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Augmented reality in education for industry 4.0: What are the barriers to adoption?

Realidade aumentada na educação para a indústria 4.0: Quais são as barreiras à adoção?

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ABSTRACT
One of the enabling technologies of Industry 4.0 is augmented reality. Augmented reality is currently supported on mobile devices and often does not require costly equipment, allowing it to expand quickly across industries such as entertainment and healthcare. Studies in education demonstrate that augmented reality can improve conceptual comprehension and learning in STEM fields and that educational organizations and teachers support its use. However, augmented reality is still used in only a few educational establishments. There have been few studies on the topic, raising concerns such as: what are the barriers to broader adoption of this technology? Understanding the issues better would allow educational organizations and instructors to take action to mitigate them. This study aims to identify and categorize the barriers, difficulties, and challenges for the adoption of augmented reality in education. The investigation was conducted in two stages: first, the barriers mentioned in 28 papers published in the Science Direct, Scielo, and Scopus databases were preliminary categorized, and then this categorization was validated by an interdisciplinary focus group of experts in education and industry 4.0. We identified seven categories as barriers to the adoption of augmented reality in education: technical, adoption, usability and user interaction, learning, pedagogical, financial, and technological nature. Our results contribute to mitigate these barriers and encourage actions to increase the potential of augmented reality in education.

Keywords: augmented reality, education, barriers, industry 4.0.

RESUMO
Uma das tecnologias de capacitação da Indústria 4.0 é a realidade aumentada. A realidade aumentada é atualmente suportada em dispositivos móveis e muitas vezes não requer equipamentos caros, permitindo sua rápida expansão através de indústrias como entretenimento e saúde. Estudos em educação demonstram que a realidade aumentada pode melhorar a compreensão conceitual e o aprendizado nos campos STEM e que organizações educacionais e professores apóiam seu uso. Entretanto, a realidade aumentada ainda é utilizada em apenas alguns poucos estabelecimentos de ensino. Poucos estudos sobre o tema levantaram preocupações tais como: quais são as barreiras para uma adoção mais ampla desta tecnologia? Uma melhor compreensão das questões permitiria que organizações educacionais e instrutores tomassem medidas para mitigá-las. Este estudo tem como objetivo identificar e categorizar as barreiras, dificuldades e desafios para a adoção de uma realidade aumentada na educação. A investigação foi realizada em duas etapas: primeiro, as barreiras mencionadas em 28 artigos publicados nas bases de dados Science Direct, Scielo e Scopus foram categorizadas preliminarmente, e depois esta categorização foi validada

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por um grupo de foco interdisciplinar de especialistas em educação e indústria 4.0. Identificamos sete categorias como barreiras para a adoção da realidade aumentada na educação: técnica, adoção, usabilidade e interação do usuário, aprendizagem, pedagogia, finanças e natureza tecnológica. Nossos resultados contribuem para mitigar essas barreiras e incentivar ações para aumentar o potencial da realidade aumentada na educação.

Palavras-chave: realidade aumentada, educação, barreiras, indústria 4.0.

1 INTRODUCTION

Augmented reality (AR), along with artificial intelligence and virtual reality, is a technology that enables industry 4.0 and is defined as a system that supplements the real world with virtual objects (generated by computers) that appear to coexist in the same space as the real world (AZUMA, 2001).

The adoption of augmented reality by the industry has been growing significantly. In the automotive industry, for example, Jaguar Land Rover has a virtual innovation center with advanced hardware and software to perform ergonomic analysis based on body movements. Ford's immersive vehicle environment lab (FIVE) is equipped with detectors that map the user's movements in a car so that designers from various countries can meet in the virtual environment to validate projects.

In addition to the automotive industry (ATICI-ULUSU et al., 2021), AR is adopted in the food industry (REJEB et al., 2021), medical equipment (GENARO and CAPOTE, 2021), construction (SIDANI et al., 2021), among others, from industrial maintenance to production management.

Specifically in the education field, studies indicate that the stimuli for exploration, interaction, and discovery provided by augmented reality benefit knowledge acquisition (SIRAKAYA and SIRAKAYA, 2020; DA SILVA and RUFINO, 2021; OLIVEIRA et al., 2021) and have enabled innovations in knowledge and communication experiences (LACÃO, 2020; HAMILTON, 2021; SCAVARELLI and TEATHER, 2021). Sampaio and Almeida (2016) concluded that introducing AR in the classroom can improve the overall quality of teaching and learning, increase concentration, and motivate students to overcome their

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difficulties, committing fewer errors and significantly improving content comprehension. AR would favor conceptual understanding and learning, especially in the STEM field (OSADCHYI, VALKO, and KUZMICH, 2021). In relation to a basically expositional class, for example, augmented reality would provide a more dynamic and interactive environment for everyone involved. In this context, AR can favor the development of competencies and different skills, so that future professionals can deal with these emerging technologies.

Akçayir and Akçayir (2017) emphasize that the technology is more accessible, as it no longer requires expensive hardware or sophisticated equipment, therefore highlighting the favorable context for the adoption of augmented reality (AR) in the educational process. However, studies indicate that AR is still not widely adopted in education. Bacca et al. (2015) identified that few educational institutions used AR technology in the educational process, and Alsadoon and Alhussain (2019) observed that although educational institutions are favorable to the adoption of AR and teachers believe and trust in its potential to stimulate a learning environment, they still do not adopt it in classes, with the teaching staff raising concerns about barriers that impact the implementation of AR in education.

Although difficulties and challenges are often mentioned, Souza et al. (2019) investigated the literature and identified a knowledge gap on this topic, with few studies analyzing the reasons why, despite the generally favorable context, augmented reality is still not widely used in education. However, it is relevant to identify these barriers, as by knowing them better, educational institution managers and teachers could propose actions to minimize them. Research contributes to understanding the challenges of the formative process of the new generations, while also providing guidelines for building competencies in their various configurations. Ellahi, Khan, and Shah (2019) emphasize that enabling technologies such as augmented reality, artificial intelligence, and cloud computing can enable future generations to improve their data capture and analysis skills, bringing these future professionals closer to the demands of industry 4.0.

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Thus, this study aims to identify the barriers, difficulties, and challenges for augmented reality adoption in education. This work is organized into four sections: in addition to the Introduction, section 2 describes the method, section 3 analyzes the results, and section 4 presents our final considerations.

2 METHODS

In terms of objectives, this study is classified as exploratory, with a qualitative approach and methodological procedures conducted in two stages.

The first stage consisted of identifying the barriers, difficulties, and challenges for the adoption of augmented reality in education through an integrative literature review. We followed the systematic search flow (SSF) method (FERENHOF and FERNANDES, 2016) and our approach parallels that described by Freitas, Gomes and Winkler (2022). The research protocol included articles or reviews published between 2014 and 2019 in the scientific knowledge bases ScienceDirect, Scielo, and Scopus that contained the following keywords in the title, abstract, or keywords fields: ("augmented reality" OR "mixed reality" OR "extended reality") AND (education OR learning OR learning) AND (barrier OR challenge OR difficulty).

We identified 280 articles, read their titles and abstracts and applied the following exclusion criteria (EC):

EC1: studies without a clear methodology

EC2: unavailable in full article

EC3: study addressing AR in special education.

This process selected 28 studies, which, following the SSF method, were organized into a spreadsheet, generating a knowledge matrix. All were read in full, and the mentioned barriers, difficulties, and challenges were preliminarily categorized.

The second stage aimed to demonstrate the validity of the proposed categorization based on the perceptions of an interdisciplinary focus group of four experts in the fields of education and industry 4.0, working at the educational institution Serviço Nacional de Aprendizagem Industrial (SENAI). SENAI is a

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relevant research locus because it is the largest private educational institution in Latin America, specialized in training professionals to increase the country's competitiveness in the context of industry 4.0 (SILVA, 2020).

3 RESULTS AND DISCUSSION

The results obtained are analyzed in the following subsections.

3.1 IDENTIFICATION AND GROUPING OF BARRIERS, DIFFICULTIES AND CHALLENGES FOR THE ADOPTION OF AUGMENTED REALITY IN EDUCATION, BASED ON LITERATURE ON THE SUBJECT

Table 1 lists 28 studies identified by the search protocol.

Table 1. Selected studies in the literature review search protocol.

CAI; WANG e CHIANG, 2014 - A case study of augmented reality simulation system application in a chemistry course
JERABEK; RAMBOUSEK e WILDOVÁ 2014 - Specifics of visual perception of the augmented reality in the context of education
COIMBRA; CARDOSO e MATEUS 2015 - Augmented reality: an enhancer for higher education students in math's learning?
BACCA et al. 2015 - Mobile augmented reality in vocational education and training
SAMPAIO e ALMEIDA 2016 - Pedagogical strategies for the integration of augmented reality in ict teaching and learning processes
KURNIAWAN et al. 2018 - Human anatomy learning systems using augmented reality on mobile application
ELLAHI; KHAN e SHAH 2019 - Redesigning curriculum in line with industry 4.0
LEE et al. 2016 - Cooperation begins: Encouraging critical thinking skills through cooperative reciprocity using a mobile learning game
FONSECA et al. 2014 - Relationship between student profile, tool use, participation, and academic performance with the use of augmented reality technology for visualized architecture models
HSU 2017 - Learning english with augmented reality: do learning styles matter?
AKÇAYIR e AKÇAYIR 2017 - Advantages and challenges associated with augmented reality for education: a systematic review of the literature
MOTA et al. 2018 - Augmented reality mobile app development for all
IBANEZ et al. 2014 - Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness
GARZÓN e ACEVEDO 2019 - Meta-analysis of the impact of augmented reality on students' learning gains.
TURKAN et al. 2017 - Mobile augmented reality for teaching structural analysis
LOPES et al. 2019 - Educational innovations with the use of augmented reality: a systematic review
ALSADOON e ALHUSSAIN 2019 - Faculty at saudi electronic university attitudes toward using augmented reality in education
KIRYAKOVA; ANGELOVA e YORDANOVA 2018 - The potential of augmented reality to transform education into smart education
LI; CHEN e VORVOREANU 2015 - A pilot study exploring augmented reality to increase motivation of chinese college students learning english

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OKUBO e MIZUNO 2018 - Influence of interactive learning support system using augmented reality on 3D object drawing
SUNGKUR; PANCHOO e BHOYROO 2016 - Augmented reality, the future of contextual mobile learning.
MUÑOZ-CRISTÓBAL et al. 2014 - City Ads: Embedding virtual worlds and augmented reality in everyday educational practice
STRETTON; COCHRANE e NARAYAN 2018 - Exploring mobile mixed reality in healthcare higher education: a systematic review
YOON et. al 2017 - How augmented reality enables conceptual understanding of challenging science content
HSIUNG 2018 - The use of e-resources and innovative technology in transforming traditional teaching in chemistry and its impact on learning chemistry
MAJID e MAJID 2018 - Augmented reality to promote guided discovery learning for stem learning
YANG; MEI e YUE 2018 - Mobile augmented reality assisted chemical education: insights from elements 4D
COMA-TATAY et al. 2019 - FI-AR learning: a web-based platform for augmented reality educational content

The barriers to augmented reality adoption in education mentioned in these studies were grouped into six categories, presented in the following subsections.

3.1.1 Technical Category

The Technical category was the most cited in the studies and is related to general difficulties with hardware and software, as detailed in Table 2.

Table 2. Barriers, difficulties and challenges of a technical nature

Category	Studies	Characteristics
Technical	BACCA et al. 2015; FONSECA et al. 2014; APUD LOPES et al. 2019; FALLS; WANG and CHIANG 2014; AKÇAYIR and AKÇAYIR 2017; GARZÓN and ACEVEDO 2019; ALSADOON and ALHUSSAIN 2019; KIRYAKOVA; ANGELOVA and YORDANOVA 2018; READ; CHEN and VORVOREANU 2015; HSIUNG 2018; YANG; MEI and YUE 2018; COMA-TATAY et al. 2019; JERABEK; RAMBOUSEK and WILDOVÁ 2014; COIMBRA; THISTLE and MATTHEWS 2015; MAJID and MAJID 2018; OKUBO and MIZUNO 2018.	Software with low capacity; problems related to the connection between technologies and formats; technical problems; low Internet connection; technological limitations, incompatible devices; high battery consumption; IT infrastructure limitations; difficulty in dynamic image processing; low brightness quality of AR technologies; low sense of depth of AR technology; few visual effects.

Cai, Wang and Chiang (2014), Fonseca et al. (2014), Li, Chen and Vorvoreanu (2015), Hsiung (2018), Garzon and Acevedo (2019) and Coma-Tatay

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et al. (2019) highlighted AR tool instability during use; software with low capacity and technical problems. The studies cite difficulties and execution problems during the use of augmented reality, stating that there are few quality applications available.

Bacca et al. (2015), Akçayir and Akçayir (2017) and Kiryakova, Angelova and Yordanova (2018) highlight difficulties related to few systems focused on teaching how to perform tasks in augmented reality applications; problems related to the connection between technologies and formats; technical problems in location-based AR applications; low internet connection. Lopes et al. and Apud Chatzopoulos et al. (2019), point out that the lack of technical support is a barrier that impacts the implementation of AR, in addition to technological limitations; high battery consumption when using applications, as well as difficulties in some applications in general when used in open environments without the use of markers.

In a broader perspective, Alsadoon and Alhussain (2019) concluded that a lack of infrastructure, technical support, and applications may make it impossible to use AR in education. Majid and Majid (2018), Okubo and Mizuno (2018), identified the need to improve the depth sensation and brightness conditions of some learning systems with AR and Yang, Mei and Yue (2018) identified problems related to visualization, such as difficulties in dynamic image processing and visual effects. An image with low quality, few visual effects and that constantly crashes compromises the performance of the application and demotivates teachers and students.

Another difficulty cited is the lack of tutorials explaining how to use the application, since most AR applications in education would not have this resource. A short video or some written instructions before starting the animation would already minimize the problem. Another barrier is the problem of internet connection, hindering performance at the time of application. The lack of technical support is a recurring problem. It would not be useful to invest in technologies and equipment and not have computer professionals providing support, sized according to the size of the institution, the number of classes that adopt AR in

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classes and the knowledge of teachers in computer science and programming.

3.1.2 Adherence Category

This category focus difficulties related to the acceptance of AR technology by managers of educational institutions, pedagogues, teachers and students (Table 3).

Table 3. Barriers, difficulties and challenges related to Adherence.

Category	Studies	Characteristics
Adherence	COIMBRA; CARDOSO e MATEUS 2015; BACCA et al. 2015; IBANEZ et al. 2014; TURKAN et al. 2017; FONSECA et al. 2014; APUD LOPES et al. 2019; AKÇAYIR e AKÇAYIR 2017; ELLAHI; KHAN e SHAH 2019; KIRYAKOVA; ANGELOVA e YORDANOVA 2018; SUNGKUR; PANCHOO e BHOYROO 2016; LARA-PRIETO et al. 2015.	Embryonic AR technologies in application in education; difficulties in accepting users; difficulty generating content on mobile devices; need to restructure the pedagogical sector; few studies have been done to substantiate that AR has the potential to impact learning outcomes; few studies on data samples to identify the causes of the effectiveness of AR-based application learning; little class time to implement some applications

Ibánez et al. (2014) and Ellahi, Khan and Shah (2019) state that, among the limitations, there are few studies on applications of augmented reality in education, few educational institutions are determined to invest and equip the next generations with the skills related to capturing, analyzing and communicating data through these ICT infrastructures. Sungkur, Panchoo and Bhoyroo (2016), Lara-Prieto et al. (2015) also pointed out difficulties in the process of adhering to the technology, stating that little has been studied in terms of applications of augmented reality and educational impact.

Lopes et al. and Apud Chatzopoulos et al. (2019) recommend increasing social acceptance by bringing people closer to the new technology. They observed that many applications are still prototypes or are in the early stages, and highlight the care that developers need to take not to generate poor experience in AR, by developing inadequate applications.

A commonly cited barrier is the lack of research that substantiates the potential of augmented reality to improve the quality of learning. Some educational institutions assess that there are still few experiences with AR and

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that it is necessary to know more about this technology and its characteristics.

Turkan et al. (2017) were concerned with solving the student comprehension deficits. In the developed application, the authors proposed a new pedagogy for structural analysis of teaching that incorporates mobile augmented reality and interactive 3D visualization, as well as investigated the potential of using AR in the teaching of structural analysis, to evaluate the pedagogical impact and design concepts employed by the AR tool. They found that the concepts of the AR project might support constructive engagement and retention of information in students.

Other barriers mentioned regarding the Adherence category are difficulties in user acceptance; difficulty in the diversity of mobile devices; little class time to implement some augmented reality applications and the need to restructure the pedagogical sector, understanding that it is not enough to simply apply AR technology during classes, but to know the best time and method to be applied, to take advantage of the potential of technology.

3.1.3 Usability and User Interaction Category

This category refers to the difficulties of pedagogues, teachers and students with technology to perform tasks and the teaching plan of the discipline, as described in Table 4.

Table 4. Barriers, difficulties and challenges related to usability and user interaction

Category	Studies	Characteristics
Usability and User Interaction	LEE et al. 2016; BACCA et al. 2015; KURNIAWAN et al. 2018; LOPES et al. 2019; FALLS; WANG and CHIANG 2014; AKÇAYIR and AKÇAYIR 2017; JERABEK; RAMBOUSEK and WILDOVÁ 2014; COIMBRA; THISTLE and MATTHEWS 2015; OKUBO and MIZUNO 2018.	Difficulty in the process of familiarization of technology with users; few educational environments using AR technology; few multimedia bases have materials of AR technology; little cooperation between teachers and developers in AR tools; difficulties in the usability of AR resources by students and teachers.

Lee et al. (2016) and Cai; Wang and Chiang (2014) state that more studies are needed on the AR cognitive effect during the user experience and emphasize the lack of viewing bases with options in multimedia platforms with sound or

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video.

Bacca et al. (2015) pointed out the need to stimulate more interaction environments between students and teachers with the use of AR technology. They reinforce the importance of cooperation between teachers and developers to specify the amount and type of information that should be placed in AR tools. Technology lacks the mechanisms to effectively establish cooperation and thus solve difficulties in the usability of augmented reality technology resources by students and teachers.

Jerabek, Rambousek and Wildová (2014), Kurniawan et al. (2018) highlight cognitive difficulties in processing the information presented to the user, its decoding, processing, properties of AR systems and their possible applications in education. Most technologies are developed by programmers, because few teachers have this ability. For a technology more appropriate for learning, the teacher should participate in the development of the tools and would be more familiar and more reliable to apply it in the classroom.

Lopes et al. (2019) reviewed 44 studies and identified that the main practices of using AR in education fall under themes such as augmented reality through mobile devices; learning through games with augmented reality; books with embedded augmented reality; augmented reality in the teaching of health sciences, engineering, architecture and design through AR. The authors concluded that the lack of mastery of teachers in the use of software and devices to develop applications hinders the construction of activities, and training them in the use of AR would minimize the difficulty.

3.1.4 Learning Category

This category refers to the difficulties related to the teaching-learning process itself, such as the application of the AR tool in the classroom and the interaction of students with the content, described in Table 5.

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Table 5. Barriers, difficulties and challenges related to learning

Category	Studies	Characteristics
Learning	HSU 2017; SAMPAIO and ALMEIDA 2016; AKÇAYIR and AKÇAYIR 2017; KIRYAKOVA; ANGELOVA and YORDANOVA 2018; SUNGKUR; PANCHOO and BHOYROO 2016; YOON et. al 2017; READ; CHEN and VORVOREANU 2015.	Few experiences in the learning process with augmented reality technology; few studies on the opinions of teachers to verify their perception of the value that AR can have in the teaching and learning process; few studies address, cognitive overload that AR can generate in a learning environment; AR can generate possibilities to distract and divert students' attention from learning materials; difficulty integrating AR with traditional learning methods.

Sampaio and Almeida (2016) state that expectations regarding the appropriate strategies for the use of technology in the learning environment need to be validated and further explored. The challenge would not only be to introduce technology into the classroom, but mainly how to use it to improve student learning? Experiences are still in early stages, students have no prior experience with AR, and most do not even know the technology. The authors add that there are few studies on teachers' opinions about the value that AR can have in the teaching and learning process. In the difficulties related to learning, the role of the teacher is fundamental to choose the appropriate resources for the didactic transposition, mediate the interaction and the learning of the students would minimize some of these barriers presented in the category.

Sungkur, Panchoo and Bhoyroo (2016), Akçayir and Akçayir (2017), Hsu (2017), Yoon et. al (2017), pointed out other barriers such as side effects of AR, such as mental effort or learning anxiety, students' difficulty when using AR and cognitive overload. Kiryakova, Angelova and Yordanova (2018) warn that the use of AR can distract and divert students' attention from learning materials. They also point out that:

> Developing appropriate augmented reality educational applications is a difficult and time-consuming process. It requires teachers to have an innovative approach both to the presentation of the content and to the means and approaches to accessing and interacting with it. (Kiryakova, Angelova and Yordanova, 2018, p. 556)

Cupitra-García and Duque-Bedoya (2018) highlight the relevance of having as a starting point a continuous, clear and strong pedagogical support,

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which ensures that the processes benefit students and that this does not seem like just another novelty. For this, a solid competencies and learning structure is required to be built. In this way, AR will be part of a pedagogical proposal in which its potential can be well explored and contribute effectively to learning.

Da Silva et al. (2019) observed that teachers have an important role in the adoption of technology in education, and that incorporating the use of the tool into traditional teaching methods, when it is used appropriately, can improve the learning process and make it more attractive for students.

3.1.5 Content Category

The Content category refers to the programming of the subjects addressed in the AR technologies, as listed in Table 6.

Table 6. Content-related barriers, difficulties, and challenges

Category	Studies	Characteristics
Content	MOTA et al. 2018; APUD LOPES et al. 2019; KIRYAKOVA; ANGELOVA e YORDANOVA 2018; MUÑOZ-CRISTÓBAL et al. 2014; STRETTON; COCHRANE e NARAYAN 2018; YANG; MEI e YUE 2018.	Lack of programming skills; difficulty in developing activities using augmented reality; difficulties of teachers, both for the presentation of the content and for the means and approaches to access; applications with non-professional content.

Mota et al. (2018) highlight the lack of programming skills as a barrier to engaging teachers in the development and customization of their own applications.

Muñoz-Cristóbal et al. (2014), Lopes et al. Apud Chatzopoulos et al. (2019) highlight the difficulty of developing activities using AR, especially by teachers, who do not master the use of software and devices to develop applications. Cochrane and Narayan (2018) add that the impacts of augmented reality-enabled mobile devices remain underexplored. Among related difficulties, the lack of programming knowledge by teachers is again mentioned. Mota et al. (2018) conducted a study with 47 educators, addressing the lack of programming skills of teachers and the results indicated the need to adapt the framework and authoring tool to support users without programming knowledge in the

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development of their own applications. The authors concluded that the block-based programming language, as used in the proposed application creation tool, can help teachers overcome their lack of programming skills, allowing them to develop their own applications.

3.1.6 Financial Category

Financial difficulties, such as lack of investments for the acquisition of technologies, ICT structures and training were the least mentioned (Table 7).

Table 7. Barriers, difficulties and challenges of a financial nature

Category	Studies	Characteristics
Financial	SUNGKUR; PANCHOO and BHOYROO 2016; AKÇAYIR and AKÇAYIR 2017.	Difficulties related to high cost of acquiring or developing tools

Sungkur, Panchoo and Bhoyroo (2016), Akçayir and Akçayir (2017) highlight the difficulty in using AR technology with large groups, because with more users, the greater the structure for application, raising the costs of acquisition and application of the tool. The authors also highlighted lack of government investment for the development and maintenance of augmented reality applications.

Using AR with large groups demands greater structure and increases the investment for the application of technology. An alternative is that educational institutions start by adopting technology with smaller classes facilitating the process of familiarization by teachers and students with the tool and also allowing to evaluate the impacts on learning, gradually increasing the volume of investments.

After the barriers to augmented reality adoption in education had been identified and preliminarily categorized, the next stage of this study consisted of validating the proposed categorization, analyzed below.

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3.2 VALIDATION OF THE PROPOSED CATEGORIZATION, THROUGH THE PERCEPTIONS OF EXPERTS IN EDUCATION AND INDUSTRY 4.0.

The validity of the preliminary categorization was demonstrated through the perceptions of an interdisciplinary focus group of four experts in the themes education and industry 4.0, identified as Teacher, Teacher Developer, Pedagogue and Software Developer. The discussion began with an explanation of the research topic and the proposed preliminary categorization. Throughout the interaction, a few questions were asked only as a general script, letting the experts express their perceptions freely.

The initial question was: *In your opinion the related barriers in each category, do they have relevance?* We observed that the problems of technology and infrastructure are relevant to the group, the Teacher pointed out that:

> Maybe the Technique category had to be technological, from what I read the descriptions of the barriers, apparently, they are technology problems and not technical problems, when it says Technique category, it is related to the skills of the user. It is missing something of technology or infrastructure. (Teacher, verbal information)

To which the Software Developer added:

> It makes sense, not to replace, but to include going to a new Technological category. The Technique exists and is different. The technique would be manpower to prepare the activities. The infrastructure part would be the technological one, such as augmented reality and virtual reality. (Software Developer, verbal information)

The barriers categorized as Adherence cover the difficulties of teachers in using mobile devices and the need to restructure the pedagogical sector. The group corroborates that these difficulties exist, according to the Teacher's statement:

> One of the biggest barriers is the student's interest in learning, AR will facilitate this process. For this, it needs to dilute the barriers, people go through training, planning classes thinking about the didactics that will be used in the classroom and better choose the pedagogical method. [...] It is going to take a while to happen on a large scale, I believe it is going to take a few years. The idea is to keep insisting that one day it will happen. (Teacher, verbal information).

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The reviewed studies mentioned problems of Usability and Interaction with the user, focusing not on the social part, but on the difficulties of users to use the technologies. This category was also evaluated by the focus group:

> The Usability and Interaction category, refers to how familiar it would be to a teacher who comes from a public school or a university with fewer resources, also students with few resources, to make the familiarization with the technology. (Developer Teacher, verbal information).

The next question was: *In your perception there are barriers that are not represented in these proposed categories?* The Teacher pointed out: "a barrier, aimed at the accessibility of technology, today the available free tools that make use of AR are difficult to access, or very complicated to use." The Pedagogue says:

> [...] about the barriers that are in the Learning category. I do not agree that AR can generate possibilities to distract and divert the attention of students from learning materials. I think AR is the learning material itself, so if the student is interacting, he is learning. (Pedagogue, verbal information)

The Software Developer adds that "for distraction to happen would have to develop something very playful, to the point that the student does not want to do something else, causing a distraction. But it is hard to do." The Teacher states that "if the class has not been well planned the use of AR, it can generate a distraction or diversion of attention", to which the Developer Teacher ratified:

> This has to do with the teacher's own planning, he can plan something that distracts the students, it is related to the pedagogical. The teacher plans class to use technology, at the time of practice the applied methodology may not bring the expected result. (Developer Teacher, verbal information).

At first, the Pedagogue and the Software Developer disagreed that AR could distract and divert students' attention during use. Therefore, when believing in the possibility of AR diverting the students' focus on educational activities, if the teacher does not have a clear methodology to apply the technology, the perceptions of the Teacher and Teacher Developer diverged from the other

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members.

The next question asked by the group was: *In your opinion, what could be improved in these categories?* The Developer Teacher pointed out that "there are intersections between these categories", pointing out that the experts understood that the proposed categories are related to each other. The Pedagogue pointed out:

> It should separate the barriers into two columns: the role of the teacher as the user and as a developer. They are different barriers that you will encounter, because in fact there are these two possibilities. The colleague, for example is a teacher who develops, because he has this expertise, but other teachers use what is already ready, they do not have the mastery of developing their own tool. (Pedagogue, verbal information).

The Content category groups the barriers and difficulties of teachers as a developer in the presentation of content with AR, meaning that the teacher can occupy both roles. About the Content category the Pedagogue also pointed out:

> The Content category could be replaced by the name pedagogical. Since teachers have two types of difficulties: the first is that the teacher can use the full media potential as a developer. The second is the pedagogical question, how to develop an application and how to insert it into classes in a way that facilitates learning. (Pedagogue, verbal information).

The Developer Teacher agreed with the proposed change adding that "when you read into the difficulties of teachers to present the Content category: I would add planning as a barrier, as well as change the name of the category to pedagogical." It is plausible to change the name of the Content category to pedagogical, since the characteristics that are part of the Content category, refer to the relationship of the teacher with technology, in the sense of development as in the application of media in the classroom. The specialists recognize the barriers pertinent to the Content category, pointing out the need for pedagogical support in the preparation of classes for the introduction of technology, in order to take advantage of the technological potential in the best possible way in the teaching-learning process.

As for the Learning category, the most cited difficulty was to integrate AR

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with traditional teaching methods. The focus group perceived difficulties in using AR with traditional methods and the lack of methodological planning to include technologies that could contribute and assist the teacher in the teaching-learning process, facilitating and diversifying student learning. Therefore, there is a need for pedagogical planning, both in the development of technology and in its use, before inserting it in classrooms.

The next question was: *In your perception, do the categories presented have different weights for the adoption of AR technology in education*? The Teacher pointed out:

> The technological issue, along with this standardization and the financial part is perhaps one of the biggest barriers in the use of AR. Devices that make use of quality AR are extremely expensive, inaccessible for a faculty member to buy. [...]. If purchasing necessary material is expensive, it makes no sense to learn how to use AR. The biggest barrier is the technological part that also involves the financial one. Imagine a room with twenty students wearing HoloLens, you will need twenty glasses to interact. Thus, the financial barrier makes it unfeasible (Teacher, verbal information).

These barriers mentioned by the Teacher are related to the cost of acquisition or development of software, fitting, therefore, in the Financial category. Still on the difficulties of a financial nature, the Software Developer added that:

> [...] Google Expeditions is free, you can make objects that would be very surreal to show in the classroom to all students, without being around. The developed models of the technology are public for any other user to download. [...]. The software is very good. (Software Developer, verbal information).

To resolve financial nature barriers, there are some free and effective augmented reality software, some more interactive and others simple, which can be an option for educational institutions that have few resources or teachers who do not have programming skills.

Concerning this deliberation, the Teacher stressed that "there are things that we teach in the classroom, which the student will not experience anytime soon, that is, due to financial, technological or structural barriers of the institution

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to which the student belongs."

Finally, the question was asked: *In your opinion, can AR technology bring results in the teaching-learning process?* The Developer Teacher replied:

> To bring AR into the classroom as a proposal for a richer experience for students, from a planning of the inputs of AR resources in the classroom at the time of learning. It has everything to be a good complement to our didactic resources and bring excellent results. (Developer Teacher, verbal information)

The Teacher further added:

> AR can be applied in all areas of knowledge. Once these barriers are diluted, education in the overall context will improve a lot. AR is as if it were a means of transition between theory and practice. It would be very interesting for the student to be able to visualize applications of AR of what is taught in the classroom, it would facilitate and improve the vision and understanding of the student. From life to play. The AR will bring this possibility so that the student can experience better, enjoy studying and have more fun learning. (Teacher, verbal information)

The focus group participants recognize and believe in the potential of augmented reality technology in the teaching-learning process.

For the experts, the difficulties have different weights, that is, the most challenging barriers to the adoption of augmented reality in education are, in order, those of a Financial nature, Content and the new category suggested by them, Technological. In addition, it was suggested to change the name of the Content category to Pedagogical. These suggestions for improvement were accepted, finally resulting in these seven categories of barriers, difficulties and challenges for the adoption of augmented reality in education: *Technique, Adherence, Usability and Interaction with the User, Learning, Pedagogical, Financial and Technological*.

As already mentioned, these barriers are not completely separate, but relate and overlap, one influencing the other.

4 FINAL CONSIDERATIONS

AR is a relatively new technology in the educational context and the identification of these difficulties can contribute to the educational institutions

managers and teachers to adopt actions to minimize them. Among the possibilities, they can engage in actions such as the familiarization of students with technology, as well as focus on the training of teachers so that they feel confident to elaborate a pedagogical planning contemplating the AR application during classes. Additionally, it is pertinent to know the tools and applications available in the market, as well as to evaluate the infrastructure available in the institution. A teacher who has difficulty creating their own AR applications can search for repositories on the internet.

This research concludes at a critical time when the world is experiencing the COVID-19 pandemic. In this time of social distancing, technology is being fundamental to maintain some activities and institutions, teachers and students of face-to-face teaching have had to adapt in the short term with different technologies to continue educational activities. In this context, adopted in remote and distance learning, augmented reality has the potential to generate more dynamic and motivating interactions for students. Education will not be the same post-pandemic, technology has become an important tool to stimulate learning. However, digital literacy is important for teachers to develop skills as well as create new methods for using digital platforms in face-to-face courses.

There are difficulties to integrate AR with traditional learning methods, to observe barriers before implementing the technology can minimize the difficulties. For future research, we suggest to increase the analysis model sample size in the categorization model and assess professionals' perceptions in the education field about the barriers. To know the obstacles found in this study allows educational organizations and teachers to identify and resolve them in their learning processes.

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