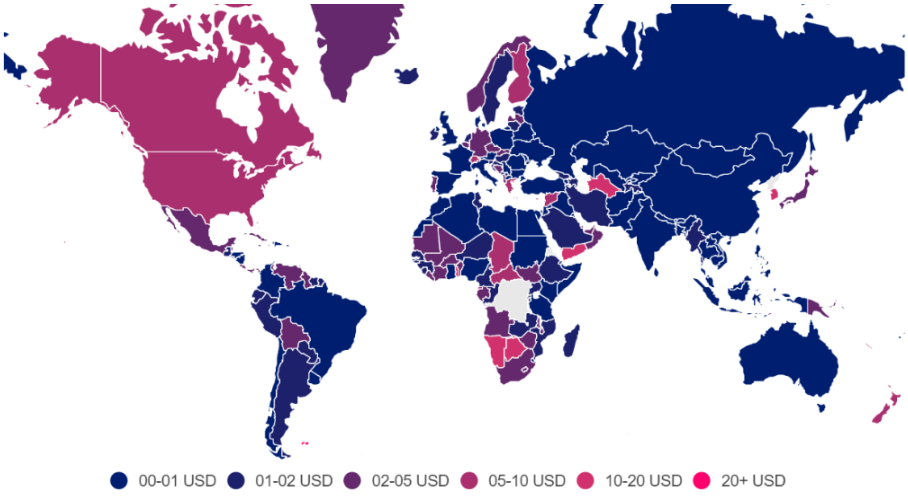
While Mexico's levels of connectivity may not be ideal, they are certainly improving, which will facilitate the mass adoption of AR solutions in a near future. In the meantime, the authors of this report consider it key to start exploring the opportunities.

b. Accessibility gaps

In the previous section, we shared some of the challenges regarding connectivity and infrastructure. However, there are also challenges around accessibility that should be considered when creating AR solutions for education in Mexico. Accessibility refers to the ability of people to access and use technology, regardless of their physical, cognitive, or socioeconomic situation.

In Mexico, there is a significant accessibility gap, especially in rural areas and low-income communities. According to INEGI, 82% of the Internet user population aged six years or older was concentrated in urban areas and 57% in rural areas (INEGI, 2021), showing a clear accessibility gap depending on the geographic area where the population is located. According to the Internet Association (2022), while 95% of Internet users have a smartphone, 22% of the population, especially those in low-income communities, still do not have access to these devices.

One of the reasons for this disparity in Internet accessibility is that connectivity costs are relatively higher compared to other countries globally and regionally. According to a report called "Worldwide Mobile Data Pricing 2022", Mexico has one of the region's most expensive mobile internet services compared to other Latin American countries, as shown by graph 3 below.



Graph 2: Worldwide mobile data pricing (Cable, 2022)

The cost of 1GB is ten times higher than in Uruguay, for instance, and worldwide, Mexico is in position 164 out of 233.

Despite these challenges, Mexico presents several opportunities for digital access, as the country has a large and growing population with increasing use of the Internet and mobile phones. According to Statista (2023) in 2022, approximately 75% of the Mexican population accessed the Internet from their mobile device at least once a month, representing an increase of more than three percentage points compared to the previous year.

c. Lack of training and support for teachers

Teacher training and support is a significant challenge for implementing AR in Mexico for the teaching staff. As observed with the pandemic, it was challenging for the staff to move to the digital world because of the lack of available technical skills and training. This lack of training can increase the knowledge gaps transmitted to students and hinder the application of technologies such as AR in the classroom.

The country also has extremely limited digital literacy, as shared by César Loeza, Director of Education at UNETE. UNESCO (n.d.) defines this as a person's *"ability to access, manage, understand, integrate, communicate, evaluate and create information safely and appropriately through digital technologies."*

Many of the experts mentioned the lack of training and digital iliteracy were two of the significant challenges facing the education sector, but the authors of this report could not find any data to corroborate. When asked for reports, documents, and statistics regarding this issue, the experts consulted mentioned that there was no such thing. This is a significant concern; not knowing the current state of teachers' skills makes it challenging to identify and allocate the necessary efforts to address this situation.

César Loeza whose organisation, UNETE, offers digital training to over 115,000 teachers in over 50% of Mexico's municipalities (UNETE, 2023), explained that Mexico's low levels of digital literacy were one of the main challenges for the adoption of digital solutions in schools. If neither the teachers nor the parents can support the child in its use of new technologies, these solutions are doomed to fail, which is why the design of these solutions must consider the context at an extremely local level, and their adoption must be accompanied by digital literacy training programs.

Despite this, the experts shared their observations that the younger generation of teachers was much more digitally literate and thus able and willing to adopt more new technologies in their teaching processes.

d. Lack of public, accessible and contextualised resources.

In Mexico, there is a lack of public and accessible AR technology resources, making it challenging to understand and integrate them into classrooms, especially in public schools. This lack of resources can lead to a knowledge gap, a lack of awareness of the potential benefits of AR technology, and increased resistance to adopting new teaching methods.

The lack of contextualised resources on AR technology can also be a barrier for schools to implement innovative solutions that align with the cultural realities of the region. According to Nohemí Vilchís, EdTech Speciality at the Observatory of the Institute for the Future of Education, in 2015, there were already more than 80,000 so-called educational apps; the vast majority of which had no research behind their design or implementation linked to children's learning process.

This may be linked to the need for more local talent to do so. As mentioned by César Parga, Chief of the Competitiveness, Innovation and Technology Section of the Organization of American States (OAS) *"there is little talent prepared to develop AR applications in the region, and usually, the people who have experience using this technology are in sectors other than education."* That being said, a number of initiatives are being launched in Mexico to increase the number of AR developers, as explained in the box below, showing a promising future in the field.

Initiative by the Organization of American States

In 2021, the OAS, in partnership with Meta, launched a series of training programs that aim to prepare more than 10,000 people from Latin America and the Caribbean (including Mexico) in frontier technologies (including AR) by 2024. A first edition of the program has already taken place. César Parga shared a very positive response in the region in that first edition. More than 25,000 people registered in the first two months of its launching, surpassing the forecast. Within these registrations were people of all ages (even though,

in the beginning, the program was intended to focus on the youth population), and between 60-65% of the people registered showed particular interest in learning about AR.

Initiative by Meta

In 2022, Meta announced that it would provide courses and certifications in Spark AR (the company's platform to develop AR content) at the Points of Innovation, Freedom, Art, Education, and Knowledge (Pilares)[5] in Mexico City (Zamarrón, 2022) to bring this type of knowledge and skills to underprivileged communities. The Pilares are community and comprehensive education centres where anyone can start or continue their studies and access sports, cultural and training workshops free of charge. These centres are in priority areas that aim to reduce violence and inequalities.

[5]For more information, visit: https://gobierno.cdmx.gob.mx/acciones/pilares/#:~:text=Los%20Puntos%20de%20Innovaci%C3%B3n%2C%20Libertad,econ%C3%B3mica%20o%20sus%20creencias%20culturales.

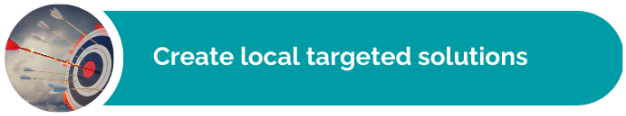
Recommendations for using AR in Primary Education in Mexico

6. Opportunities and recommendations for AR education solutions in Mexico

AR technology can be a valuable tool for education in Mexico. However, it is essential to recognize that it is not a silver bullet that can solve all the problems facing the Mexican education system. Just like any other tool in the toolbox of solutions already under exploration to improve education in Mexico, AR can contribute to this goal.

A number of experts considered that the change in mentality among teachers brought about by the pandemic, whereby they now regard the use of technology as an opportunity and not a threat, made the environment much more appropriate for the development and implementation of new digital technologies, including AR.

Based on the conversations with experts and desk research, the authors of this report make a series of recommendations on how AR solutions could be adopted in Mexico's primary education system, linked to the following questions: to what extent can AR improve educational outcomes by improving children's engagement and interest? To what extent can AR-based education solutions be scaled in Mexico?



Mexico's myriad of contexts does not allow for one solution for the entire education system. It requires solutions that are designed considering the local context. In this sense, analyzing the context of the beneficiaries is crucial because it helps ensure that solutions are tailored to the specific needs and realities of the learners, capitalizing on the opportunities available and mitigating the corresponding risks. Context primarily includes cultural, language, socioeconomic status, and educational level. Failure to conduct these analyses can result, and in Mexico have often resulted, as shared by the academic Ana María Berruecos, Founder of idea.d2in, in educational solutions that are not relevant and thus do not generate the positive impact expected.

Achieving this analysis involves working with the local community and stakeholders (especially teachers, school directors, and parents, as well as community leaders) via focus groups, interviews, surveys, and co-design methods, making them part of the solution to ensure their buy-in. Teachers play a fundamental role in adapting educational solutions to the needs of their students so that they can receive a high-quality education. It is therefore essential to include them in the AR solution's entire design and implementation life cycle to make it a valuable tool. César Loeza and Luis Medina both shared that because of how micro-contextual the solutions have to be, for instance including the teacher's level of digital skills, these are often solutions that only apply for the place they have been developed for.

Develop offline solutions

Any digital solutions developed for use in Mexico's education sector must consider the varying levels of connectivity, infrastructure, and accessibility in Mexico. Not only must they work in urban centers, they must also be usable in remote areas.

It is therefore crucial to design and develop solutions that can be used offline, which can be achieved by creating content that can be downloaded quickly and easily stored on a mobile device. In this way, users only require a few minutes of Internet access to use the solution. It is also important to design solutions that work on low-end devices since access to high-end devices is limited. This can be achieved by developing solutions for less processing power and memory space. Finally, solutions should be designed to be compatible with various devices (in the case of AR: phones and tablets) and with different operating systems.

Align to pedagogical strategies

Diana Alfaro Martínez, Director of Itera Solutions commented that, while there are a number of digital technology solutions for education in existence and in development, only rarely do they take a pedagogical approach. This refers to a teacher's method and practices. *"It's how they approach their teaching style, and relates to the different theories they use, how they give feedback, and the assessments they set. When people refer to the pedagogy of teaching, it means how the teacher delivers the curriculum to the class."* (Montclair State University, n.D.). Edgar Tapia, Regional Manager of Caligrafix Mexico (asscíated with PleIQ presented in section 4), pointed out that *"the adoption of technologies for primary education has been increasing considerably in Mexico. However, they have not been woven into the teaching process, leaving children as passive spectators, for example: watching a video, watching a presentation, listening to songs, to mention some examples."*

According to the experts consulted, teachers are constantly looking for new ways to apply resources and teaching strategies to capture students' interest, maintain their motivation, and effectively transmit knowledge. For example, educational solutions can be based on the classification system of educational objectives developed by Marzano and Kendall based on Bloom's taxonomy[6] as mentioned by Fernando Valenzuela, Founding Partner Global Impact EdTech Alliance. While these textbook approaches are certainly useful, the experts consulted recommended working directly with educators, pedagogues, and other similar specialists to ensure the solution considers children's learning approaches and that children are at the core of the solution.

[6] This taxonomy is a classification model proposed by researcher Robert Marzano between 1989 and 1992 that supports the classification of practical educational objectives.

Align to official strategies

The experts also highlighted that AR solutions must be not only align to pedagogical methodologies but also to the government's educational strategies so that they can be adopted in the classroom and support official educational goals and objectives. Most of the existing cases (view section 4) exist on independent or additional tools. This alignment ensures that the technology use is aligned to teachers' official workplan and thus, does not constitute additional work for them, but fits into their agenda and that of the children. To achieve this, official strategies, agendas, and plans in the educational field will have to be followed. It may be of use to not only rely on the official papers, but also consult with a teacher or school director to ensure the solution also aligns with the application of said guidelines and rules.

Support teacher education and training

AR technology is still emerging and evolving, and many teachers may need to become more familiar with it, its use, and its opportunities and risks for use in the classroom. This is especially true in Mexico, where teachers show limited knowledge of digital skills. Therefore, supporting teacher education and training is essential to ensure the effective integration of digital technologies in the classroom and the expected outcomes. In addition, this technology needs to appeal to the teachers, promising not only better educational outcomes, but also not increasing their workload. In this sense, solutions should be designed to facilitate the work of the teaching staff. As mentioned by Luis Medina Gual, Coordinator of the Inter-institutional Doctorate in Education at the Universidad Iberoamericana, *"the initiatives that have helped to get into the DNA of the education system are those that allude to the unloading of teaching work or redefine the work of teachers."*

In addition, it is vital to promote workshops, seminars, and conferences to learn about AR technology and how to integrate it into their teaching practices. These spaces can be carried out in collaboration with universities, international organisations, and civil society focused on these issues.

Create and implement responsible solutions

The use of AR technology in classrooms can present ethical issues which are magnified when it comes to children, as they correspond to a vulnerable group. A number of experts pointed out that the increasing adoption of technology for education corresponds to earlier digital footprints for students, which can have a range of implications in the future, but also in the immediate moment, related to privacy and security. It is, therefore, key to develop AR solutions that are

ethical, responsible, and transparent and do not compromise the privacy or safety of students, aligning with international best practices. In addition, it is necessary to promote information about this, especially among students, teachers, school directors, and parents, so they can promote the responsible adoption and use of these solutions. As Ana Cecilia Perez, General Director and Co-Founder of Escuelas Ciberseguras, mentioned: *“There is a lack of general awareness and training for parents, teachers, administrative staff and children about the risks of privacy of personal data and how these platforms can expose children to other types of risks.”*

This can be achieved by using resources created by international organisations, civil society, or academia. For example, in 2021, C Minds published a document together with the IADB called "School guide for the protection of student data in Latin America" (Del Pozo, 2021) to provide the necessary information to managers and teachers seeking to strengthen the protection of their student data on the online platforms they use in and for educational institutions.

7. Conclusion

There are many challenges in the Mexican primary education system, especially related to high dropout rates and poor learning outcomes. These existed before COVID-19, but the pandemic increased many of these problems, and the government's efforts to face them have been qualified as insufficient and inadequate.

Augmented Reality (AR) is positioning itself as a tool to support these global challenges and improve educational outcomes. Existing research and consultation with experts has showed that it promotes student engagement and interest, supports personalised learning, and strengthens soft skills, among other benefits. It also required a relatively modest investment, an important factor in a country with considerable wealth disparity. The impact is even more impressive when AR is combined with technologies like AI or strategies like gamification. Despite this knowledge, there are very few applications of AR for use in the classroom in primary education across the world, even less in Mexico, because its adoption across sectors is so recent.

Because any opportunity is accompanied by challenges, the adoption of AR in Mexico's primary education sector has its share of the latter, which is why the report offers a number of recommendations to achieve the benefits of AR for primary education while mitigating the risks. Firstly, the authors point to the importance of developing hyperlocal and targeted solutions to target the country's disparities in terms of digital literacy. Considering teachers' relatively low levels of digital and technological knowledge, they also recommend a holistic approach that not only includes developing a solution but also takes into consideration training and educating the different stakeholders, including teachers, school directors, legal guardians and children. Any solution must also be accessible offline, with all the considerations that entails, due to Mexico's very unequal levels of connectivity, infrastructure, and accessibility. The other recommendations are related to taking a pedagogical approach and following official education strategies when developing the solution, so that it is practical and makes sense for the teacher, school, and students to adopt. Finally, given the increasing risks posed by a digital presence, especially for vulnerable groups like children, the authors recommend following best international practices so that the solutions developed are responsible, ethical, transparent, and centered around children.

All in all, returning to the original questions guiding this research, the authors found that the use of AR in the classroom for primary education can drastically improve educational outcomes, attending some of Mexico's main challenges in the field. That being said, this technology must be understood as one more tool in the box of tools to address educational challenges in Mexico, not as a silver bullet. In terms of the possibility of scaling the solution, Mexico's uneven landscape in many fields mean that solutions need to be local. There is no one-size-fits-all solution.

The consensus of all experts on all topics broached was particularly striking, pointing to an already deep understanding of the opportunities and issues faced in Mexico's education field. To fully leverage the benefits and opportunities of AR in Mexico's education field, this initial non-exhaustive research must be put to practice and complemented with more research as well as local pilot projects. This will allow for the identification of the specific benefits for Mexico's

schoolchildren and an understanding of how these solutions can be applied in the local context. Among the conseses was also the fact that Mexico does not receive sufficient investment to explore new alleyways for improving educational outcomes and discover the solutions that can contribute to creating a brighter future for today's younger generations.

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