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Development of Design Principles to Author AR in Education Based on Teacher's Perspectives

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Trabalho apresentado ao Programa de Pós-graduação em Ciência da Computação do Centro de Informática da Universidade Federal de Pernambuco, como requisito parcial para obtenção do grau de Doutor Acadêmico em Ciência da Computação.

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As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of discovery.
Laistrygonians and Cyclops,
angry Poseidon- don't be afraid of them:
you'll never find things like that on your way
as long as you keep your thoughts raised high,
as long as a rare excitement
stirs your spirit and your body.
Laistrygonians and Cyclops,
wild Poseidon- you won't encounter them
unless you bring them along inside your soul,
unless your soul sets them up in front of you.
May there be many a summer morning when,
with what pleasure, what joy,
you come into harbors seen for the first time;
may you stop at Phoenician trading stations
to buy fine things,
mother of pearl and coral, amber and ebony,
the sensual perfume of every kind-
as many sensual perfumes as you can;
and may you visit many Egyptian cities
to gather stores of knowledge from their scholars.
Keep Ithaka always in your mind.
Arriving there is what you are destined for.
But do not hurry the journey at all.
Better if it lasts for years,
so you are old by the time you reach the island,
wealthy with all you have gained on the way,
not expecting Ithaka to make you rich.

Ithaka gave you the marvelous journey.
Without her, you would not have set out.
She has nothing left to give you now.
And if you find her poor, Ithaka won't have fooled you.
Wise as you will have become, so full of experience,
you will have understood by then what these Ithakas mean.
(Constantine Cavafy, 1911. Translated by Edmund Keeley/ Phillip Sherrard)

As a typical goal-oriented person I tend to value the destination above all, however, through this PhD I have come to appreciate the path a lot more and all the growth, knowledge and experience it has enabled me both personally and professionally. I am deeply grateful for all the experiences I had the opportunities to live, including living abroad and learning so much from lots of talented and generous people. By the way, the people are the most incredible gifts from this journey. I consider myself really lucky to have met so many brilliant people (fellow researchers, advisors, teachers and classmates) some of whom now I have the privilege of calling them friends. I am really grateful for all the knowledge and wisdom you shared with me and all the memories we have built together. I know I will not be able to mention them all by name without running the risk of forgetting some, but, I would like to mention my profound gratitude to my great advisors, Professor Dra. Veronica Teichrieb and Professor Dra. Patricia Smith who have encouraged and motivated me as well as helped me stay on course. I am also grateful to Veronica for the opportunity to be welcomed at Voxar Labs. I feel really lucky to be part of this wonderful group of talented and generous people. I am indebted to their support (received from both current and former members) throughout this work. I also thank Patricia for the opportunity to discuss my work with her research group GENTE, which is full of talented people who provided me insightful comments. I also want to thank the friends I made at EDUMATEC for their incredible support and helpful discussions about ATLAS TI, Flávia Andréa, Márcia Nogueira and Talita Helena. To Professor Dr. Bertrand Schneider and Dr. Iulian Radu who have heartily welcomed me into their lab, LIT (Learning, Innovation and Technology) at Harvard Graduate School of Education and for imparting so much knowledge. I am also grateful to Luís Felipe and João Moizes for their contributions to this project along with PET lab students, Gabriela, Eidson, Matheus and Tales. I am also really grateful for the amazing teachers, designers and engineers who participated in this research. I also want to thank the members of my proposal's defense, Professor Dr. Romero Tori, Professor Dra. Eliane Schlemmer and Professor Dra. Simone Santos for their invaluable contributions to this work. I can not finish this short text without explicitly mentioning my incredible family who have gave me so much support throughout my entire life including this short portion that brought me here. To my husband, whose love and wisdom gave so much strength throughout this process and anchored my heart in right place. To my great and dear friends who always had some encouraging words to share with me. To God and my mentors who have inspired and motivated me to stay on course and keep going. When we finish a project like this, we always tend to evaluate how it went, what we could have done better, how we can improve it, and so on, although I know that anything is never in its final version, I can only hope that this piece of work can be useful and inspire discussion and action on how we can bring technology in more meaningful ways for our learners.

ABSTRACT

Augmented Reality (AR) has a positive impact on students' motivation and cognitive performance on varied age levels and different contexts. However, its use is still far from widespread in education. One of the reasons mentioned in the literature is the lack of AR authoring tools thought from the educational perspective. This work investigates *what features are important for AR authoring in education*. We aimed to identify how teachers would like to create AR experiences based on their pedagogic needs through Design Based Research (DBR) with the participation of an interdisciplinary team to investigate and propose design principles for AR educational authoring. Our study was carried out in 4 steps: (1) analysis of practical AR problems by researchers and practitioners in collaboration, (2) development of solutions informed by existing design principles and technological innovations from step 1, (3) iterative cycles of testing and refinement of solutions identified in practice, and (4) reflection to produce design principles for AR teaching authorship. In step 1, we performed the literature research and interviewed 15 teachers who used technology, 7 teachers and 2 coordinators who used AR, along with a survey with 106 teachers from varied contexts. Based on the initial results, we defined a "case study" focused on language learning for children and teenagers. Step 2 consisted of a series of iterative sessions with an interdisciplinary group to map the problems, sketch possible solutions and decide the one to be prototyped and tested. In step 3, an AR tool, Virtual Playground, which allows the creation of augmented storytelling collaboratively, as well as its authoring tool, Virtual Playground Creator, have been conceived, prototyped and tested with users through a series of interactions and two iterative cycles of testing and refinement of solutions. The first and second rounds of tests were carried out with 5 and 6 English teachers with previous AR experience, respectively. We also analyzed AR authoring tools that do not require programming. Most of them lack important features for teachers, specifically pedagogical ones. Finally, in step 4, through reflection about the results obtained, we developed design principles and enhanced the solution implementation. The main result of this study is 11 design principles identified and divided into three aspects: infrastructure, augmented reality, and pedagogy. These principles were validated during the tests. The design principles proposed were evaluated positively by teachers. An in depth discussion of the context and application of those principles was provided. The AR authoring tool prototype

was based on seven of the identified design principles and presents the following characteristics: it is flexible and enabled teachers to author different lesson plans as well as to work with diverse skills and competences.

Keywords: augmented reality; authoring systems; education; design-based research.

RESUMO

Realidade Aumentada (RA) tem um impacto positivo na motivação e no desempenho cognitivo dos alunos de várias idades e em diferentes contextos. Porém, seu uso ainda está longe de ser difundido na educação. Um dos motivos apontados na literatura é a falta de ferramentas de autoria de RA pensadas na perspectiva educacional. Este trabalho investiga *quais características são importantes na autoria de RA para a educação*. Buscamos identificar como os professores gostariam de criar experiências de RA com base em suas necessidades pedagógicas por meio de Design Based Research (DBR) com a participação de uma equipe interdisciplinar para investigar e propor princípios de design para autoria educacional de RA. Nosso estudo desenvolveu-se em 4 etapas: (1) análise dos problemas de RA a partir da literatura e práticos por pesquisadores e profissionais em colaboração, (2) desenvolvimento de soluções a partir de princípios de design existentes e inovações tecnológicas advindos da etapa 1, (3) ciclos iterativos de teste e refinamento das soluções identificadas na prática, e (4) desenvolvimento dos princípios de design para autoria docente de RA. Na etapa 1, realizamos a revisão da literatura e entrevistas com 15 professores que usavam tecnologia; 7 professores e 2 coordenadores que utilizaram RA juntamente com uma pesquisa com 106 professores de contextos variados. A partir dos resultados iniciais, definimos um estudo de caso focado na aprendizagem de línguas para crianças e adolescentes. A etapa 2 consistiu em uma série de sessões iterativas com um grupo interdisciplinar a fim de mapear os problemas, esboçar as soluções possíveis e decidir aquela a ser prototipada e testada. Na etapa 3, uma ferramenta de RA, *Virtual Playground*, que permite a criação de narrativas aumentadas de forma colaborativa, bem como sua ferramenta de autoria foi concebida, prototipada e testada com os usuários por meio de uma série de interações e ciclos iterativos de teste e refinamento de soluções. A primeira e a segunda rodada de testes foram realizadas com 5 e 6 professores de inglês com experiência prévia em RA, respectivamente. Também analisamos ferramentas de autoria de RA que não exigem programação. Boa parte delas carecem de recursos importantes para os professores, especificamente os pedagógicos. Finalmente, na etapa 4, através da reflexão sobre os resultados, desenvolvemos princípios de design e aprimoramos a implementação da solução. O principal resultado deste estudo são 11 princípios de design identificados e divididos em três aspectos:

infraestrutura, realidade aumentada e pedagogia. Esses princípios foram validados durante a segunda rodada de testes. O protótipo da ferramenta de autoria de RA foi baseado em sete dos princípios de design identificados e apresenta as seguintes características: é flexível e permite que os professores criem planos de aula diferentes, bem como trabalhem com diferentes habilidades e competências.

Palavras-chave: realidade aumentada; ferramentas de autoria; educação; pesquisa baseada em design.

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1 INTRODUCTION

Augmented Reality (AR) can be used for a range of fields such as professional training, medical visualization, entertainment, and many other areas (CARMIGNIANI et al., 2011). Its potential has been increasingly recognized by researchers and the industry (BACCA et al., 2014; GIBBS, 2017). Unlike other computer interfaces that draw users away from the real world and onto the screen, AR enhances the real world experience (BILLINGHURST; DUENSER, 2012). Although many educational applications are related to STEM (ALMGREN et al., 2005; RADU; SCHNEIDER, 2019) due to its potential to help students visualize abstract concepts in a coherent way, AR also has an interesting potential in the field of ELA (English, Language and Arts). It can help contextualize language for learners as well as enable them to explore it interactively (BILLINGHURST; KATO; POUPYREV, 2001; SILVA; ROBERTO; TEICHRIEB, 2015). Its unique features can also be used to express creativity (LEVIN; SUGRUE; MCDONALD, 2014).

Many studies have shown that AR has a positive impact on students' motivation (SERIO; IBáñEZ; KLOOS, 2013; RADU, 2014) and cognitive performance (THEODOROU et al., 2018). AR has also been demonstrated to provide higher satisfactory learning experiences (RADU, 2014) and can aid varied age levels ranging from young children (KIDS, 2014) to university students (CAI; WANG; CHIANG, 2014; REDONDO et al., 2013).

(RADU et al., 2021) reviewed empirical scientific findings related to AR in education and identified specific cognitive, motivational and social processes that are enhanced by AR technology. Their work also reviewed public opinion about AR in education gathered through websites and blogs. These website posts revealed a general positive outlook of AR. They suggest that AR has substantial capacity to enhance cognitive processes. They also mentioned the benefits of AR to increased collaboration and communication skills, safety and security in learning experiences, and to connect students at long distances. AR was also credited to enhance learning accessibility since it does not depend on books or supplies, and in many cases is cost effective in comparison to Virtual Reality (VR). These posts revealed consistent findings that AR can be effective in increasing student motivation and that it can make learning more interesting, fun, and engaging.

At the same time, we have seen an increasing interest in AR from big companies, such as Google (GIBBS, 2017). Investors are also funding research into wearables development, predicting that the screens in consumers' pockets will be replaced by AR interfaces. Examples of such efforts are Microsoft Hololens (MICROSOFT, 2019) and Magic Leap (INC, 2019).

Despite the research findings and popular opinion, the use of AR is still far from widespread in education. Many factors may influence teachers' technology adoption, such as their own technology skills and educational beliefs (ERTMER; OTTENBREIT-LEFTWICH, 2010; PARASKEVA; BOUTA; PAPAGIANNI, 2008). Social learning and support in workplace environments, the tools available as well as the possibility of customization of educational experiences are also factors that play a role in teachers' adoption of this technology (VERMETTE et al., 2019).

When we consider using technology in educational contexts, such as AR, we observed that it is important to think about not only how much this technology is used, but how well teachers can integrate it in their lesson and how it effectively fosters students development. The Future Classroom Lab proposed a maturity model to understand how mature and advanced is the level of innovation in the schools (Future Lab, 2014). This model has five levels that range from basic use of technology to complete empowerment of teachers and students and provides detailed explanation on how these levels are expressed. It shows that from the third level onward, the learner can work more independently and creatively supported by technology by using *Authoring Tools*. This demonstrates that the use of such tools can foster the process of innovation in schools. This model suggests that elements such as collaboration, creativity through content creation (authoring tools) and ability to assess students in more flexible ways are related to more mature uses of technology. Thus, we understand that by analyzing this model we can take interesting insights that can be applied to AR authoring tools.

Naturally, (ROBERTO et al., 2016a) have shown that both time and technical expertise are two of the reasons that hinder the far-reaching use of authoring tools. This is particular true for teachers. Although AR authoring tools exist in the market, few of them are thought from the educational perspective. (BACCA et al., 2014) point out the need for further research regarding authoring tools for creating AR activities so that teachers can create their own AR content. In order to use AR effectively, they need to connect this technology with their learning goals, which requires some degree of authoring or at least customization. (RADU et al., 2021) conducted a survey to investigate what curriculum topics can be benefited by AR in both popular opinion (through posts on websites) and academic literature. They found out that using AR as a creation tool was highly cited in websites indicating a strong need for authoring tools by students and teachers which was not the case in AR research. Therefore, the lack of authoring tools is one of the main reasons that contribute to the fact that AR use has not reached higher levels of maturity in schools yet.

As previously discussed, the educational scenario can benefit from the use of AR. However, it is crucial to consider pedagogical aspects when authoring AR applications for education, which is almost unavailable on existing AR authoring tools. As (DONALLY, 2018) noted, although many educators are won over by the wow factor, oftentimes they are not able to see a direct connection between immersive technology tools (AR included) and content areas and student objectives. Thus, authoring tools may enable the necessary flexibility for AR to be widespread and, most importantly, used effectively.

1.1 OBJECTIVES

The main objective of this research is to *identify how teachers would like to create AR experiences based on their pedagogic needs*. In order to achieve our goal, the following specific objectives are to be achieved as detailed below:

1. Investigate the possibilities offered by AR for education and the AR authoring tools for non-programmers available;
2. Understand teacher's uses of AR technology as well as their needs and limitations for AR use in schools;
3. Propose and validate a prototype solution designed in collaboration with a multidisciplinary team to solve the problems found through the interactions with users and following a design based research approach. This approach is properly described in **Chapter 5**;
4. Generate design principles for AR authoring tools aimed at education.

1.2 THESIS STRUCTURE

This thesis is structured following the DBR steps as described in **Chapter 5**. We detail below the structure of this thesis in relation to the steps involved in the DBR approach.

1. Step 1 of DBR is the analysis of practical problems by researchers and practitioners in collaboration. It consisted of a literature review of the possibilities offered by AR for education (**Chapter 2**), and language teaching (**Chapter 3**), as well as AR authoring tools (**Chapter 4**). This step also encompassed the understanding of teacher's context, use and needs related to AR as detailed in **Chapter 6**;
2. Step 2 concerns the development of solutions informed by existing design principles and technological innovation and it is detailed in **Chapter 7**;
3. Step 3 involves iterative cycles of testing and refinement of solutions in practice and it is described in **Chapter 8**;
4. Step 4 of DBR is the reflection to produce design principles and enhance solution implementation, which is detailed in **Chapter 9**;
5. Finally, **Chapter 10** presents the conclusions of this study.

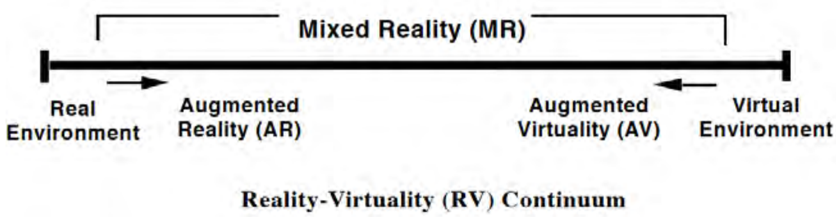
2 AUGMENTED REALITY

One salient feature of AR interfaces is to enhance the real world experience (BILLINGHURST; KATO; POUPYREV, 2001). Thus, AR refers to a type of technology that combines the real and virtual world coherently. This technology superimposes virtual information, such as objects, pictures and text in the real world in a seamless way.

The most widely accepted definition of AR was given by (AZUMA, 1997) who explains that for a system to be considered AR, it must have three characteristics, namely: (1) combination of real and virtual worlds, (2) real-time interaction, and (3) accurate 3D registration of virtual and real objects. Over time some new aspects have been added to this concept, such as simulation, online effects, and 2D perspective elements (SALMI; KAASINEN; KALLUNKI, 2012). Researchers advocate that understanding AR in a broad sense is more productive for educators and designers since this definition implies that varied technologies could be used to implement AR systems, such as desktop computers, handheld devices, head-mounted displays and so on (BROLL et al., 2008; JOHNSON et al., 2010; LIU, 2009). Therefore, authors argue that AR should be understood as a concept rather than a type of technology in order to be more productive for researchers, educators and designers (WU et al., 2013). Besides, although the sense of sight is the most explored in AR applications, (AZUMA et al., 2001) explain that this technology can be potentially applied to all senses.

(MILGRAM et al., 1994) established a continuum that is helpful to explain the concept of AR. This continuum covers the different possibilities of mixing real and virtual environments, as illustrated in Figure 1. In one of its extremes, we have the real environment and in the other end, the virtual environment. Between those extremes, there are AR and Augmented Virtuality, which is a mostly virtual world with some real objects.

Figure 1 – Reality-Virtuality Continuum.



Font: (MILGRAM et al., 1994).

As can be seen, the main difference between Augmented Reality and Virtual Reality (VR) is that in AR the real-world is enhanced with virtual objects, whereas in VR, the user is immersed in a complete virtual environment. Due to the rapidly-evolving characteristic of this field, discussions have been made concerning the definition of Mixed Reality (MR). (SPEICHER; HALL; NEBELING, 2019) have shown that there is no universally agreed definition of MR. They interviewed 10 experts and reviewed 68 academic papers and identified six existing notions of MR.

One popular definition is the traditional notion of MR in accordance with the Reality-Virtuality Continuum (AZUMA, 1997) as exposed above. That means a mix of real and virtual objects on a spectrum between a fully real and a fully virtual world. In other words, everything that is between the real environment and VR is Mixed Reality, which includes AR and Augmented Virtuality (AZUMA, 1997). VR (the far end of the spectrum) classification was debatable since some consider it to be part of MR and others did not. Other definitions include MR as synonym for AR; MR as a type of collaboration; MR as a combination of AR and VR; MR as an alignment of environments and, finally, MR as a “stronger” version of AR. The last definition is mainly characterized by an advanced environmental understanding as well as interactions, both of the user with virtual objects and the virtual objects with the environment, which potentially means that MR is bound to a specific hardware of software that provide the necessary functionality. From these definitions, the authors derived a conceptual framework with seven dimensions to characterize MR applications in terms of number of environments, number of users, level of immersion, level of virtuality, degree of interaction, input and output. For the purpose of this work, we will consider MR as a mix of real and virtual objects on a spectrum between a fully real and a fully virtual world in accordance with the Reality-Virtuality Continuum proposed by (AZUMA, 1997).

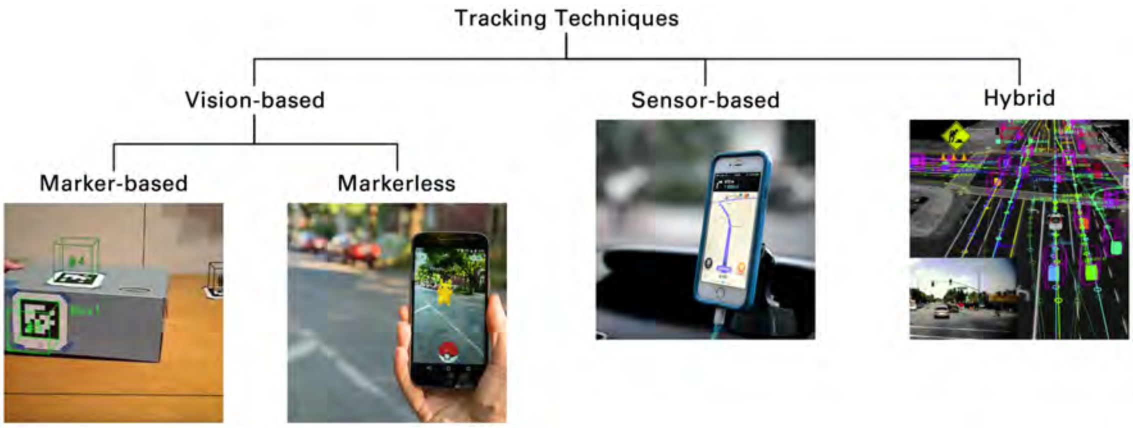
Another term that has been increasingly popular in the area is Extended Reality or XR, which is an umbrella term bringing together emerging technologies, such as Virtual Reality (VR), Augmented Reality and Mixed Reality (MR) (MATHEW; PILLAI, 2022).

Our work focuses on AR. Since it combines the real and digital environments, in order to provide effective AR experiences, three factors must be taken into account: tracking techniques of the real scenes, display hardware to present the augmented content and, finally, interaction techniques so users can manipulate the augmented contents.

2.1 TRACKING TECHNIQUES

Tracking is a fundamental enabling technology for AR systems. It is responsible for "understanding" the environment, which is necessary in order to record the position and orientation of real objects in physical space and to allow consistency between real and virtual objects. There are several ways to classify tracking techniques (ROBERTO; LIMA; TEICHRIEB, 2016), but it is most commonly divided in three groups, namely: vision-based tracking, sensor-based tracking and hybrid tracking (ZHOU; DUH; BILLINGHURST, 2008), as seen in Figure 2.

Figure 2 – Classification of tracking techniques and one example of each type.



Font: Image elaborated by the author.

Vision-based techniques understand the scene from images and video captured from the device's camera. These approaches use image processing and computer vision methods to calculate the position of the camera relative to real scene and objects. Therefore, knowing where the camera is and where are all the objects in the environment, it is possible to correctly insert and display virtual content on the scene. Traditionally, these techniques can be further divided in two groups: marker-based tracking and markerless tracking (RABBI; ULLAH, 2013).

Marker-based tracking uses artificial elements that are very distinguished from the scene called markers. Because they are so different from the environment and have some known properties (such as well defined patterns and size), they can reduce the computational complexity to calculate the camera's position to correctly add the objects in the scene. Different types of markers include template-based, ID-based, and random dots (ROBERTO, 2012). Figure 2 shows an example of an ID-based marker.

Markerless tracking, on the other hand, uses characteristics in the actual scene such as points, edges, corners and textures to calculate camera position. In other words, the environment itself acts as a marker. These techniques are more complex to be developed and require higher computational power to run. However, they do not require the insertion or intrusive elements in the environment. There are versions of this method that require a model of the object or scene that will be tracked such as a CAD Model, which is a virtual version of the object. But there are versions of this approach like the example in Figure 2 that can calculate the camera movement without previous knowledge of the scene.

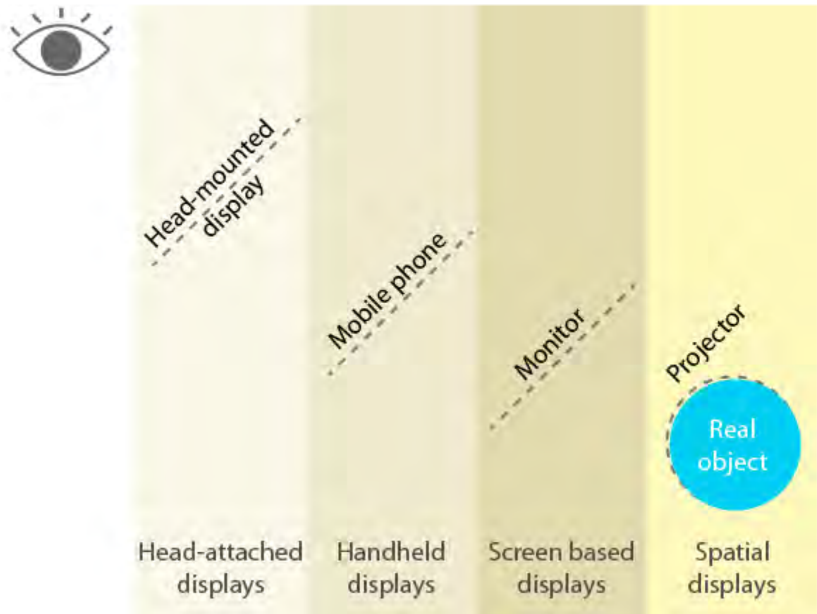
Sensor-based techniques can use all the devices' sensors except the camera to estimate their position and orientation. Several sensors, such as magnetic, acoustic, inertial, optical and mechanical sensors are embedded in many devices, which can support that function (ZHOU; DUH; BILLINGHURST, 2008). Each sensor has its own advantages and disadvantages which will have a different impact depending on the system being developed (ROLLAND; BAILLOT; GOON, 2001). Figure 2 shows an example of a mobile phone using the GPS to track the device's position in the street and guide the driver to his/her destination.

Hybrid techniques combine the information captured using cameras and other sensors to compute the camera position (VENTURA; HöLLERER, 2012). They are usually used for more challenging and complex situation such as self-diving cars as shown in Figure 2 because these approaches combine the advantage of both worlds. However, these methods are more complex to implement. Apple's ARKit and Google's ARCore, probably the two most popular AR platforms nowadays, are hybrid approaches. But to reduce the complexity of the computation to calculate the device's position faster and save battery, they use the sensor-based module most of the time and combine vision-based module only when necessary (ROBERTO et al., 2016).

2.2 DISPLAY TECHNIQUES

Along with an accurate tracking system, the display hardware is an important part of an AR system and plays a role when it comes to provide an immersive experience for the user. *AR Visualization* techniques are powerful tools for exploring the real world structures along with additional contextual information (KALKOFEN et al., 2011). Display techniques can be classified according to the user's viewpoint as illustrated in Figure 3 (BIMBER; RASKAR, 2005).

Figure 3 – Different AR displays according to the user's viewpoint.



Font: Image elaborated by the author.

Head-attached displays, as the name suggests, are the ones attached to the user's head. Users need to wear them and graphic content is displayed at their sight. Normally the user wears this type of displays on their heads via a headband, a helmet or around an eyeglasses frame. That is why they are called head-mounted displays (HMD). They are divided in two different categories: optical see-through (OST) and video see-through (VST). OST allows the user to see the world with their natural eyes and overlay virtual content onto the users view. Examples of this type of displays are Hololens[1] and Magic Leap[2]. VST, on the other hand, obstruct users view of the real world by presenting a video view of the world overlaid by graphics. One example is the Oculus Rift[3]. These devices offer a new degree of immersion to the users. (AGRAWAL et al., 2019) define immersion as "a state of deep mental involvement in which the subject may experience disassociation from the awareness of the physical world due to a shift in their attentional state".

The market has been quickly evolving through the development of wearable devices and investors are funding research into wearables development, predicting that the

1 Available at <https://rb.gy/9ki0ti>.
2 Available at <https://rb.gy/jimsam>.
3 Available at <https://rb.gy/pnndg2>.

screens in consumers' pockets will be replaced by AR interfaces. As pointed out by (KLJUN; PUCIHAR, 2020), the price range of these displays is currently tenfold that of the cheapest smartphones supporting AR SDKs. Nevertheless, it is expected that they will became more affordable in the future.

Handheld displays are the most popular AR platform nowadays due to the availability of AR SDKs to run native AR applications and phones supporting WebAR in all price range (KLJUN; PUCIHAR, 2020). Two examples of popular mobile device AR applications are Snapchat[4] and Pokémon Go[5]. Literature shows that the majority of AR applications have been implemented on smartphones (WEERASINGHE et al., 2019; PUCIHAR; KLJUN, 2018; KOUTROMANOS; SOFOS; AVRAAMIDOU, 2015; PORTER; HEPPELMANN, 2017). Handheld displays are a good alternative to AR applications because they are minimally intrusive, socially acceptable, readily available and highly mobile (ZHOU; DUH; BILLINGHURST, 2008). Despite their popularity, this type of display also has its limitations. For example, the small size of the display on handheld devices is not ideal for 3D user interfaces. Also, it provides less immersion when compared to head-mounted displays.

Screen based displays use video mixing techniques to display merged images in a regular monitor. This technique is usually referred to as "window on the world" (BIMBER; RASKAR, 2006). It represents one of the most cost efficient AR approaches since it requires off-the shelf hardware components and standard PC equipment. Some of its disadvantages are: small size of monitors which reduce immersion degree and *Field of View (F.O.V.)*. Besides, limited resolution of merged images and indirect remote interaction techniques (most commonly supported rather than direct interaction with real and graphic content) are also points of concern. The mirracle[6] is an AR application that allows users to see internal organs in a monitor and interact with them using natural gestures.

Spatial displays aim to eliminate the need of using equipment attached to user's bodies and, thus, provide minimal intrusiveness. These displays project virtual content directly on site. It allows multiple users at a time and, hence, enables collaboration. They make use of video-projectors elements, holograms, radio frequency tags and

[4] Available at <https://rb.gy/yxofo5>.
[5] Available at <https://rb.gy/6u4hzr>.
[6] Available at <https://rb.gy/bbscg8>.

tracking technologies to display graphic information directly in the real environment. One example of this type of display is the AR Sandbox, which uses advanced computer graphics techniques to project graphic information on sand allowing students to learn about topography[7]. Some of the disadvantages of this kind of displays are: shadow casting of the physical objects and of interacting users and restrictions of the display areas. Mobility is also a problem for projection-based displays since the setup for most of them is fixed (ZHOU; DUH; BILLINGHURST, 2008).

2.3 INTERACTION TECHNIQUES

AR Interaction is a decisive aspect whenever we aim to design applications that are both appropriate and intuitive for its users. Human-computer interaction is the link between the input and output in an AR application (SCHMALSTIEG; HÖLLERER, 2015). AR interfaces are divided into four types: tangible AR interfaces, collaborative AR interfaces, hybrid AR interfaces and emerging multimodal interfaces (CARMIGNIANI et al., 2011).

In *tangible AR interfaces*, object manipulations are mapped one-to-one to virtual object operations and follow a space multiplexed input design. Since AR applications allow an intimate relationship between virtual and physical objects, this type of interaction is a promising approach for good interface designs because it takes advantage of the immediacy and familiarity of everyday physical objects for effective manipulation of virtual content (BILLINGHURST; GRASSET; LOOSER, 2005). Some of its characteristics are: (1) each virtual object is registered to a physical object; (2) the interaction with virtual objects is done through the manipulation of the corresponding physical objects. Thus, physical objects and interactions are as important as the virtual imagery and provide a very intuitive way to interact with the AR interface (BILLINGHURST; GRASSET; LOOSER, 2005). One good example is the ARBlocks (SILVA; ROBERTO; TEICHRIEB, 2015), which enables students to interact with animated content through real blocks and, thus, learn languages.

Collaborative AR interfaces encompass the use of multiple displays to support remote and co-located activities (CARMIGNIANI et al., 2011). AR techniques can be used to allow users to move smoothly between virtual and real worlds. It also enables multiple users to be immersed on a scene and view augmented content in the setting. Thus, it

[7] Available at <https://rb.gy/oqu4zj>.

allows face-to-face and remote collaboration by integrating multiple user's devices in different contexts and, therefore, enhancing telepresence. (SCHMALSTIEG; HÖLLERER, 2015) explain that in a 3D environment populated by multiple displays, coordinated multiple views are often employed in the form of a shared space. In this scenario, a common global coordinate system is shared across all displays, but every display has an individual tracked-viewpoint. Thus, augmentations appear in the same 3D location for all displays.

Besides, AR has some characteristics that facilitate collaboration, namely: its ability to enhance reality; the presence of spatial cues for both face-to-face and remote collaboration; support for tangible interaction metaphor and ability to transition smoothly between reality and virtuality (BILLINGHURST; KATO, 2002). An example of a collaborative AR interface is the Construct3 (KAUFMANN; SCHMALSTIEG; WAGNER, 2000), a 3D geometric construction tool based on the Studierstube library. This system aims to foster mathematics and geometry education.

Hybrid AR interfaces combine different but complimentary interfaces and displays (e.g.: opaque, stationary displays and see-through, head-worn displays) as well as the possibility to interact through varied interaction devices (CARMIGNIANI et al., 2011). In everyday interactions, developers might not know beforehand what exact displays and devices will be used and who would be involved. These aspects might also change during the course of interaction. Thus, hybrid AR interfaces provide a flexible platform which is able to accommodate a changing set of input and output devices as well as the interaction techniques. One example of hybrid interface is the system developed by (SANDOR et al., 2005) which combines head tracked, see-through and head-worn display to overlay AR and provides visual and auditory feedback. This system supports end users in assigning physical interaction devices to operations as well as virtual objects to perform them and re-configuring the mappings between devices, objects and operations as the user interacts with the system.

Multimodal interfaces combine real objects input with natural forms of language, such as: speech, touch, natural hand gestures, or gaze. Other forms of interaction, such as pen input or haptics can also be used. One example of this interface is the MIT's sixth sense (SANDOR et al., 2005), or simply, WUW, which is a wearable gestural interface that allows the user to interact with the physical object through natural hand gestures, arms movement, and/or interaction with the object itself. A key idea of multimodal interfaces is to use multiple sensory channels together to trade one technique's weaknesses for another one's strengths (SCHMALSTIEG; HÖLLERER, 2015). They also have the ability to support users' ability to combine different modalities or to switch input modes depending on the setting or the task at hand. This type of interaction has been largely developed and is heralded to be one of the preferred type of interaction for future AR applications as they offer a robust, efficient, expressive, and highly mobile form of human-computer interaction (CARMIGNIANI et al., 2011).

2.4 AR IN EDUCATION

Educational possibilities using AR have been increasingly explored by researchers and practitioners (SANTOS et al., 2014). The number of works investigating and evaluating AR in education has been increasing (SILVA et al., 2019a).

(SUH; PROPHET, 2018) present the definition of immersive technology as a "technology that blurs the line between physical, virtual, and simulated worlds, thereby creating a sense of immersion". This term is used to refer to different technologies, such as VR and AR. They differentiate, though, two types of VR: (1) non immersive VR, which refers to VR content displayed via a computer screen. In this case, traditional media, such as keyboard and mouse, are used for interaction. Examples of this type are Web-based virtual environments, such as Second Life and Minecraft; and (2) immersive VR, also known as iVR (SOUTHGATE, 2020), which refers to scenarios where users are required to wear head-mounted displays and are completely emcompassed by the virtual environment. The authors add that in these environments, users responses can be observed and recorded in a controlled situation. Cave Automatic Virtual Environment (CAVE) is an example of immersive VR.

This type of technology is promising for education and learning. Research has shown that the most effective educational experiences are those designed around social constructivist learning approaches, which involve mastering tasks in the context of personally relevant, collaborative, realistic situations (ERTMER; NEWBY, 2013). Immersive technologies are well-suited to provide those aspects (BONASIO, 2019). In their work, (SUH; PROPHET, 2018) investigated 54 articles about immersive technology in diverse settings, including education, marketing, business, and healthcare. They aimed to propose a framework that accounts for the interplay between key elements associated with immersive technology use. Their results revealed that 46% of the papers had been published in journals related to education, which illustrate its relevance in this field. Their framework posits that immersive system features influence users' cognitive and affective reactions, which in turn influence the outcomes of immersive technology use. They also posit that individual differences have moderating effects between immersive system features and user's cognitive and affective reactions and the outcomes of immersive technology use. Their literature review has shown that immersive technology allows users to immerse themselves in virtual scenarios that otherwise cannot be easily available. A result of this immersion is the ability to perceive, feel, and cognitively process information that would have otherwise been unavailable. In this way, immersion augments human cognition (SUH; PROPHET, 2018).

(BONASIO, 2019) explains that immersion is important to design effective learning experiences and it can take many forms:

(a) *Psychological immersion:* research has shown that content can be best learned by attempting relatively complicated tasks that have relevance to the real world (DEDE, 2009). Immersive experiences tap into that aspect and provide experiences driven by social and collaborative interactions, where the setting itself contributes to fostering tacit skills;

(b) *Sensory immersion:* occurs when students are able to "feel" themselves being part of a virtual world. This has been used extensively for procedural learning application;

(c) *Narrative and symbolic immersion:* the author explains that narrative is an important motivational and intellectual component of all forms of learning. An immersive experience can trigger powerful semantic associations. She claims that in a mediated, simulated experience, immersion requires the willing suspension of disbelief which is prompted by emotional investment in a compelling narrative;

(d) *Actional immersion:* involves initiating a process for the participant that leads them to take actions which have novel and intriguing consequences in the context of their own prior experience.

Additionally, certain cognitive factors are triggered by immersive technologies, which are particularly relevant in a learning content (BONASIO, 2019). The author explains that these cognitive factors involve:

(a) *Embodied cognition:* these experiences enable students to practice and perfect skills in a safe and accurate learning environment;

(b) *Mastery-focused learning:* (BONASIO, 2019) states that MR provides constant stimulus-response-positive reinforcement paradigm that results in efficient, mastery-focused learning;

(c) *Cognitive load:* AR and VR reduce information bottlenecks and increase performance on skills-based tasks, resulting in gains in knowledge, abstract reasoning, and critical thinking.

Another aspect that can benefit from immersive technologies is social and emotional learning, defined by (AIDMAN; PRICE, 2018) as: “the process through which children and adults acquire and effectively apply the knowledge, attitudes, and skills necessary to understand and manage emotions, set and achieve positive goals, feel and show empathy for others, establish and maintain positive relationships, and make responsible decisions.” Immersive technologies can also foster diversity since it can foster social emotional learning, which can be encompassed by many aspects such as: break through emotional barriers and allow learners to experience life from the perspective of others, building empathy-related skills (HERRERA et al., 2018).

Besides, (DONALLY, 2018) points out numerous benefits of using immersive technologies in the classroom. For her, the most important one is student benefit. She highlights that the insertion of immersive technologies piques student’s interest. She argues that students are eager to see the new technology because it is part of their culture. Nevertheless, research involving teachers, developers and researchers is needed in order to delve deeper into immersive technologies affordances in real classrooms that extend beyond providing students a novelty experience. Strides have been made in this direction by (SOUTHGATE, 2020) who has investigated iVR and school education through her project named the VR School Study. She argues that “the concept of learning affordances provides educators with a lens to interrogate how the specific features of virtual environments can facilitate learning in ways that are markedly different to traditional pedagogy or other forms of technology-enhanced learning".

(DONALLY, 2018) also argues that it is a given that technology is embedded into our everyday lives, and, thus, it is even more important for the students and their future work and social lives to learn and use them productively. The Immersive Learning Research Network, in its yearly report about the state of Extended Reality (XR), an umbrella term that encompasses both AR and VR (CHUAH, 2018), and Immersive Learning, presents findings that corroborate with this point. Their report points out that developing the capabilities of the future workplace is a promising learning opportunity that XR and Immersive learning can help fulfill. They identified numerous contexts where XR will play a critical role in developing the workforce of the future. They recognized a clear need to expand it to all areas of onboarding, which includes the development of soft skills and diversity training. They also reported that immersive experiences would provide new opportunities for career guidance, especially for younger students who are not fully aware of their own talents or unlikely to be exposed to new career paths (LEE et al., 2020).

Among the various benefits of immersive technology, (DONALLY, 2018) highlights the following:

1. *Providing authentic learning experiences:* when learning is authentic, teachers have an opportunity to engage students with purposeful, deepened learning (DONALLY, 2018; LEE et al., 2020). We understand that technology can be a part of this process by enabling more authentic experiences for students;

2. *Transporting students to places outside of the classroom:* she states that augmented, virtual, and mixed reality can help bridge the gap of expected knowledge and needed experiences and bring students to many locations around the world in the case of VR, thus, eliminating limitations of location and funding;

3. *Offering support and a means of communication for ELL (English Language Learner) students:* the author explains that one obstacle that some students face is a language barrier. She explains that when English language learners have access to immersive technology, they're no longer hindered by understanding, because the experience speaks for itself;

4. *Creating innovative spaces to collaborate and share information:* she explains that beyond online videos, students now can access more realistic and effective support through immersive technology, such as AR. Besides, she adds that immersive technology offers powerful tools that teachers can harness to provide personalized and custom learning experiences to the students.

She also highlights that immersive technologies align with ISTE (International Society for Technology in Education) standards for students[8]. These standards address important skills students must possess to be prepared for opportunities and success in the future. They are related to: (1) student empowerment; (2) digital citizenship; (3) student creation; (4) design and innovation; (5) computational thinking; (6) creative communication and (7) global collaboration.

As an example of student's interest for new technology, in her book, (DONALLY, 2018) mentioned the incredible popularity of Pokémon Go[9], which attracted users through AR, gamification, competition as well as its interesting and meaningful content. For her, "combining the excitement of playing an AR game (identifying your students' interests) with your lesson objectives is the start to having the most success with immersive technology." However, despite these new learning opportunities, AR use for educational purposes is still not widespread.

In this work, we will focus on the potential of AR in education. Since this technology was first created it has been increasingly changing. In the early years, this type of technology was seen as bulky and heavyweight and appropriate mostly for industrial and military fields. Nowadays, advancements in different areas such as hardware and software and reduced costs enabled AR technology to spread through different fields. (CARMIGNIANI et al., 2011) point out that AR can be used for a range of fields such as professional training, medical visualization, entertainment, advertising, maintenance and repair, robot path planning and many other areas. Although all fields of knowledge can potentially take advantage from AR technology, more than a decade ago, (TORI; KIRNER; SISCOUTTO, 2006) already argued that teaching, learning and training will be particularly modified by the introduction of this new piece of technology and changes in interaction between teachers and students as well as students and information allowed by the mix of virtual and real information.

8 Available at <https://rb.gy/asp3aa>.
9 Available at <https://rb.gy/6u4hzr>.

(SOUTHGATE, 2020) discusses an important concept in her book, learning affordance. This concept refers to the actual or perceived properties or attributes of a thing which suggest to a user how it might be interacted with. This term has been commonly used to refer to the potential (utility) of a given technology for learning. She argues that the learning affordance perspective understands that the technology itself does not necessarily cause learning, but that it can afford certain tasks or experiences that can result learning. Thus, we understand that AR, as well as other immersive technologies, such as VR, have particular affordances that may help to support learning, such as: its ability to encourage kinesthetic learning and the possibility to see virtual content in a 3D perspective coherently with the real-world. The educational possibilities of AR have been increasingly recognized by researchers (SILVA et al., 2019a; SANTOS et al., 2014).

Different from VR, AR enables the combination of the real and virtual world in a coherent way. (PORTER; HEPPELMANN, 2017) claim that at its core, the power of AR grows out the way humans process information. They explain that the ability to absorb information is limited by our mental capacity. The demand on this capacity is the “cognitive load”. Each mental task we undertake reduces the capacity available for other simultaneous tasks. Cognitive load depends on the mental effort required to process a given type of information. As an example, reading instructions from a computer screen and acting on them creates a greater cognitive load than hearing those instructions, because the letters must be translated into words and then interpreted. The authors add that cognitive load depends on “cognitive distance”, which means the gap between the form in which information is presented and the context in which it is applied. An interesting example is when someone tries to refer to a smartphone while driving. The driver needs to check the information from the screen, retain it in his/her working memory, translate this information into the physical environment, and then act on it, all while driving the vehicle. Dealing with this significant cognitive distance between the digital information on the screen and physical context in which this information is applied creates cognitive load. The authors explain that there is no better graphical user interface than the physical world when it is enhanced by a digital overlay of relevant data and guidance when and where needed. AR, thus, eliminates dependence on out-of-context and hard-to-process 2D information on pages and screens while greatly improving our ability to understand and apply information in the real world (PORTER; HEPPELMANN, 2017).

The coexistence of virtual and real environments also allows learners to experience phenomena that otherwise would be impossible in the real world, interact with two- or three-dimensional synthetic objects in the mixed reality environment and develop important practices and literacies that cannot be developed in other technology learning environments (WU et al., 2013). For example, the work of (SQUIRE; KLOPFER, 2007) shows that AR games could be used to activate learner's prior knowledge, connect it to the physical world and engage students in academic content and practices. The authors argue that "AR applications allow the physical environment to enter both the problem space and students' thinking". Their game suggests how environmental affordances can affect a problem-solving path within an augmented reality environment. (SQUIRE; JAN, 2007) presented a game that allowed students to experience how scientists work, and to apply their scientific understandings, particularly their argumentation skills, to resolve issues in their local community.

AR affordances are supported by multiple learning theories, such as: situated learning, multimedia learning theory, experiential learning theory and animate vision theory (DUCASSE, 2020; DEDE, 2009; SANTOS et al., 2014).

Situated learning theory understands learning as a social process, in which knowledge is shared in a community of practice that includes people of different degrees of expertise. Communication, collaboration and interaction between these members are, thus, key aspects of knowledge sharing (DUCASSE, 2020). (DEDE, 2009) corroborates this notion when he explains that "situated learning requires authentic contexts, activities, and assessment coupled with guidance from expert modeling, mentoring, and 'legitimate peripheral participation'". His notion of legitimate peripheral participation is very similar to the concept of community of practice where graduate students could learn how to perform field and laboratory work by working with expert researches who would model the practices to them. Thus, in this situated learning scenario, learners are encouraged to work on concrete and practical problems, to learn by doing and experiencing the real world. (BONASIO, 2019) states that situated learning use of immersive technologies, AR included, can increase rates of skills transfer, enabling students to apply theoretical concepts learned to real-world scenarios.

On the other hand, multimedia learning theory refers to words (written or spoken) and pictures. (SANTOS et al., 2014) explain that multimedia learning theory has three assumptions: dual channels, limited capacity, and active processing. Dual channels refer to the existence of two separate channels for visual information and auditory information. These channels can only accommodate a limited amount of information at a given time, thus, the limited capacity assumption. Finally, this theory understands humans as active learners. Incoming information from the channels are processed by organizing them into coherent mental representations, and integrated to previously acquired knowledge. Design principles can be extracted from this theory that are directly related to AR annotation applications as explained by (SANTOS et al., 2014). These principles that are directly related to AR annotations are: multimedia principle, spatial contiguity principle, and temporal contiguity principle. Multimedia learning theory can be extended to AR annotation by doing two substitutions: (1) the system of real objects replaces the picture, and (2) the virtual texts and symbols replaces the words. These substitutions are well-suited for instructional applications, where learners must follow a set of instructions to perform a given task. Spacial contiguity can be extended to AR since it can be argued that people learn better when corresponding virtual words and physical objects are presented near rather than far from each other on the screen (SANTOS et al., 2014).

Experiential learning theory views entire experiences as the source of learning. This theory argues that learning occurs when students integrate new experiences within their pre-existing knowledge. Thus, it emphasizes “independent judgment, free thinking, and personal experience” (DUCASSE, 2020). This theory was first proposed by Kolb (KOLB, 2014) and describes four phases in the learning cycle, which students must go through in order to complete the learning experience. Learning starts with a concrete experience, which becomes the basis of observation and reflection. From learner’s observations, they formulate theories, which then are tested for implications in new situations. Results of this testing stage provide new concrete experiences. AR can also be used to leverage learning according to this theory tenets. (DUCASSE, 2020) shows that experiential learning theory can be applied to design AR outdoor experiences to promote on-site environmental learning.

Animate Vision theory links visual perception to acting and moving in the physical world (SANTOS et al., 2014). Thus, authors argue that visualizations in learning experiences should take advantage of visual stimuli and motor responses. Immersive technologies, such as AR are well-equipped to provide that since it allows users to use their hands and entire bodies to change the perspective of visualization.

AR can also be successfully combined with the tenets of gamefication to provide students with powerful learning experiences by allowing teenagers to be protagonists in the creation of a museum AR experience (SCHLEMMER et al., 2016) as well as enabling users to participate in a rich cultural heritage experience (SCHLEMMER et al., 2018).

2.4.1 AR Impact on Education

(BILLINGHURST, 2002) adds that educational experiences offered by AR technologies are different from a number of reasons including: support of seamless interaction between real and virtual environments, use of tangible interface metaphor and ability to transition smoothly between reality and virtuality.

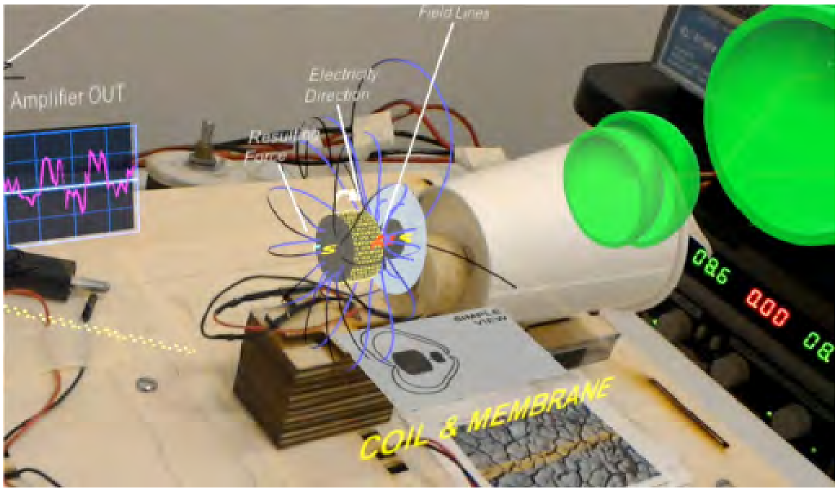
Many studies have shown that AR has a positive impact on student's motivation (SERIO; IBáñEZ; KLOOS, 2013; RADU, 2014) and cognitive performance (THEODOROU et al., 2018). (RADU, 2014) analyzed 26 publications that compared AR versus non-AR applications aiming to analyze the potential of AR compared to other educational mediums. He noticed in multiple papers user's high enthusiasm to engage with AR experiences, meaning users demonstrated higher satisfaction, having more fun, and being more willing to repeat the experience. He highlighted that was the case even when the AR experience was deemed more difficult to use than the non-AR alternative. This increase in motivation can be perceived in a myriad of contexts raging from children playing AR games to learn about endangered animals (JUAN et al., 2010), to high school students learning about geometry (KAUFMANN; DÜNSER, 2007) and middle-school students learning about visual art (SERIO; IBáñEZ; KLOOS, 2013). As regards content understanding, research has shown that for certain topics, such as: learning spatial structure and function and language associations, AR can be a more effective teaching alternative than other media such as books, videos or PC desktop experiences (RADU, 2014). AR can be used to leverage learning of different contents from math and science to human and arts. AR applications can aid varied age levels ranging from young children to university students[10] (CAI; WANG; CHIANG, 2014; REDONDO et al., 2013). We discuss below important AR capabilities that can be explored in education, namely: visualization, instruction and guidance and interaction.

[10] Available at <https://rb.gy/roqsgg>.

2.4.1.1 *Visualization*

Coexistence of virtual and real information allows learners to visualize complex spatial relationships and abstract concepts. There are applications that explore this characteristic to leverage chemistry (ALMGREN et al., 2005) and physics (RADU; SCHNEIDER, 2019) understanding. The Augmented Chemistry (ALMGREN et al., 2005) is an application meant to scaffold organic chemistry learning. The system is composed of a booklet, a gripper, a cube, a platform, a camera and a software. By using the gripper, the user can pick up elements from the booklet and add them to the molecule in construction on the platform.

Figure 4 – Magnetic fields around the coil and the magnet that are generating the sound waves in the AR system.



Font: (RADU; SCHNEIDER, 2019).

(RADU; SCHNEIDER, 2019) have designed a Hololens-based system that exposed collaborators to an unstructured learning activity in which they learned about the invisible physics involved in audio speakers as illustrated in Figure 4. They have shown that educational AR representations were beneficial for learning specific knowledge as well as increasing participants' self-efficacy. These examples illustrate an important capability of AR technology: *visualization*. Commercial applications have also taken advantage of this aspect. Elements 4D[11] and Anatomy 4D[12], although currently discontinued, are two examples of applications that allow students to visualize augmented content related to chemistry and anatomy respectively. The Cell[13] is an application that also leverages

[11] Available at <https://rb.gy/wixkv0>.
[12] Available at <https://rb.gy/nm7rxb>.
[13] Available at <https://rb.gy/vmqp34>.

the visualisation capability of AR to present a 3D scale model of a cell with organelles descriptions. Quiver[14], on the other hand, is an application that enables students to color printed pages and see those images augmented with the colors they chose. They also have the Quiver Masks, which allows users to see interactive augmented reality masks on their faces. Companies, such as 4D Mais, have also created AR card games to help young learners visualize different animals related to the letters of the alphabet[15] aiming to improve students literacy skills. There are also companies, such as lifeliqe[16], who are providing the science curricula for K-12 enhanced with 3D, AR and VR. They provide a standard-aligned digital science curriculum with models and lesson plans for teachers. The Google Expeditions application[17] provides AR (animated) 3D models that educators can incorporate into their lessons, but it does not provide any additional guidance that could be used with those content. As (PORTER; HEPPELMANN, 2017) explain, AR applications provide a sort of x-ray vision, revealing internal features that would be difficult to see otherwise.

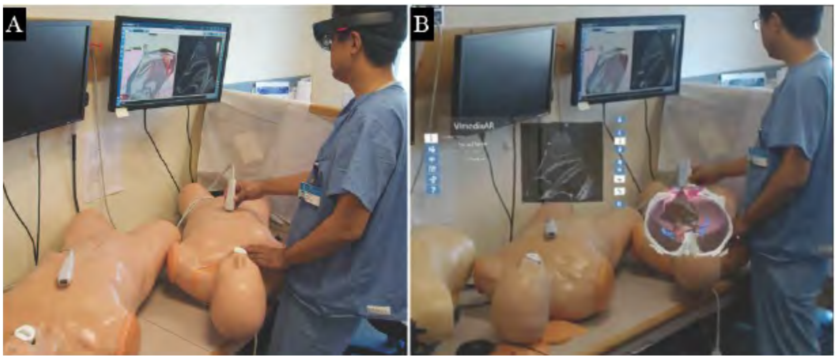
2.4.1.2 Instruction and Guidance

Other key capabilities of AR that can be explored in education are its ability to improve how users receive and follow instructions as well as its capacity to transform the way users interact with and control the product themselves (PORTER; HEPPELMANN, 2017). That is, AR transforms *Instruction and Guidance* practices. AR can provide real-time, step-by-step visual guidance on different tasks, transforming complicated 2D schematic representations of procedures into interactive 3D holograms that walk users through the necessary processes (PORTER; HEPPELMANN, 2017). In (MAHMOOD et al., 2018), we see a system that can record mixed reality capture (i.e: holograms projected on the real-world elements), which allows instructors to demonstrate manipulation of a probe and help residents understand the proper technique to understand the spatial perspective in ultrasound education as illustrated in Figure 5. In (GOTO et al., 2010), authors present an AR-based instructional support system that uses existing instructional videos as additional AR content. They conducted an usability test, in which users evaluated the

[14] Available at <https://rb.gy/etuv5g>.
[15] Available at <https://rb.gy/gnd9kc>.
[16] Available at <https://rb.gy/uhf6oh>.
[17] Available at <https://rb.gy/msrxul>.

use of instructional video in their system through tasks involving building blocks and origami. They have found that user's visibility improves when the instructional video is transformed to display according to his/her view.

Figure 5 – Simulator and the Hololens. (a) shows user with headset on. (b) is worn from the instructor's perspective and exhibits holograms from an observer's point of view.



Font: (MAHMOOD et al., 2018).

2.4.1.3 *Interaction*

Another important characteristic of AR is *interaction*. (PORTER; HEPPELMANN, 2017) explain that traditionally, people have used physical control such as buttons, knobs, and built-in touch screens to interact with products. They argue that with the rise of smart connected products (SCPs), apps have increasingly replaced physical controls and allowed users to operate products remotely. They argue that AR takes the user interface to a whole new level since a virtual control panel can be superimposed directly on the product and operated using an AR headset, hand gestures, and voice commands. This capability of AR is still nascent in commercial products, however, it can be revolutionary (PORTER; HEPPELMANN, 2017). Reality Editor (HEUN; REYNOLDS; HOBIN, 2017), an AR app developed by the Fluid Interfaces Group at MIT's Media Lab illustrates the potential of this characteristic. This app makes it easier to add an interactive AR experience to SCPs. It enables users to point a mobile device at an SCP, see its digital interfaces and capabilities that can be programmed, and link those capabilities to voice commands, hand gestures or to other smart products as exemplified in Figure 6.

Figure 6 – The Reality Editor shows a new user interface paradigm called spatial search. It allows the Reality Editor to use big data in the Cloud to help users make better choices around them.

Font: (HEUN; REYNOLDS; HOBIN, 2017).

2.4.2 Examples of AR in Education

A classical example of AR applications for education is the MagicBook (BILLINGHURST; KATO; POUPYREV, 2001), which consists of a handheld AR display, a computer graphics workstation, and the physical book. By using the MagicBook, students are able to interact with the physical object (the book) as well as with AR since the 3D content is projected on the book's pages. In addition, this book can also be used as an immersive virtual space. Students are immersed in the virtual space by seeing each other represented by avatars in the story setting.

(WU et al., 2013) explain that advancements in handheld computing open up new opportunities for AR applications and create a subset of AR: mobile-AR. The Cyberchase Shape Quest application is an example of a mobile–AR application that provides educational puzzles involving geometry, spatial reasoning and problem solving skills[18]. Figure 7 presents a screenshot of the game.

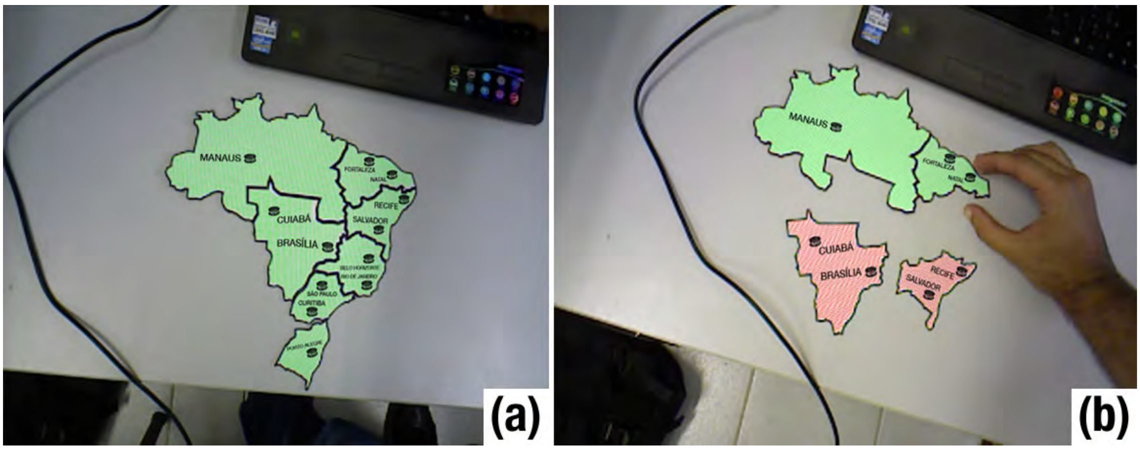
Another example is the AR Jigsaw Puzzle (SILVA et al., 2014), an application that uses real puzzle pieces to display augmented content and, therefore, foster geographic skills. In Figures 8 (a) and (b), it is possible to see the AR Jigsaw Puzzle being used to complete a map of Brazilian states that received stadiums for the Fifa World Cup 2014. Figure 8 (a) shows the map correctly assembled while Figure 8 (b) illustrates that the system gives feedback when pieces are correctly put together. In this example, AR enables to add more interactions, such as sound and animation, to real puzzle pieces. Also, the material could be reused by simply changing its digital content.

[18] Available at <https://rb.gy/iyjnl9>.

Figure 7 – Screenshot of Cyberchase Shape Quest game.

Font: <https://rb.gy/iyjnl9>.

Figure 8 – AR Jigsaw Puzzle in use. (a) It shows the puzzle correctly assembled. (b) It shows the puzzle being assembled. The tool gives feedback when pieces are correctly put together by changing its color accordingly.



Font: (SILVA et al., 2014).

These three examples illustrate how AR can take advantage of the immediacy and familiarity of everyday physical objects for effective manipulation of virtual content, such as books or puzzles, through the use of tangible AR interfaces. These interfaces are powerful because they use the familiarity of everyday objects to ease the interaction (BILLINGHURST; GRASSET; LOOSER, 2005).

3 LANGUAGE TEACHING APPROACHES

The field of second (or foreign) language teaching has undergone many fluctuations and shifts over the years, which Celce-Murcia compares to the swings of a pendulum (CELCE-MURCIA, 2001). These shifts reflect the cultural contexts of the time as well as learners needs along with beliefs regarding language and learning. (LARSEN-FREEMAN, 2012) states language teaching theories would presumably focus upon the link between learning and language.

(CELCE-MURCIA, 2001) points out that prior to the twentieth century, language teaching methodology vacillated between two types of approaches: getting learners to use a language, in other words, to speak and understand it, versus getting them to analyze it, that is, to learn its grammatical rules. For instance, English teaching has been dominated for many years by the Grammar-Translation Method, whose goal was to help learners understand and appreciate foreign language literature. This method dates back to the pre-twentieth-century and translation is the main technique used, hence, the name grammar-translation. Also, it was taught that the exercise of learning a new language would be intellectually beneficial although it was recognized that students would probably never use the target language. By the end of the nineteenth century, the Direct Method, whose goal is to teach students to use the language rather to analyze it had begun to function as a viable alternative to grammar-translation. This is a reaction to the grammar-translation approach and its failure to produce learners who could communicate in the foreign language they have been studying (CELCE-MURCIA, 2001). In this method, language is seen as a tool for communication. Language is primarily spoken, not written. Thus, students learn everyday common speeches as well as the culture of native speakers. The Direct Method has one very basic rule: no translation is allowed.

On the other hand, the Reading Approach was a reaction to the Direct Approach and its limitations. Reading was viewed as the most usable skill to have in a foreign language since not many people traveled abroad at that time; also, few teachers could use the foreign language well enough to teach it effectively using the Direct Approach. In this method, only the grammar useful for reading comprehension was taught. Vocabulary is controlled at first and expanded later on. Translation is once again a respectable classroom procedure (CELCE-MURCIA, 2001). The Audiolingualism Approach is a reaction to the reading approach and its lack of emphasis on oral-aural skills. Unlike the Direct Method, which emphasizes vocabulary acquisition through exposure to its use in situations, the Audio-Lingual Method drills students in the use of grammatical sentence patterns (LARSEN-FREEMAN, 2000). Audilingualism has a strong theoretical basis on structural linguistics (BLOOMFIELD, 1933) and behavioral psychology (SKINNER, 1957). In this approach, the way to acquire the sentence patterns is through conditioning - helping learners to respond correctly to stimuli through shaping and reinforcement. As these few examples illustrate, approaches varied on emphasis on the language skills over time. Over time, we witnessed the development of more integrative approaches for teaching.

(BROWN, 2000) explains that the integration of the four skills, namely, listening, speaking, reading and writing, is the only plausible approach within communicative, interactive framework. We highlight the following observations that support such techniques (BROWN, 2000):

1. Production and reception are two sides of the same coin, thus, cannot be separated;
2. Interaction means sending and receiving messages;
3. Written and spoken language often (but not always!) bear a relationship to each other; to ignore that relationship is to ignore the richness of language;
4. For literate learners, the interrelationship of written and spoken language is an intrinsically motivating reflection of language and culture and society;
5. By attending primarily to what learners can do with language, and only secondarily to the forms of language, we invite any or all of the four skills that are relevant into the classroom arena;
6. Often one skill will reinforce another; we learn to speak, for example, in part by modeling what we hear, and we learn to write by examining what we can read;
7. In the real world most of our natural performance involves not only the integration of one or more skills, but connections between language and the way we think and feel and act.

Many techniques can be used in the classroom to integrate the four skills and, moreover, to foster student' protagonism in the learning process. As (LAZARATON, 2001) points out: "learning is no longer seen as a one-way transfer of knowledge from teacher to student; today we understand that students learn from teachers, from classmates, and the more the learner seeks these opportunities, the more likely he or she will learn to use the language". Some interesting techniques that can be used to learn a language interactively are stories, since they are powerful means of language teaching (PECK, 2001). Stories are widely used to help children explore the language. The use of storytelling, dramatic activities and role plays are good for learning because they can engage and promote interaction among students. Although children are usually more willing to take part in drama activities than adults, activities like role plays can be particularly suitable for practicing the sociocultural variations in speech acts such as complimenting, complaining and the like (LAZARATON, 2001). As happens with storytelling, they can be performed from prepared scripts, created from a set of prompts and expressions, or written using and consolidating knowledge gained from instruction and discussion. Thus, these techniques can be used in classrooms from an integrative perspective combining the four language skills.

This integrative perspective of the language is aligned with the Brazilian common national curriculum base (BRASIL, 2016), which aims at the integral education of students in their physical, emotional, cognitive and social dimensions. In that sense, learning English: (1) provides opportunities for student involvement and participation in a social, global and plural universe; (2) contributes to the students' critical agency and the exercise of citizenship; and (3) expands the possibilities for interaction and mobility, creating new ways of building knowledge.

Other important aspects to be considered are the integration of media and the 21st century skills in the learning process. (BAKER, 2010) explains that teachers can no longer afford to ignore the presence of new media, such as the internet, television, music, or movies. Media literacy is, thus, an important topic to be integrated throughout the curriculum to enable students have an opportunity to become actively engaged in learning. Life on the screen: Visual literacy in education

(PELLEGRINO; HILTON, 2012) view 21st century skills as knowledge that can be transferred or applied in new situations. This transferable knowledge includes both content knowledge in a domain and also procedural knowledge of how, why, and when to apply this knowledge to answer questions and solve problems. The latter dimension are often called “skills”. They identify three broad domains of 21st century skills: cognitive, intrapersonal and interpersonal. Research has evidenced that deeper learning and 21st century skills prepare young learners for adult success.

3.1 LESSON PLANNING AND MEDIA INTEGRATION

The term “lesson” is considered to be a unified set of activities that cover a period of classroom time, usually ranging from forty to ninety minutes (BROWN, 2000). The author adds that these classroom time units are administratively significant for teachers because they represent “steps” along a curriculum before which and after which teachers have a hiatus (of a day or more) in which to evaluate and prepare for the next lesson. A lesson plan is, thus, an extremely useful tool that serves as a combination guide, resource, and historical document reflecting a teacher’s teaching philosophy, student population, textbooks, and most importantly the learning goals (JENSEN, 2001). It serves both as a map guiding teachers in knowing what to do next and as a record of what was done. The latter aspect can be a valuable resource when planning assessments. (JENSEN, 2001) explains that a good lesson plan is a result of both macro and micro planning. On the macro level, a plan reflects a philosophy of learning and teaching which is reflected in the methodology, the syllabus, the text and the other course materials and results in a particular lesson. In other words, a lesson plan is the end point of many other stages of planning that culminate in a daily lesson.

Despite numerous variations, (BROWN, 2000) explains that seasoned teachers generally agree on what the essential elements of a lesson plan should be. These elements are listed below.

1. Goals: it is the overall purpose that teachers will attempt to accomplish by the end of the class period. It serves as a unifying theme for the lesson;

2. Objectives: it is a explicit statement of what students will gain from the lesson. Objectives are most clearly captured in terms of what students will do. They must be written in a way that allows teachers to verify by the end of the lesson if they were achieved or not;

3. Materials and Equipment: good planning includes knowing what is needed to be taken or arranged to have in the classroom;

4. Procedures: although lessons vary widely at this point, (BROWN, 2000) mentions that important aspects to include in lesson plans are: (a) an opening statement or activity as a warm-up; (b) a set of activities and techniques in which teachers have considered appropriate proportions of time for whole-class work, small-group and pair work, teacher talk as well as student talk and (c) closure;

5. Evaluation: it is an assessment, formal or informal, that a teacher makes after students have sufficient opportunities for learning;

6. Extra-Class Work: this item is sometimes misnamed as “homework”. However, students don’t necessarily do extra-class work only at home. In any case, if it is warranted, extra-class work needs to be planned carefully and communicated clearly to the students.

Like most activities, a lesson plan has stages: a beginning, a middle, and an end. In most normal circumstances, especially for a teacher without much experience, the first step of lesson planning will already have been performed, that is, choosing what to teach. It is not uncommon for teachers to receive a textbook and be told to teach from it, with either a suggestion or a requirement of how many chapters or units they should cover (BROWN, 2000). Nevertheless, teachers should take into account some important aspects when planning their lessons. Variety, sequencing, pacing and timing are important issues teachers need to be mindful. They should make sure there is sufficient variety in techniques to keep the lesson lively and interesting. As (BROWN, 2000) puts it: “most successful lessons give students a number of different activities during the class hour, keeping minds alert and enthusiasm high”. It is also important to ensure activities are sequenced logically. That is, elements of a lesson will build progressively toward accomplishing the ultimate goals. In other words, the lesson must be coherent. Additionally, teachers need to pace their lesson adequately. That means activities are neither too long or too short; and that teachers anticipate how well the various techniques will “flow” together.

Another important aspect is to gauge difficulty. (BROWN, 2000) explains that if teachers follow the *i*+1 principle of providing material that is just a little above, but not too far above, student's ability, the linguistic difficulty should be optimal. Teachers should also account for individual differences in their class. Although for the most part, a lesson plan will aim at the majority of students in class who compose the "average" ability range, teachers should also take into account the variation of ability in their students, especially those well above or well below the classroom norm. Another crucial aspect is to balance student and teacher talk. It is important to provide students a chance to talk, to produce language, and even to initiate their own topics and ideas.

Finally, a good lesson plan is also flexible. As explained by (JENSEN, 2001), "lesson plans are not meant to be tools that bind teachers to some preordained plan". In their daily practice, teachers inevitably deal with unplanned and unexpected events in class. In these circumstances, teachers may need to assess the situation quickly, make midstream changes in their plan, and allow the lesson to move on. Even failure can be a valuable lesson for teachers.

Lessons are, thus, live events. It is important to plan lessons that account for student's interaction needs when learning a language. (BROWN, 2000) defines interaction as the collaborative exchange of thoughts, feelings, or ideas between two or more people, resulting in a reciprocal effect on each other. He explains that theories of communicative competence emphasize the importance of interaction as human beings use language in various contexts to "negotiate" meaning, or simply stated, to get an idea out of one person's head and into the head of another person and vice versa. Besides appropriate questioning strategies, the author highlights the role of group work to promote interaction among students. It is important to note that group work usually implies small group work that is, students in groups of perhaps six or fewer. Large groupings defeat one of the major purposes for doing group work, which is giving students more opportunities to speak. (BROWN, 2000) defines group-work as a generic term covering a multiplicity of techniques in which two or more students are assigned a task that involves collaboration and self-initiated language.

The main advantages of group work according to (BROWN, 2000) are:

1. Group work generates interactive language: in so-called traditional language classes, teacher talk is dominant. Group work helps to solve the problem of classes that are too large to offer many opportunities to speak. (BROWN, 2000) points out that by one estimate, if just half of class time were spent in group work,

one could increase individual practice time five-fold over whole-class traditional methodology. Closely related to sheer quantity of output made possible through group work is the variety and quality of interactive language. Small groups provide opportunities for student initiation, for face-to-face give and take, for practice in negotiation of meaning, for extended conversational exchanges, and for student adoption of roles that would otherwise be impossible;

2. Group work offers an embracing affective climate: this aspect refers to the security of a smaller group of students where the individual is not so starkly on public display, vulnerable to what the learner might perceive as criticism and rejection. Small group also helps increase student motivation;

3. Group work promotes responsibility and autonomy: whole class activity often gives students screen to hide behind. Group work, on the other hand, places responsibility for action and progress upon each of the members of the group somewhat equally. It is difficult to "hide" in a small group;

4. Group work is a step toward individualizing instruction: small groups can help students with varying abilities to accomplish separate goals. The teacher can recognize and capitalize individual differences (e.g: age, cultural heritage, field of study, cognitive style) by careful selection of small groups and by administering different tasks to different groups.

Nevertheless, some teachers are afraid of group work. Most popular concerns regarding group work are the following (BROWN, 2000):

1. The teacher is no longer in control of the class;

2. Students will use their native language;

3. Student's errors will be reinforced in small groups;

4. Teachers cannot monitor all groups at once;

5. Some learners prefer to work alone.

While the author acknowledges that some of these apprehensions are understandable, he explains that group work does not mean simply putting students into groups and having them do what they would otherwise do as a whole class. In his words: “(...) the limitations or drawbacks to group work are all surmountable obstacles when group work is used appropriately - that is, for objectives that clearly lend themselves to group work”. Selecting appropriate group techniques is, thus, a key aspect in promoting effective group work learning opportunities. (BROWN, 2000) clarifies the distinctions between pair work and group work. Pair work is more appropriate than group work for tasks that are: (1) short, (2) linguistically simple, and (3) quite controlled in terms of structure.

The activities below are appropriate pair activities that are not recommended for groups of more than two:

1. Practicing dialogues with a partner;
2. Simple question and answer exercises;
3. Performing certain meaningful substitution "drills";
4. Quick (one minute or less) brainstorming activities;
5. Checking written work with each other;
6. Preparation for merging with a larger group;
7. Any brief activity for which the logistics of assigning groups, moving furniture, and getting students into the group is too distracting.

The author explains that pair work enables teachers to engage students in interactive (or quasi- interactive) communication for a short period of time with a minimum of logistical problems. Nevertheless, the role of pair work should not be misunderstood. It is not to be used exclusively for the above type of activities. It is also appropriate for many group work tasks. The author argues that the first step in promoting successful group work is to select an appropriate task. In other words, choose something that lends itself to the group process. He argues that lectures, drills, dictations, certain listening tasks, silent reading, and a host of other activities are obviously not suitable for small-group work. There are, though, a myriad of activities appropriate for group work, such as: games, role plays and simulations, drama, projects, interview, brainstorm, information gap, opinion exchange, jigsaw as well as problem solving and decision making.

Another important aspect that needs attention is assessment. Researchers have argued about the importance of authentic forms of assessment when teachers directly examine student performance on worthy intellectual tests as opposed to traditional assessment that relies on indirect or proxy ‘items’- efficient, simplistic substitutes from which evaluators think valid inferences can be made about the student’s performance at those valued challenges (WIGGINS, 1990). The term authentic assessment is often used interchangeably with “performance assessment” and “alternative assessment” (YONG, 2018).

(KOH, 2017) argues that authentic assessment is an effective measure of intellectual achievement or ability because it requires students to demonstrate their deep understanding, higher-order thinking, and complex problem solving through the performance of exemplary tasks. Hence the author adds that authentic assessment can serve as a powerful tool for assessing students’ 21st-century competencies in the context of global educational reforms. Authentic assessment is aligned with the thoughts of John Dewey, a prominent philosopher of education, who underscored the importance of experience in education by arguing that learners cannot know something without directly experiencing it (KOH, 2017). (KOH, 2017) states that authentic tasks assess not only students’ authentic performance or work, but also their dispositions such as persistence in solving messy and complex problems, positive habits of mind, growth mindset, resilience and grit, and self-directed learning. The use of scoring rubrics is a key component of authentic assessment as it enables the provision of descriptive feedback, self- and peer assessment using criteria and standards as in the form of holistic or analytic rubrics (KOH, 2017).

According to (MORIA; REFNALDI; ZAIM, 2017), some of the characteristics of authentic assessment are: it (1) requires students to perform, create, produce or do something; (2) uses real world context or simulations; (3) is non-intrusive in that it extended the day to day classroom activity; (4) allows students to be assessed on what they usually do in class every day; (5) uses a task that represent meaningful instructional activities; (6) focuses on process as well as product; (7) taps into higher level thinking and problem solving skill; and (8) provides information about strengths and weakness of students. (MORIA; REFNALDI; ZAIM, 2017) claim that authentic assessment can be one solution for assessing learning activities. Their work demonstrates that authentic assessment is adequate to encourage students’ interest and critical thinking, especially in writing. The authors argue that this process allows teachers to evaluate students in writing intensely.

In addition, students were excited in finishing any kind of writing assignments that had been developed. Authentic assessment can be used to better facilitate teaching and learning of English, especially for writing.

In our current world, media is also another relevant way to engage students and promote interaction. (BRINTON, 2001) proposes a framework for structuring media lessons. She presents a framework that intends to put the application of media to language teaching into a unified perspective and to assist teachers in better structuring media lessons. It is important to highlight that she considers as language teaching media all aids, mechanical and non-mechanical, glossy and non-glossy, commercially available and teacher-made. According to her, an ordinary class can be divided into five stages as presented in the following list.

1. The information and motivation stage: when the topic and relevant background information are presented;

2. The input stage: when the teacher ensures comprehension of the item or items presented;

3. The focus stage: when the students practice the tasks and are provided with guided opportunities to manipulate items until they feel comfortable and confident;

4. The transfer stage: a more communicatively oriented stage, in which students are given opportunities to offer personal comments or share experiences relating to the given context;

5. Optional feedback stage: when audio or video recordings of students are used to guide the assessment. The author cites as examples a student speech, an interview, a class discussion, a role play, a group problem solving activity.

According to (BRINTON, 2001), teachers should be encouraged to use media materials when variety is called for, when they help teachers reinforce the points they wish to make or serve as contextualization, when they expedite teaching task and serve as a source of input, and/or when they help to individualize instruction and appeal to a variety of cognitive styles in the classroom. Moreover, teachers should use media to involve students more integrally in the learning process and to facilitate language learning by making it a more authentic, meaningful process.

3.2 HOW LANGUAGE LEARNING CAN BENEFIT FROM AR AND STORYTELLING

Many techniques can be used in a classroom to integrate the four skills and, moreover, to foster students' protagonism in the learning process. One of these techniques that can be used to learn a language interactively are stories, since they are powerful means of language teaching (PECK, 2001). Stories are widely used to help children explore the language. The use of storytelling, dramatic activities and role plays are good for learning because they can engage and promote interaction among students. Storytelling is defined as a form of communication in which people share understandings and experiences as well as a traditional way to transfer knowledge, values and beliefs (YILMAZ; GOKTAS, 2017). It is, thus, unique in the sense that it delivers information while keeping receivers interested and impressed (PARK; JUNG; YOU, 2015). Although children are usually more willing to take part in drama activities than adults, activities like role plays can be particularly suitable for practicing the sociocultural variations in speech acts such as complimenting, complaining and the like (LAZARATON, 2001). As happens with storytelling, they can be performed from prepared scripts, created from a set of prompts and expressions, or written using and consolidating knowledge gained from instruction and discussion. Thus, these techniques can be used in classrooms from an integrative perspective combining the four language skills.

Teachers can no longer afford to ignore the presence of new media, such as the internet, television, music, or movies (BAKER, 2010). Studies have shown that technology-supported storytelling activities have been used as an effective method to improve student's engagement and entertainment during storytelling activities (CASSELL; RYOKAI, 2001; FRIDIN, 2014). Interactive storytelling has, thus, emerged through the combination of personal narratives with new technologies to tell stories. Interactive storytelling brings more alternatives in developing stories, enhances storyteller's imaginations and creativity (STAPLETON; HUGHES; MOSHELL, 2002). It also provides educators with a range of options that facilitate learning using interactive tools (ALSUMAIT; AL-MUSAWI, 2013). Additionally, interactive stories enable the reader/player to participate and affect the plot of the story, offering new genres of narrations, more engaging and adaptive (MARKOUZIS; FESSAKIS, 2015). (STAPLETON; HUGHES; MOSHELL, 2002) argue that capturing the imagination is an important step into creating truly compelling stories. The National Storytelling Network (NSN) has identified five aspects of high-quality storytelling: its must be interactive, it must use words and language, it must use actions (such as vocalizations and physical movements), it must present a narrative, and it must encourage the active imagination of the listener (ALSUMAIT; AL-MUSAWI, 2013).

Mixed Reality allows for the merging of our imagination with physical self and virtual presence (STAPLETON; HUGHES; MOSHELL, 2002). Moreover, the emergence of immersive technologies has brought new possibilities and challenges for storytelling in these environments since the interaction with the environment itself becomes a significant part of the narrative and users become more active in the stories (BUCHER, 2018).

AR is an interactive technology that has an interesting potential to support both language learning and storytelling processes. (BILLINGHURST; DUENSER, 2012) explain that unlike other computer interfaces that draw users away from the real world and onto the screen, AR enhances the real world experience. It offers three inherent advantages: real world annotation, contextual visualization and visual-haptic visualizations (SANTOS et al., 2014). (GODWIN-JONES, 2016) reinforces that its potentials can also be suited for languages "through its ability to use add-on digital assets to explore and expand scenes and locales from the real world, there is an obvious connection between AR and current theories of second language acquisition which emphasize localized, contextual learning and meaningful connections to the real world".

In language education, AR has been used to get students to create campus tours (LAKARNCHUA; PEGRUM, 2015), to engage them in location-based games (HOLDEN; SYKES, 2011) and to engage in tangible AR experiences to learn both native and foreign languages (SILVA; ROBERTO; TEICHRIEB, 2013; SILVA; ROBERTO; TEICHRIEB, 2015).

One of the main features of AR for language teaching is that it comprises a set of mobile technologies affordances that have long been acknowledged for learning (BONNER; REINDERS, 2018). These features include portability, and social interactivity facilitation, context sensitivity, connectivity and individuality (i.e: devices and mobile environments can be adapted to suit individual's needs, interests and so on, which can facilitate personalised learning). Second, AR supports "embodied or extended cognition, both of which emphasize the inextricable connection between mind and environment and cognitive activity as grounded in bodily states and activities" (LAKARNCHUA; PEGRUM, 2015). Third, AR can encourage students to participate actively in (co-) constructing their learning environment, by posting comments or questions relating to a particular location for example (BONNER; REINDERS, 2018). Thus, these examples demonstrate that AR's potential can be leveraged to promote student's language development in an integrative and interactive way.

As regards to storytelling, AR can make it more interactive and immersive by providing a multisensory experience, which can incite student's imagination, narrative skills and creativity (YILMAZ; GOKTAS, 2017). Learners can take part in the story, which might help them gain a deeper understanding of the narrative. AR can also be used to support many characteristics that make up for a high-quality storytelling, such as: promoting interactivity, the use of actions (such as vocalizations and physical movements), and the use of active imagination (ALSUMAIT; AL-MUSAWI, 2013). There are several AR storytelling applications already available. Some of these applications depend on a physical book to be experienced[1]. Others have beautifully designed stories for users to experience, but they are not allowed to create their own [2]. Other apps allow users to create their own stories, nevertheless these apps are mostly thought for entertainment and do not necessarily take into account pedagogic aspects, such as the need for content management and moderation[3].

3.3 TEACHING EXPERIENCES WITH TECHNOLOGY

In the following subsections, we will discuss important aspects related to teaching experiences with technology, namely: innovation in education and factors that influence teachers' adoption of technology.

3.3.1 Innovation in Education

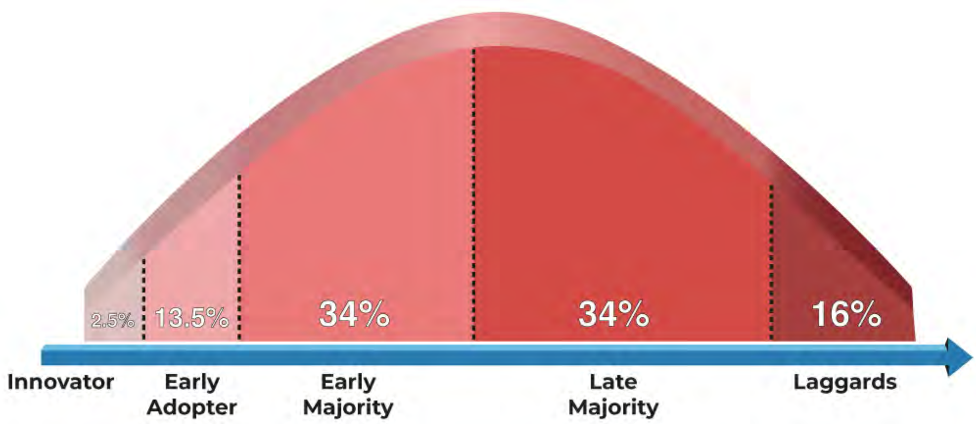
Innovation is usually defined as the introduction of something new that supports a change in social practice (KIRKLAND; SUTCH, 2009). Studies have shown that the perception of an innovation is crucial to its success. One of the most popular models is Roger's diffusion of innovation theory (ROGERS, 2003), which is broadly used in the area of technology diffusion and adoption. The author defines adoption as a decision to fully use an innovation as the best course of action available, whereas, rejection is a decision

[1] Available at <https://rb.gy/mckvnt> and <https://rb.gy/nyqfol>.
[2] Available at <https://rb.gy/lrptki> and <https://rb.gy/es8l7v>.
[3] Available at <https://rb.gy/zoexqm> and <https://rb.gy/e8qh4t>.

of not to adopt an innovation. He defines diffusion as the process in which an innovation is communicated through certain channels over time among the members of a social system (ROGERS, 2003). Through this theory, we can understand the importance of the social system in the adoption and diffusion of innovation. Higher levels of innovation can not be achieved in isolation, but, as a social process that involves different stakeholders.

(ROGERS, 2003) proposes a standard for adopter categorization. The criterion used for adopter categorization is inovativeness, i.e., the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a social system. The author demonstrates that adopter distributions closely approach normality. Thus, he divides the adopters into five categories, namely: 2.5% innovators; 13.5% early adopters; 34% early majority; 34% late majority; and 16% laggards as displayed in Figure 9.

Figure 9 – Adopter categorization on the basis of innovativeness.



Font: Adapted from (ROGERS, 2003).

It is important to point out that although the division of groups is not symmetrical, it obeys characteristics that the group participants share with each other. He adds that these 5 categories are ideal types, i.e., they are conceptualizations based on observations of reality and designed to allow comparisons. He emphasizes that ideal types are not simply an average of observations about a category and that exceptions can be found. In the list below we provide some dominant characteristics and values for each adopting category followed by more detailed generalizations.

1. Innovators: adventure is almost an obsession for innovators. They are eager to try out new ideas. Their cycle of relationships is, in general, cosmopolitan. To be an innovator there are several prerequisites, which include: control of

substantial financial resources to absorb the possible loss due to an unprofitable innovation and the ability to understand and apply complex technical knowledge. The innovator must be able to deal with the high degree of uncertainty about an innovation at the time of adopting it. Their salient value is boldness. They want danger, boldness and risk. They must be open to accept possible setbacks of ideas that prove unsuccessful. Although not necessarily respected by their social system, they play an important role in the diffusion process: launching new ideas into the social system;

2. Early adopters: these are a more integrated part of the local social system compared to innovators. They work more locally. This category has the highest degree of opinion leadership in most social systems. Potential adopters look to early adopters for advice and information about innovation, they are also often sought out by change agents to accelerate the diffusion process. In general, they represent the discreet and effective use of new ideas. Thus, they feel inclined to make sensible choices. Their role is to reduce uncertainties regarding the adoption of new ideas and share their innovation experiences with close peers in their interpersonal network;

3. Early majority: interact frequently with their peers, but rarely play leadership roles. They are an important link to the diffusion process. Provide interconnection between system networks. They can deliberate for a while before adopting a new idea. Their decision period is relatively long compared to the previous 2 groups;

4. Late majority: they adopt new ideas after the average members of the social system. For this group, adoption may be out of economic necessity or in response to growing pressures from their networks. Innovations are greeted cautiously and they tend not to adopt until many others have done so. The weight of the system's rules must favor innovation before this category is convinced to adopt it. Almost all uncertainty must be removed before they decide to adopt. Despite being convinced of the usefulness of the innovation, peer pressure is necessary for this group to adopt it;

5. Laggards: they have practically no opinion leadership; many find themselves isolated on social networks. Their decisions are usually guided by what has been

done in the past and they primarily interact with people of traditional values. They tend to be suspicious of innovations and change agents. Their orientation to change slows down the adoption process, and often when they do adopt it, it has already been surpassed. Their precarious economic position may be one of the explanations for their extremely cautious stance. Although there is discussion about the laggard nomenclature, the author emphasizes that it would be a mistake to assume that individuals in this category are at fault for adopting an innovation relatively late. He explains that this can be an illustration of individual accountability when the system could explain this reality more accurately.

The Future Classroom Lab has proposed a maturity model in order to understand how mature and advanced is the level of innovation in the schools (Future Lab, 2014). This model also explores the importance of the social system in innovation adoption. The Future Classroom Lab proposes a reference guide for the maturity model, in which they acknowledge five levels of use. They have detailed explanation on how they are expressed concerning five dimensions: (1) teachers' and (2) learners' roles, (3) learning objectives and assessment, (4) school capacity to support innovation in the classroom as well as (5) tools and resources. These five levels of maturity are explained below:

1. **Exchange:** this level corresponds to isolation of teaching and learning, with technology used as a substitute for traditional methods:
   a) *Teachers' roles:* teachers choose the format, approach and digital resources for learners to use;
   b) *Learners' roles:* learners use digital learning materials occasionally (usually alone) provided or presented by the teacher;
   c) *Learning assessment:* teachers set the learning goals and carry out the assessment using traditional approaches;
   d) *School support:* little or no training and support for teachers regarding digital learning;
   e) *Tools and resources:* a narrow range of technology is effectively used in less than 5% of lessons.
2. **Enrich:** here, the learner becomes the user of digital technology, which improves learning and teaching practices:

a) *Teachers' roles:* teachers use technology as a way to enrich their current approaches;

b) *Learners' roles:* they use digital resources a few times and are able to use it both individually and in collaboration in a pre-defined task. They are able to communicate clearly using technology to present ideas;

c) *Learning assessment:* assessment encourages active learning and students have the opportunity to use feedback and assessment evidence to improve performance. Technology is used for assessment purposes;

d) *School support:* Schools encourage technology use, but, school leaders are commonly reactive to change;

e) *Tools and resources:* technology is effectively used in 5-25% of lessons. It sometimes replaces more traditional approaches for learning and teaching.

3. **Enhance:** in the third level, the learner is able to learn more independently and be creative, supported by technology providing new ways to learn through collaboration:

   a) *Teachers' roles:* teachers are comfortable with re-organising classroom layout as part of technology use and help students incorporate technologies into their projects;

   b) *Learners' roles:* learners are able to choose the technology application and use it to work independently and engaged in collaborative problem-solving or research activities;

   c) *Learning assessment:* learners are involved in deciding learning objectives, which include higher order thinking skills. Progress through the task is tracked;

   d) *School support:* the school encourages teachers to experiment with new approaches to learning and teaching and they receive appropriate training and pedagogical support;

   e) *Tools and resources:* technology is effectively used in 25-50% of lessons for collaboration, communication, and real-world problem solving.

4. **Extend:** in this level, connected technology and progress data extends learning and allows learners greater control on how, what and where they learn:

a) *Teachers' roles:* teachers design activities using technology to empower students to manage their own learning;

b) *Learners' roles:* learners are able to manage their own learning using technology. They make decisions on what, how and when they learn;

c) *Learning assessment:* there is a range of assessment approaches including self- and peer assessment. Assessment goes beyond traditional subject boundaries to include inter-disciplinary skills;

d) *School support:* the school has a clear vision and strategy for digital learning that addresses key barriers to innovation;

e) *Tools and resources:* teachers and students identify and use new technologies, which are used effectively in 50-75% of lessons.

5. **Empower:** this level concerns the capacity to extend learning and teaching through ongoing whole school innovation, with teachers and learners empowered to adapt and adopt new approaches and tools:

a) *Teachers' roles:* teachers spend most time designing collaborative problem-solving or research and independent learning activities;

b) *Learners' roles:* are connected to others and are able to use a range of technology. They are able to decide what, where, how and when to learn;

c) *Learning assessment:* learners negotiate the learning objectives, which are continuously reviewed and revised. Students receive feedback quickly, usually instantaneously;

d) *School support:* leaders encourage a whole school approach to supporting innovation in learning and teaching;

e) *Tools and resources:* technology is effectively used in more than 75% of lessons. Teachers use a wide range of technologies to support change in the learning process.

According to this model, from the third level onward, the learner can work more independently and creatively supported by technology. The future classroom model is a self-review tool that enables schools to reflect on their teaching and learning and their capacity for technology-supported innovation. As a school moves from one level to the next, its capacity to be innovative in technology-supported learning and teaching increases. It is important to highlight, though, that good practices and effective learning can happen at all levels, and that level five does not mean that further innovation is not possible.

Another interesting point is that this framework is aligned with active methodologies, which emphasize the protagonist role of students, their direct involvement, participation and reflection in all stages of their learning process in a flexible, interconnected and hybrid way. They can achieve this by experimenting, designing and creating with teacher's guidance and support (BACICH; MORAN, 2018). Studies have shown that when the teacher speaks less, guides more and students are able to participate more actively, learning becomes more meaningful (DOLAN; COLLINS, 2015).

We can observe in the maturity model that the higher the mature level of technology use, the more active is student's involvement in the learning process. This indicates that by using technology in more mature ways we might be able to support more meaningful and deep learning.

3.3.2 Factors that Influence Teachers' Adoption of Technology

Studies have shown that there are many factors impacting teachers' technology adoption in the classroom. Some of these aspects are: (1) teachers' confidence and computer self-efficacy; (2) their educational beliefs and attitudes concerning technology; (3) their personal skills and experience with technology; and finally (4) the circumstances at their workplace, such as access to up-to-date infrastructure and a supportive work culture (VERMETTE et al., 2019).

These aspects play an important role whenever teachers select and decide to use technology. Level of experience in using technology is demonstrated to influence an individual's attitude to computers and, thus, their computer self-efficacy. Thus, a strong sense of computer self-efficacy of school teachers can impact the extent and the way technology can be used in everyday practice, significantly changing both teachers' and students' roles (PARASKEVA; BOUTA; PAPAGIANNI, 2008). Self-efficacy can be developed through positive experiences with technology (ERTMER; OTTENBREIT-LEFTWICH, 2010). This helps to illustrate the importance of teachers' personal skills and experience with technology. However, (ERTMER; OTTENBREIT-LEFTWICH, 2010) explain that these experiences do not have to be personally experienced by the teacher. Vicarious experiences is also known to have the potential to develop teacher self-efficacy.

Other important aspects to be considered are teachers' educational beliefs and attitudes concerning technology. There is a correlation between teachers' beliefs and their subsequent classroom activities (ERTMER; OTTENBREIT-LEFTWICH, 2010). Also, evidence shows that teachers with more traditional beliefs will implement more traditional or "low-level" technology uses, whereas teachers with more constructivist beliefs will implement more student-centered or "high-level" technology uses.

(VERMETTE et al., 2019) emphasize the importance of teachers' social fabric in personalizing digital classroom ecosystems. In this study, authors showed that even the tech enthusiasts teachers face a myriad of barriers when trying to integrate new digital classroom tools, such as keeping up with new requirements for learning and troubleshooting hardware and software. They point out that although informal social learning is helpful, it is often not enough. They explain that it is important to have institutional support for integration of digital classroom tools. The authors explain that if the teacher is the help-provider for colleagues, he or she can feel overwhelmed with frequent troubleshooting requests. This situation can take precious teaching time from them. In other words, these results reinforce the importance of institutional support for integration of digital classroom tools.

On that note, (BACICH; MORAN, 2018) explain that the digital convergence requires very profound changes that affect schools in all its dimensions, namely: infrastructure, pedagogical aspects, teacher training and mobility. The authors add that teacher's role nowadays is much broader and complex. Teachers are not just focused on transmitting specific information, but they are mainly designers of personalized and group learning scripts and advisors/mentors of student's professional and life projects. Therefore, all these aspects must be taken into account when we consider the addition of a new technology into the school environment in order for it to be successful.

4 AUTHORING TOOLS

It is widely known that there are a variety of AR applications aimed at education (BACCA et al., 2014; RADU, 2014; GARZÓN; PAVÓN; BALDIRIS, 2019). However, in order for these tools to be widespread in this field it is important to have suitable authoring tools as opposed to what happens nowadays in which the process of authoring still takes place mostly at the source code level (SCHMALSTIEG; HÖLLERER, 2015). Studies have shown that both time and technical expertise are two of the reasons that hinder the far-reaching use of authoring tools (ROBERTO et al., 2016a).

(HAMPSHIRE et al., 2006) distinguish between AR authoring for programmers and for non-programmers. The former category usually refers to code libraries, such as the ARToolKit[1]. Nevertheless, they require programming knowledge from the user. On the other hand, the later refers to tools in which abstraction is added and low level programming ability is removed or hidden. In this work, we will explore AR authoring tools for non-programmers. (HAMPSHIRE et al., 2006) explain that non-programmer tools are content-driven and usually include graphical user interfaces for building applications without writing any lines of code. Thus, these tools can also be named content design tools. From now on, we will refer to authoring tools for non-programmers as content design tools.

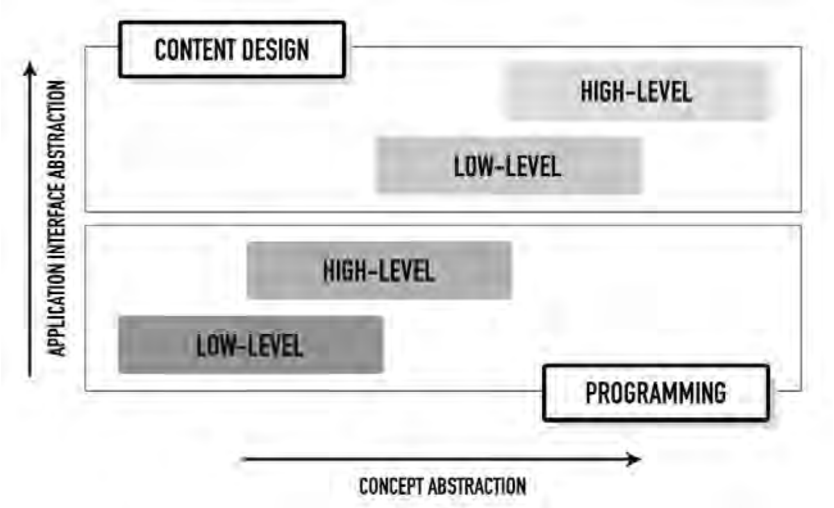
Content design tools can be categorized into two subsets: low-level and high-level. (HAMPSHIRE et al., 2006) explain that low-level content design tools require scripting skills, such as AR Scratch (RADU; MACINTYRE, 2009). On the other hand, high-level ones use visual authoring techniques. All of these authoring approaches are built upon each other as illustrated in Figure 10.

(ROBERTO et al., 2016a) explain that there are two types of AR paradigms to create AR solutions. The stand-alone and the AR plug-in approaches as displayed in Figure 11. The former paradigm of authoring tools enable building entire AR experiences. These tools integrate components such as sensor interfaces, tracking and rendering engines. The latter provides AR functionalities for non-AR authoring environments. The designer interacts directly with the hosting software to create AR experiences.

In the stand-alone AR authoring tools, as explained by (ROBERTO et al., 2016a), all

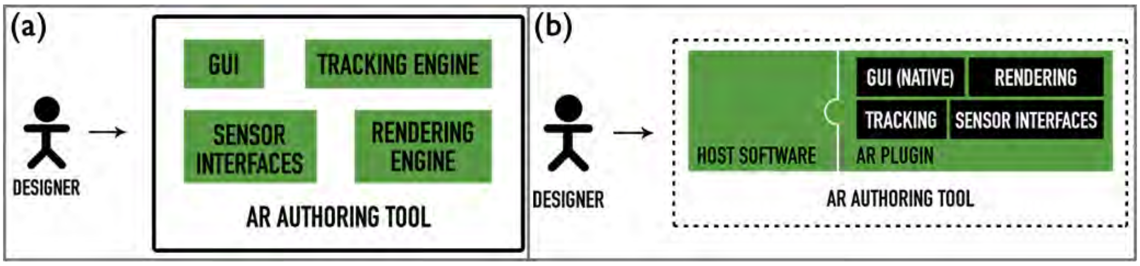
[1] Available at <https://rb.gy/zbzb5p>.

Figure 10 – Schematic view of AR authoring Tools.



Font: (ROBERTO et al., 2016a).

Figure 11 – Illustration of Stand-alone and Plug-in paradigm.



Font: (ROBERTO et al., 2016a).

the necessary components for the development of AR experiences are embedded in the software. These components may include a graphical user interface, a series of importers, sensor interfaces, tracking and rendering engines, among others.

In turn, AR plug-in approaches work in a similar way as traditional digital plug-ins. In other words, they are third-party software components installed on existing multimedia authoring and execution tools in order to enable additional features to these applications. (ROBERTO et al., 2016a) explain that AR plug-ins provide AR capabilities to software that natively does not support it, such as tracking techniques, access to physical sensors, among others. This can be beneficial since it provides AR capabilities to a tool that the user is already familiar with. However, it may be harder to implement depending on the tool.

Regarding the plug-in authoring paradigm, (SCHMALSTIEG; HÖLLERER, 2015) state that the maturity of existing modeling and animation software is a significant advantage that should not be overlooked. It can be leveraged by adding AR, as previously mentioned, as a new target platform supported by content creation. An example of AR plug-in platform is DART (MACINTYRE et al., 2004), which extends Macromedia Director, a widely used environment for multimedia content creation in the early 2000s. Thus, DART allows designers who are already familiar with Macromedia Director to create a variety of AR applications.

In (HARINGER; REGENBRECHT, 2002), it is presented the PowerSpace, a system that enables the generation of AR content through the use of a well-known slide editor (Microsoft Power Point). On the other hand, (LEDERMANN; SCHMALSTIEG, 2005) present the Augmented Reality Presentation and Interaction Language (APRIL). This system is useful for creating complex non-linear AR experiences on top of the Studierstube system, a popular AR tool in the late 2000s. It allows for building innovative user interfaces that use collaborative augmented reality (SCHMALSTIEG et al., 2002).

Some authoring tools may produce AR experiences for desktop. However, (SCHMALSTIEG; HÖLLERER, 2015) point out that although the desktop approach can leverage established desktop interaction techniques, it does not take advantage of the full potential of the immersive nature of AR. As examples of tools built using the desktop interaction are the PowerSpace (HARINGER; REGENBRECHT, 2002) and the Augmented Reality Presentation and Interaction Language (APRIL) (LEDERMANN; SCHMALSTIEG, 2005).

(SCHMALSTIEG; HÖLLERER, 2015) also point out the existence of authoring by performance. In this context, the AR interface is directly used to describe the content. An example of this is the work of (LEE et al., 2004), which describes a tangible AR approach focused on creating interactions between actors while immersed in the AR experience.

(SCHMALSTIEG; HÖLLERER, 2015) explain that web technology has emerged as a leading vehicle for both the production and consumption of multimedia information. Due to this dominance, web content is considered increasingly attractive to developers of AR browsers and tools, as a lot of the work done on conventional web technologies might be leveraged and repurposed for AR.

Regarding that matter, the authors mention that the most recent web standard HTML5 and its associated family of technologies are evolving toward a versatile application platform that addresses the fundamental needs for AR. They also highlight that since a large number of professionals have already been trained in web development, the adoption of web formats for AR may allow for drawing upon these existing skills in AR development and content provision.

Moreover, one important feature of the web is that anybody can publish content without having to go through a central authority beforehand. In the words of (SCHMALSTIEG; HÖLLERER, 2015), it "decouples producers and consumers of multimedia information". In the web, users have access to a variety of information channels. This channel idea is important for scalable AR browsing. Users could subscribe to a number of AR channels providing placemarks and other AR content. This idea of web channels being used for AR was introduced by (MACINTYRE et al., 2011) with their Argon Browser. This browser builds on a standard web browser engine (WebKit) to deliver an AR environment that enables multiple channels to be viewed simultaneously.

It is also important to point out the elements of authoring (SCHMALSTIEG; HÖLLERER, 2015). According to these authors, there are two main dimensions along which an application is organized: the temporal organization and the spatial one. The first determines the visibility and behavior of objects of the application over time while the latter settles the location and size of objects in relation to the viewer.

To promote widespread use of a new medium such as AR, authoring tools need to be designed such that they account for the unique challenges and affordances of AR medium (SCHMALSTIEG; HÖLLERER, 2015). This research specifies that AR authoring tools must meet the following requirements:

1. **Real world interfaces:** this refers to the need of addressing different possibilities of relating application content to the real world;

2. **Hardware abstraction:** this refers to the need for a strategy for hardware abstraction and interaction concept that can be transparently applied to a wide range of input devices;

3. **Authoring workflow:** professional tools used by content creators and domain experts should be supported in the AR authoring process, thus, removing the need to reimplement successful solutions in these areas. The runtime engine must allow users to control the spatial and temporal aspects of content creation. Finally, to support a collaborative workflow and allow future reuse, authors point out that it is highly desirable to modularize applications.

As shown, many advancements have been made when it comes to AR authoring tools, however, for these tools to be effectively used in the classrooms, it is important to have content based authoring tools or AR authoring tools for non-programmers that require no programming skills from teachers and students. The reality is that the majority of teachers are not able to program. However, that does not mean they can not take advantage of the enormous potential AR has to offer for learning. In order to use AR effectively, they need to connect this technology with their learning goals, which require some degree of authoring or at least customization. This is closely related to the need for more personalization in schools. (BACICH; NETO; TREVISANI, 2015) explain that to personalize means that activities must consider the learners, their needs, difficulties, and evolution, in other words, the learners must be in the center of the process. They argue that personalization happens in a variety of school spaces, including the classroom. Nevertheless, they highlight that it is not enough to include technology in the classrooms without rethinking the roles of both teachers and students. Thus, in order to personalize learning, teachers must review their lesson plans in order to provide opportunities for students to effectively build their knowledge. For the student, the benefits of personalization are, above all, increased motivation - which replaces the frustration of not learning and not keeping pace, often dictated by the teacher - as well as increased learning, in the sense that the student has the opportunity to learn individually, with the group, with the use of technologies and with the teacher (BACICH; NETO; TREVISANI, 2015).

AR could be created by utilizing and connecting various innovative technologies, such as: mobile devices, wearable computers, and immersion technologies. Nevertheless, like many innovations, the educational values of AR are not solely based on the use of technologies, but closely related to how AR is designed, implemented, and integrated into formal and informal learning environments (WU et al., 2013). Content design tools might provide flexible alternatives for AR content creation and, thus, benefit better integration of this technology into the curriculum.

As (DONALLY, 2018) points out, creating content also has advantages for the students and gives the flexibility to adapt to specific needs rather than waiting on a tool to be created. She explains that one of the benefits of being a content creator is the pride and satisfaction that comes from having the vision to go beyond what others have done before. As discussed in Subection 3.3.1, students autonomy and creative use of technological resources are correlated to more mature and meaningful uses of technology.

4.1 AR AUTHORING TOOLS FOR EDUCATION

As previously mentioned, the focus of this work is to investigate authoring tools in the context of education. Although there are several studies about AR authoring tools, few of them are about content-design tools developed aiming at the field of education (CUBILLO et al., 2014; CUBILLO et al., 2015; CHINTHAMMIT; THOMAS, 2012; RODRIGUES et al., 2015) and most of these tools lacked the possibility of reuse of the material created by the users.

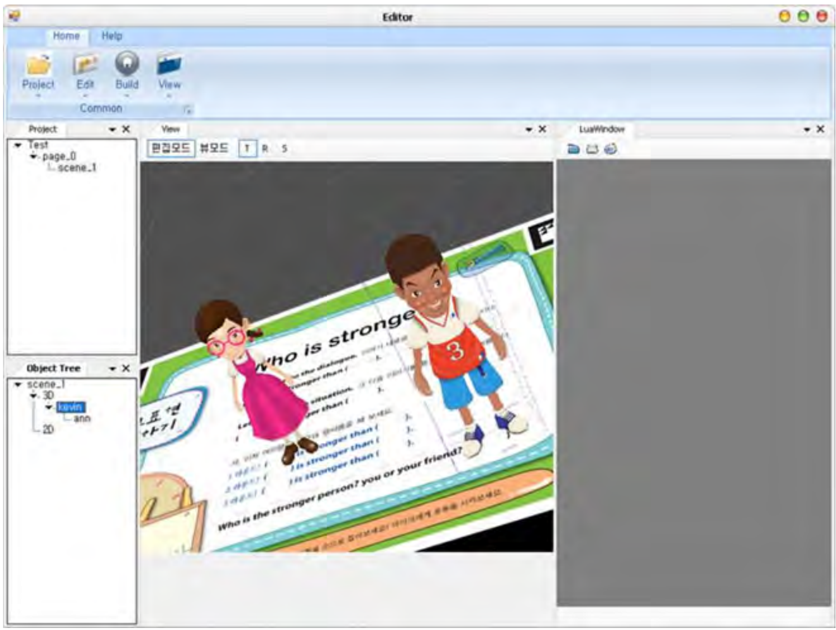
(JEE et al., 2011) present an AR authoring tool built on top of the existing commercial software Maya as presented in Figure 12. To confirm the educational benefits of the tool, the authors conducted a comparative study in elementary and middle schools in English and science lessons. The immersive e-learning system brought benefits to the class. Both teachers and students reported that they could concentrate more on the class and actively participate in the assignments.

Figure 12 – AR authoring tool built on Maya.

Font: (JEE et al., 2011).

(FARIAS; DANTAS; BURLAMAQUI, 2011) proposed an API (Application Programming Interface) called Educ-AR, based on the ARToolkit as illustrated in Figure 13. The authors carried out an experiment with twenty people to prove the efficiency of the tool. They reported that most students approved the use of AR techniques. They also noted that the exposure of the contents became more interesting and attractive.

Figure 13 – Educ-AR.



Font: (FARIAS; DANTAS; BURLAMAQUI, 2011).

In turn (LUCRECIA et al., 2013) described an AR authoring tool for creating educational activities, the AuthorAR. This tool was conceived as a free desktop application, capable of running in personal computers. The authors based their work on extensive literature review in the field through which they identified the lack of tools enabling the creation of the content.

(CUBILLO et al., 2014) presented an Augmented Reality Learning Environment (ARLE), which can be used both by teachers and students. They tested the tool with teachers and students from a vocational training center. The teachers assessed the system positively. They emphasized its speed, ease of adding new virtual resources and descriptions.

Another example of AR authoring tool for education is the WebAR (an web augmented reality-based authoring tool) proposed by (RODRIGUES et al., 2017). According to the authors, WebAR is an AR authoring tool that is able to generate easy-to-use AR content, which enables the tool to be flexible and, thus, eliminate the need for the AR specialist involvement. Also, their work shows that while AR content tools available enable the creation of AR application for different contexts, teachers do not reuse them. Hence, the tool developed has this feature added to it. Although authors do not report tests with the users at this point, the reuse of materials is an interesting feature since teachers usually do not have much time to prepare a new application for every classroom they teach.

(DO; LEE, 2009) bring another interesting example of AR authoring tools for non-programmers. This paper proposed the ARBookCreator, an AR authoring tool to create 3D e-books without the need to know programming, AR or to create physical markers to create the new book. The ARBookCreator allows users to compose a 3D e-book by combining both the traditional input method (mouse/keyboard) and the tangible input method (markers). They can create content in a similar way as they would do in the Microsoft Power Point.

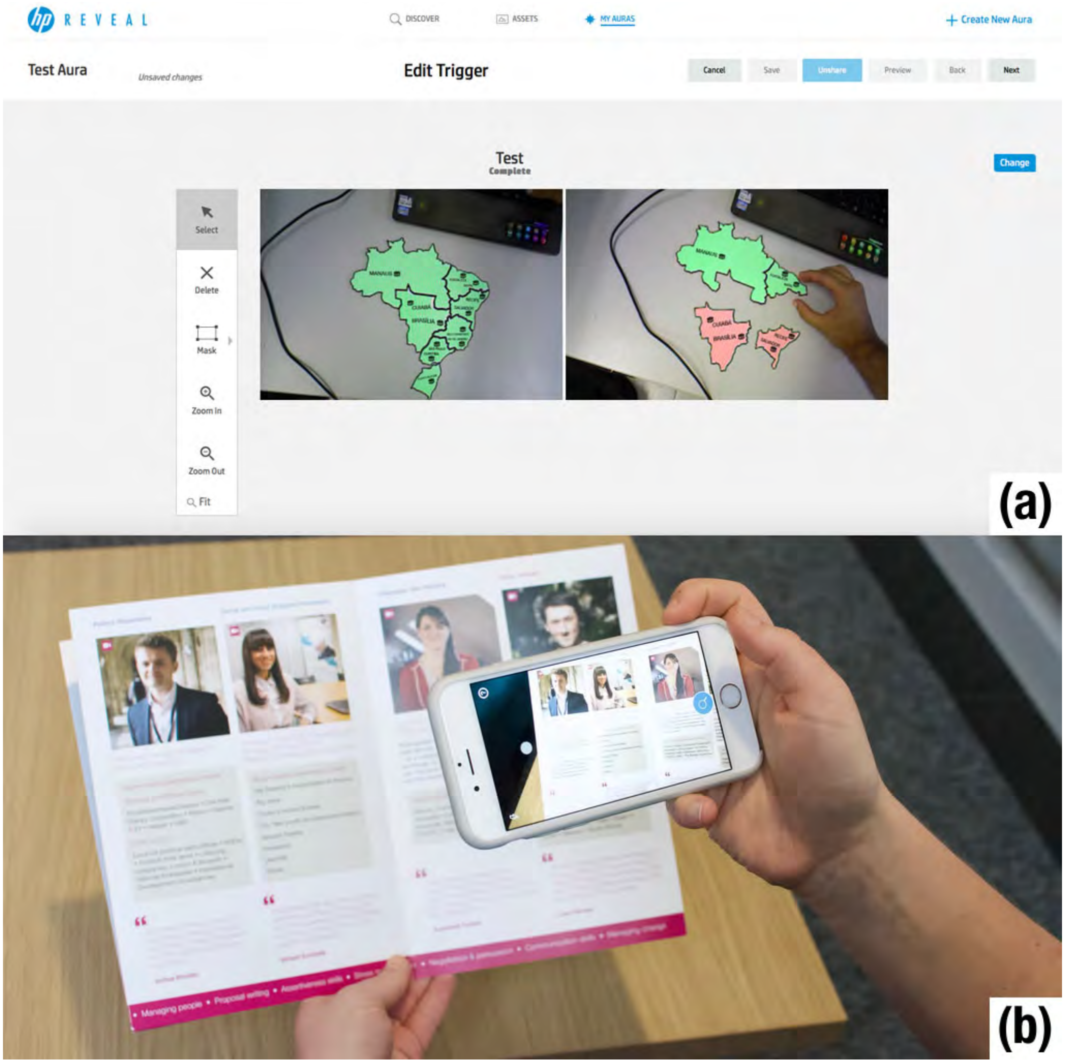
The tools described in (RODRIGUES et al., 2015) and the others presented so far are academic ones. This usually means they lack the infrastructure required to be known and used outside the university helm, such as marketing, proper distribution platform, user support, and maintenance. However, there are other commercial tools that do not require programming knowledge. These tools are not particularly designed for education, but some of them have been used by teachers with relatively small effort. One popular application that explores AR creation is HP Reveal[2], formerly known as Aurasma Studio, which enables users to create digital content known as auras for printed materials as seen in Figures 14 (a) and (b).

Build AR, currently rebranded as Envisage[3], is another AR authoring tool that enables quickly building AR scenes as can be seen in Figure 15. This solution provides computer vision based tracking of both markers and arbitrary images, and allows users to add 3D models, images, text, video and sound to the AR scene. The content created is saved into a proprietary file format, and can be viewed using the Build AR viewer software, which is freely available for download. Similar to HP Reveal, this tool has not been designed specifically for education, but, it can be used by teachers without the need to program. The opportunity to create content without programming knowledge has enabled teachers to create content to aid learning as (MARTIN-GUTIERREZ; CONTERO, 2011) who present a technology for learning sketching, designation and rules of standard mechanical elements created using Build AR.

Also, the Layar Creator[4] is a web-based authoring tool that can deploy AR content on printed materials as illustrated in Figure 16. It allows users to associate virtual contents, such as buttons that have links to various services available on the mobile device to printed pages. The created content is published as a layer in the Layar mobile AR

[2] Since late 2020, HP Reveal is no longer available.
[3] Available at <https://rb.gy/uszwtv>.
[4] Available at <https://rb.gy/wqvaxk>.

Figure 14 – (a) Screenshot of HP Reveal authoring tool; (b) Example of application using HP Reveal.



Font: Since late 2020, HP Reveal is no longer available.

browser.

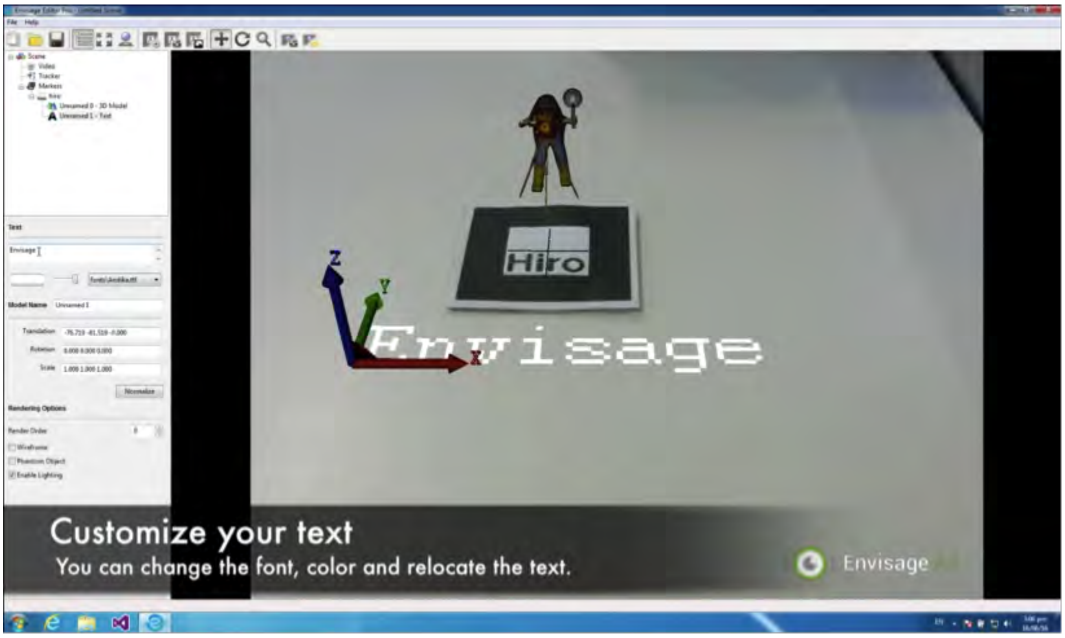
Another web-based authoring tool is the Wikitude Studio[5], which allows users to create mobile AR content and deploy it either onto the Wikitude AR browser app or even create a custom mobile app as displayed in Figure 17. It supports different types of media, such as 3D models and animations.

Zapworks Studio[6] is another tool that can be used to create AR experiences. It offers three different options for AR creation, namely: widgets, designer and studio. It allows users to create AR experiences that can be accessed through a zapcode.

Additionally, there is the Blippbuilder[7], which enables the creation of AR layers

5 Available at <https://rb.gy/apayxr>.
6 Available at <https://rb.gy/aa8j6g>.
7 Available at <https://rb.gy/li7zpq>.

Figure 15 – Screenshot of the Envisage authoring tool.



Font: <https://rb.gy/uszwtv>.

Figure 16 – Screenshot of the Layar Creator authoring tool.

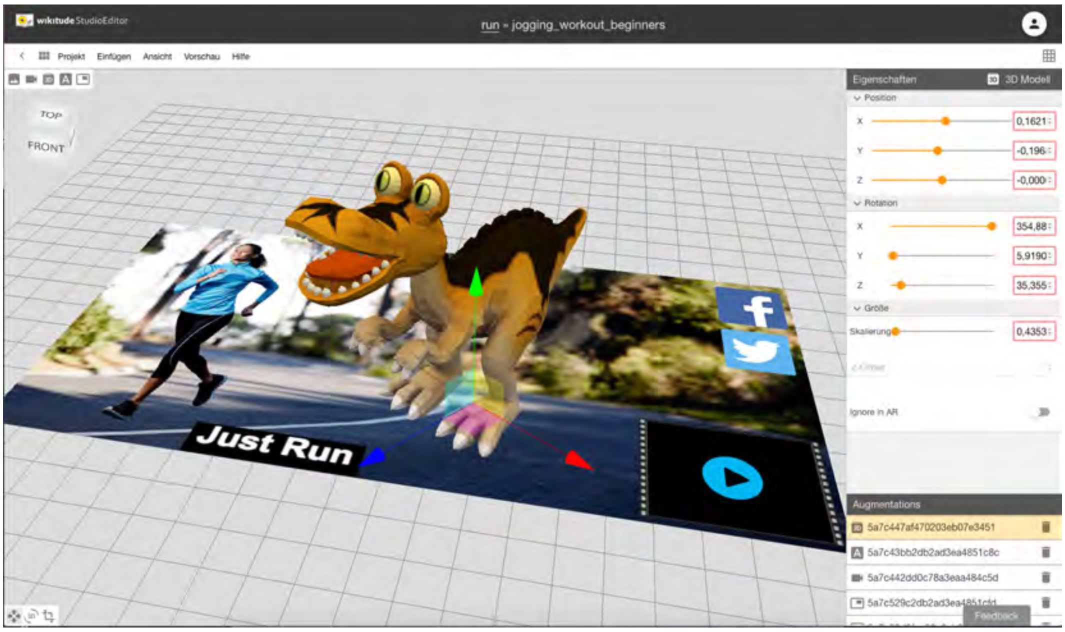
Font: <https://rb.gy/wqvaxk>.

associated to printed materials by both programmers and non-programmers as shown in Figure 18.

Another example is CoSpaces EDU[8], a web-based platform that enables users to use primitive shapes and pre-made assets to design an interactive AR overlay. They can

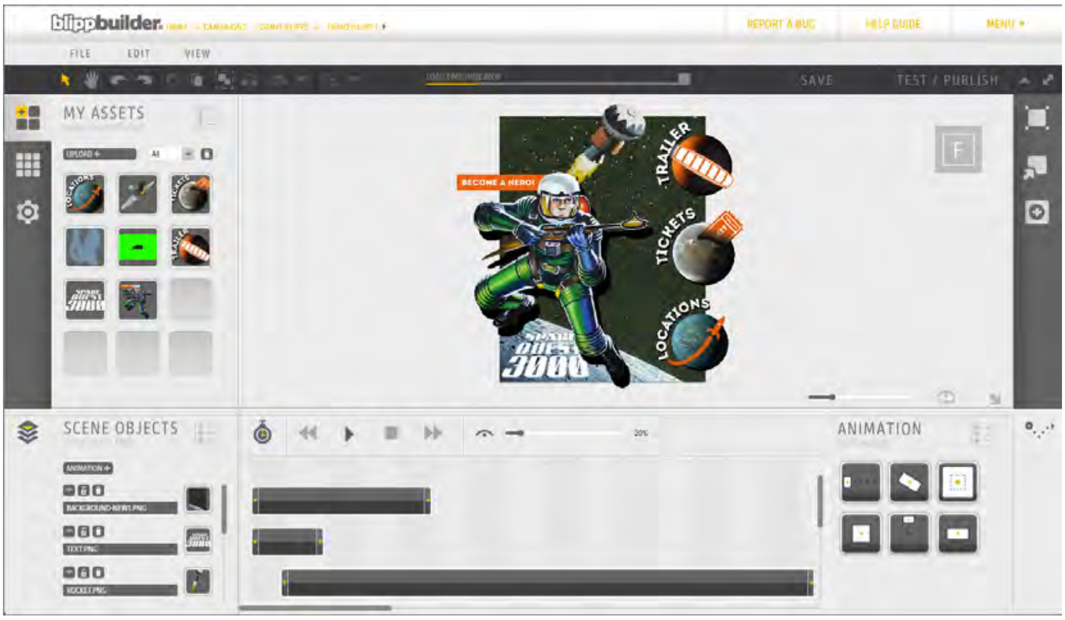
[8] Available at <https://rb.gy/qeyxen>.

Figure 17 – Screenshot of the Wikitude Studio authoring tool.



Font: <https://rb.gy/apayxr>.

Figure 18 – Screenshot of the Blippbuilder authoring tool.



Font: <https://rb.gy/li7zpq>.

code the objects to be interactive and animated by using blocks similar to the Scratch as can be seen in Figure 19. Unlike the other commercial tools found in this work, CoSpaces EDU was specifically designed for learning.

Another example of a tool that is designed with learning in mind is Metaverse, which is a platform for creating, sharing and interacting with AR experiences. In the

Figure 19 – Screenshot of CoSpaces EDU.

Font: <https://rb.gy/qeyxen>.

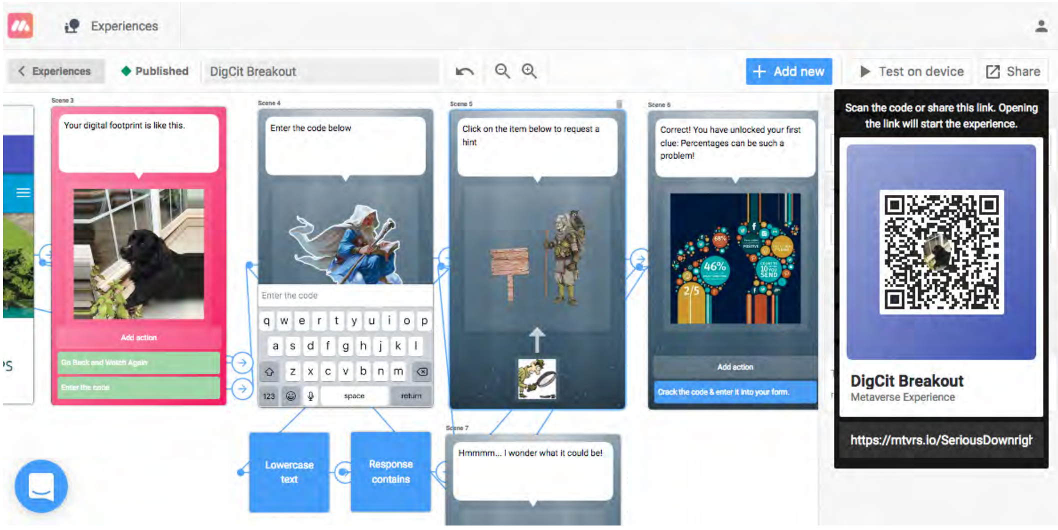
Metaverse Studio[9], it is possible to create scavenger hunts, digital breakouts for teams of students as well as stories and presentations using AR in a story-board like platform as can be seen in Figure 20. The company maintains a page where educators can share their experiences using Metaverse. The posts show very diverse uses of the tool. Many experiences with K-12 students are reported, for instance, teachers have used it to review math and science content[10] as well as to have learners practice foreign languages[11]. Students were also able to create experiences and interactive exhibits to the community, which have also enabled teachers to promote project based learning situations[12].

Thus, the opportunity to create experiences without programming knowledge has enabled teachers to create content to aid learning. (MARTIN-GUTIERREZ; CONTERO, 2011) presented a technology for learning sketching, designation and rules of standard mechanical elements created using BuildAR, which is no longer available.

AR has also been used in schools to create scavenger hunt games. For instance, AR has been used by a History teacher and a developer to create a scavenger hunt game for middle school students in order to help them review the first world war. Their results have shown that students were excited and engaged in the activity (TAVARES; LIMA; CARVALHO, 2015). In (MENDONÇA, 2018), we can see an example of AR used

9 Available at <https://rb.gy/qysdk0>.
10 *"Metaverse Changed My 4th-Grade Classroom"*, available at <https://rb.gy/lbnd8i>.
11 *"Creating Augmented Reality Apps In Spanish Class"*, available at <https://rb.gy/kdd18w>.
12 *"Using Metaverse to Enhance Project Based Learning"*, available at <https://rb.gy/gsr1pm>.

Figure 20 – Screenshot of Metaverse Studio.



Font: <https://rb.gy/qysdk0>.

successfully in a game-like learning scenario (GEE, 2008) with elementary school students. The students created a scavenger hunt game in the school using Aurasma. This activity was conducted as an extra curricular course in the school. The course proposals are organized around the topic of study related to digital technologies. They start from the students' interest based on a list of suggestions provided by the teacher. The author argues that these courses work as affinity spaces, where students share common interests and work together with peers from different classes and ages. They learn how to self-regulate throughout the work based on the goals negotiated previously with the teacher. The scavenger hunt game was later played by middle school students and the feedback received was positive both from the students who developed the game and the ones who played it.

Another example is the work of (SCHLEMMER, 2014). This work aims to understand the relationship between design and cognition in teaching in a context of configuration of Hybrid and Multimodal coexistence, in the perspective of Gamification in higher education. In this paper, the author describes the steps conducted in her class "cognition in digital games". Throughout her classes, students played and had the opportunity to interact with different invited teachers to discuss the theories studied. For instance, in some of the classes, the teacher used Aurasma to spread geolocalized hints (video and audio) about the theorists who created the theories under study, as well as "living hints", i.e, teachers who were later invited to discuss with students about the theories studied. The author concludes that the design-cognition relationship in teaching happens as the teacher configures, together with the students, the living spaces, in which the other person is recognized as legitimate in the interaction and, thus, someone one can learn from.

As can be seen through these examples, most AR authoring tools for non-programmers already available are not specifically targeted at education. Nevertheless, teachers are able to explore them in diverse contexts. They are mostly web-based and enable users to associate diverse digital content (e.g: videos, 3D models, animations, buttons) to printed material.

It is also interesting to note that the examples found vary widely in terms of maturity of technology use. For instance, (FARIAS; DANTAS; BURLAMAQUI, 2011) proposed a tool to help teachers create presentations more easily. (LUCRECIA et al., 2013) proposed a tool called Author AR whose aim is to aid language acquisition in special education. This tool was thought as a teacher tool and enables the incorporation of specific templates in order to create educational activities. The authors explain that it allows the creation of two kinds of activities: exploratory activities, in which teachers can set up a relation between a multimedia content and an AR marker, and structuring phrases activities, which allow teachers to create those kind of activities in which students have to compose a phrase. Both tools have not been tested in real settings. The learning experiences proposed seem to center around the teacher enriching existing approaches to teaching by interaction with AR technology, which characterizes initial maturity in the use of technology (Future Lab, 2014). In turn, (CUBILLO et al., 2014) proposed an AR authoring tool named ARLE, which incorporates new technologies into notes or books created by teacher trainees. This tool integrates multimedia resources in any printed or viewed surface by personalizing information according to student profiles, and allows for sharing of materials to stimulate feedback in both directions: towards the student and towards the teacher. The authors explain that this bidirectional feedback allows users to check if the rendered content clarifies the explained concepts, while the creators of the resource are able to verify the appropriateness and clarify the contents taught. We observe that this tool proposes a learning experience that takes into account the need for personalized learning.

On the other hand, other works try to experiment with different teaching arrangements, in which students leave the classroom walls, such as the scavenger hunts example mentioned before (TAVARES; LIMA; CARVALHO, 2015; MENDONÇA, 2018). In (MENDONÇA,

2018) students themselves are able to create the experiences. We observe that the activities proposed are either a punctual review of the content or an extra curricular option for the students. In (SCHLEMMER, 2014), AR technology was well-connected to the content being studied. This variety shows that both teachers and researchers are still experimenting and learning how to use AR in more mature ways. However, we observe that it is still difficult to integrate AR into the curriculum. Also, it is evident that although some features afford more mature uses, the context of innovation ultimately determines the maturity of the learning experiences created.

Through the examples found in the literature, we observed that tools are usually developed based on literature research and later on tested with the end users. However, (LOCATIS; AL-NUAIM, 1999) highlight the importance of analyzing the authoring tools and the context in which they will be used. They stress the importance of evaluating these aspects in relation to technology and product life cycles along with business and marketing strategies contributing to a technology success. Other works have also pointed out the need to allow diverse teams to collaborate in the design process (COLEMAN, 2012; KNAPP; ZERATSKY; KOWITZ, 2017).

(COLEMAN, 2012) presents the development process of an AR authoring tool (DART) for non-technologists informed by a multidisciplinary team. The author also proposes and validates AR authoring tools guidelines resulting from this process. Some aspects highlighted by this work were:

1. The importance of approachable hardware;
2. The need to allow diverse teams to collaborate;
3. The demand for mature content pipelines that leverage existing tools and workflows.

This project also revealed:

1. The significance of rapid prototyping;
2. The need to evaluate the entire user experience early and often (which is essential);
3. The importance of leveraging existing media development tools for AR authoring.

Although these guidelines are useful for general applications, few works have investigated what are the specific needs of teachers. (VERT; ANDONE, 2017) have investigated this issue. The authors based their decisions only on scientific literature. This work cites characteristics desirable for AR authoring tools as detailed below:

1. Location based-content - Possible feature for learning activities which require the students to be in a certain place, such as location-based educational games;

2. Complex controls - This feature would enable educators to assign more complex controls and actions to AR content, such as: distinct information associated to the direction in which students rotate a virtual 3D model;

3. Personalization - This feature would enable students identify themselves, in order to keep track of their activity in the learning experience;

4. Assessment - This feature is strongly related to personalization. The application could assess the student by measuring parameters of its activity or by allowing the educator to insert assessment items such as quizzes;

5. Statistics - This feature would provide an overview of the usage of the AR experience which would inform educators concerning students patterns, such as: how many students activated it or in which part of the experience they stayed longer;

6. Collaboration between end-users - Students should be able to share the same augmented reality scene;

7. Collaboration between authors - It should allow multiple teachers and students to be able to work on the same augmented reality content;

8. Offline version - AR content should be available even if data connection is interrupted or is not available.

The characteristics for an AR authoring tool for education pointed by (VERT; ANDONE, 2017) provide a good start point. However, since it did not involved teachers and was based only in the literature, it may have missed some aspects that could only be noted when consulting those that are working in the field. Thus, involving teachers is an important aspect to find characteristics for an AR authoring tool that would be simple and easy for them to use.

Simpler and easier to use authoring tools would enable much more exploration from teachers and students. When it refers to immersive technology such a AR, (DONALLY, 2018) states that the use of immersive technology content creation may lead to students forming groundbreaking resources. Among other benefits, this can also allow learners to practice their problem solving skills as exemplified in (MENDONÇA, 2018; SCHLEMMER, 2014). In these examples, students used AR to solve problems related to creating a game that would be enjoyed by their peers and to solving the mystery of who would be the special guest and the theories studied in the class to prepare accordingly, respectively.

5 METHODOLOGY OVERVIEW

(AMIEL; REEVES, 2008) claim that educational technologies are more than simply an independent variable in a study of student learning. For them, integrating technologies into the classroom leads to substantial changes in social organization, student-teacher relationships, among other factors that cannot be investigated successfully by other types of research, such as predictive research. Thus, they advocate that researchers must make a commitment to conducting interventionist research in real-world contexts such as schools, accepting the complexity of the setting. This is important to avoid the gap commonly found between educational technology and its use in education. As despite the impulse of the market to get more and new equipment, little transformation is noticed in educational practice and everyday school life or even in informal educational procedures (MATTA; SILVA; BOAVENTURA, 2014).

Design-based research (DBR), thus, stands as a viable research alternative since it is an innovative approach that brings together the advantages of qualitative and quantitative methodologies while it focuses on the development of applications that can be carried out and effectively integrated into community social practices, always considering its diversity and specific properties, but also what can be generalized and thus facilitate the resolution of other problems (MATTA; SILVA; BOAVENTURA, 2014). (PLOMP, 2007) defines DBR as a “systematic study of designing, developing and evaluating educational interventions (like programs, teaching-learning strategies and materials, products and systems) as solutions for complex problems in educational practice”. He also adds that it aims at “advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them”. Its ultimate goal is to build a stronger connection between educational research and real-world problems (AMIEL; REEVES, 2008).

It calls for iterative cycles of study that lead to a better understanding of the process of intervention (it is process-oriented). (SAHASRABUDHE; MURTHY; IYER, 2013) explain that in DBR if the intervention applied is not effective, it is possible to iterate the intervention until it becomes effective. They explain that each iteration of modifying the intervention is named as a research cycle. The outcome of every research cycle is used as input for the next one. This ultimately helps in enhancing the intervention on the basis of the “failures” in the earlier research cycles. The cycles conclude after a particular version of the intervention presents desired results.

(MCKENNEY; REEVES, 2012) point out five features of DBR, namely: theoretically oriented, interventionist, collaborative, responsively grounded, and iterative.

1. *Theoretically oriented:* scientific understanding is used to frame not only the research, but also to shape the design of a solution to a real problem. Empirical testing is used to validate, refine, or refute hypotheses and conjectures that are embodied in the design. The development of theoretical understanding in DBR evolves through consideration of not only empirical findings, but also consideration of their implications for specific dimensions of the design in question;

2. *Interventionist:* DBR strives to positively impact practice, bringing about transformation through the design and use of solutions to real problems. Intervention might encompass different kinds of solutions, including educational products (e.g. learning materials), processes (e.g. teaching repertoires), programs (e.g. professional development scenarios), or policies (e.g. protocols for school evaluation);

3. *Collaborative:* it requires collaboration among a range of actors connected to the problem at hand. It starts with the identification and exploration of a problem together with the problem owners, the craft wisdom and ground-level instincts of research partners in schools and other design research contexts are valued, studied, and put to use. The research is validated by all involved;

4. *Responsively grounded:* the products of DBR are shaped by participant expertise, literature, and especially field testing. The emerging theoretical and practical insights and in some cases, even the research design, adjust course based on the empirical data, which are collected in real world settings. It is structured to explore, rather than mute, the complex realities of teaching and learning contexts, and respond accordingly;

5. *Iterative:* the insights and the interventions of educational design research evolve over time through multiple iterations of investigation, development, testing, and refinement. As (MATTA; SILVA; BOAVENTURA, 2014) put it: it is methodology focused on building practical solutions, it is not made to finish.

Although different authors, such as (SAHASRABUDHE; MURTHY; IYER, 2013), may divide DBR in different steps, in this work, we adopted a DBR inspired approach following the steps detailed in (AMIEL; REEVES, 2008). These authors detail four main phases in implementing DBR as described below and illustrated in Figure 21:

1. *Analysis of practical problems by researchers and practitioners in collaboration:* It corresponds to the need and context analysis, which is done in the beginning. The practitioner is seen as a valuable partner in establishing research questions and identifying problems that merit investigation. They are also part of the process of the negotiation of research goals. This is followed by a review of the literature regarding the domain. It represents the basis for the formulation of a conceptual framework for the study and to the choice of principles to be applied for addressing the problem;

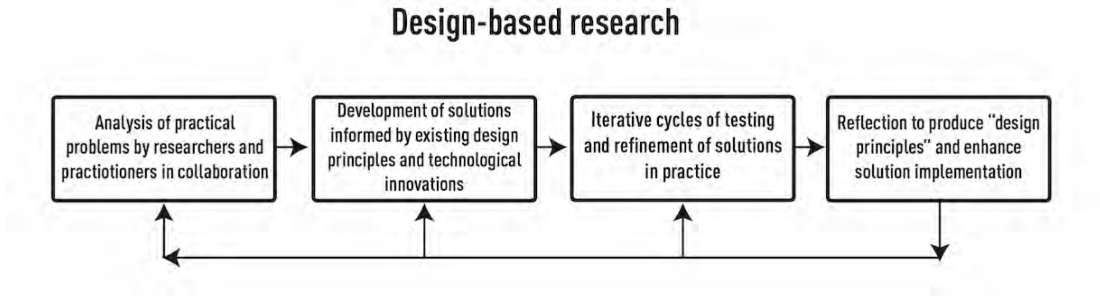
2. *Development of solutions informed by existing design principles and technological innovations:* This phase involves the creation of products or artifacts to address the problem, which are created based on the knowledge generated in the previous phase. The development of design principles undergoes a series of testing and refinement cycles. Data is collected systematically in order to re-define the problems, possible solutions, and the principles that might best address them;

3. *Iterative cycles of testing and refinement of solutions in practice:* This phase refers to the evaluation of the proposed intervention to see if it addresses the problems and gives the desired outcomes;

4. *Reflection to produce design principles and enhance solution implementation:* As data is re-examined and reflected upon, new designs are created and implemented, producing a continuous cycle of design-reflection-design. The outcomes of design-based research are a set of design principles or guidelines derived empirically and richly described, which can be implemented by others interested in studying similar settings and concerns.

(MATTA; SILVA; BOAVENTURA, 2014) argue that from the point of view of traditional science, the potential of generalization of the DBR is quite limited. They explain that the term generalization is more suitable for experimental research, and should be replaced

Figure 21 – Phases of the Design-based research.



Font: (AMIEL; REEVES, 2008).

by the term replication which implies recognizing that the transfer of a solution, or even part of it, of a complexity of praxis and action for another complex situation, will require careful consideration of feasibility and validation. DBR proposes to apply and solve, not prove something. The intention is gain an understanding that will have meaning in addition to the immediate adjustment (MATTA; SILVA; BOAVENTURA, 2014).

DBR is a research approach, not a method itself, and therefore qualitative or quantitative methods can be used as long as they are interpreted as related to the phenomena being studied, and aimed at the practical application and its development (MATTA; SILVA; BOAVENTURA, 2014).

In order to achieve the goals of this research, this work followed a qualitative research approach. According to (MERRIAM, 2009), qualitative research is "an umbrella term covering an array of interpretive techniques which seek to describe, decode, translate, and otherwise come to terms with the meaning, not the frequency, of certain more or less naturally occurring phenomena in the social world.". The author adds that qualitative researchers aim to understand the meaning people have constructed, that is, how people make sense of their world and the experiences they have in the world.

This type of research has four characteristics that are key to understand its nature (MERRIAM, 2009):

1. The focus is on process, understanding, and meaning;

2. The researcher is the primary instrument of data collection and analysis;

3. The process is inductive, that is, researchers gather data to build concepts, hypotheses, or theories rather than deductively test hypotheses as in a positivist research;

4. The product is richly descriptive.

This research is also exploratory and descriptive. Exploratory research aims to provide greater familiarity with the problem in order to make it more explicit or build hypotheses (GIL, 2002). Descriptive research, on the other hand, has as its main goal describe the characteristics of a particular population or phenomenon, or, establish relationships among variables (GIL, 2002).

These types of research are particularly suitable to our goal, which is to understand what features are important when authoring for education using AR. Thus, we intend to identify how teachers use and would like to create AR experiences based on their pedagogic needs. Hence, it would be possible to develop tools that are hopefully better integrated in the learning environment. According to (CORNU, 1995), “only when new technologies are integrated, will they have a wide effect on teaching and on learning”. Additionally, (DONALLY, 2018) claims that the flexibility of the tool determines how widespread immersive technology will integrate into the curriculum. She also adds that the ease of use of the tool will drive its adoption across all skill levels. DBR is, thus, suitable for this investigation since it is one research method that can address multiple interacting variables and allow for iterations of the intervention until it becomes effective (SAHASRABUDHE; MURTHY; IYER, 2013). To apply DBR implies as results new knowledge and new products (MATTA; SILVA; BOAVENTURA, 2014). The new knowledge in this research was materialized through the design principles proposed. The products were materialized through the propotypes of an AR application and its authoring tool. Nevertheless, since our goal is to provide a model for authoring, we will evaluate the concept model with real users, not in the schools. This is the concept proof of the model. Thus, our main difference is that we investigate AR authoring tools for education using a process inspired by the design-based approach. Our work proposes to first understand teachers and their needs and use this input as guidelines for the creation of an authoring tool. This process is also aligned with the principles of good interaction design. According to (PREECE; ROGERS; SHARP, 2019) “the best way to ensure that developers gain a good understanding of user’s goals, leading to a more appropriate, more usable product, is to involve target users throughout development”.

The approach described in (AMIEL; REEVES, 2008) can be considered generic, since it is not intended to solve a specific design problem. It can be considered as an overview to understand DBR (SAHASRABUDHE; MURTHY; IYER, 2013). As it does not detail the process of conducting the research cycles, we adapted it to our research needs.

In the Figure 22, we detail the methods used in each step of the DBR approach to answer our research questions. We list the instruments used to collect data and the participants involved in each step. We also describe the input that came from previous steps along with the artifacts or design principles generated from each step after reflection. In all sessions involving participants, they were requested to read and sign a consent form and to allow a video recording of the session. The consent form used can be found in appendix A. Since part of the research was conducted in the United States, this research has been reviewed by their ethic committee. The consent form used can be found in appendix B.

Figure 22 – Method overview. Image elaborated by the author.

Font: Image elaborated by the author.

To treat the qualitative data generated throughout the research, we used the coding cycles proposed by (SALDAñA, 2013). This author emphasizes that coding is just one way of analyzing qualitative data, not being the only way. He explains that a code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data. The author shows a coded datum taken from a set of field notes about an inner city neighborhood as an example. In his example, the descriptive code SECURITY, summarizes the primary topic of the excerpt: *I notice that the grand majority of homes have chain link fences in front of them. There are many dogs (mostly German shepherds) with signs on fences that say "Beware of the Dog".*

(SALDAñA, 2013) proposed two coding cycles, including 34 coding possibilities. He emphasizes that coding is a cyclical process that requires recoding. Before the first coding cycle, we have the "pre-code" stage, which involves circling, highlighting, bolding, underlining or coloring rich or significant participants quotes or passages that strike the researcher (SALDAñA, 2013). The author also claims memo writing is a critical analytic heuristic in order to register the researcher's perceptions throughout the study. Its purpose is to document and reflect on the researcher's coding processes and code choices; how the process of inquiry takes shape; and emergent patterns, categories and subcategories, themes and concepts in the data - all possibly leading toward theory. The first cycle of coding involves those processes that happen during the initial coding of data. For this stage, (SALDAñA, 2013) offers 24 possibilities of codes divided into seven subcategories: grammatical, elemental, affective, literary and language, exploratory, procedural, and a final profile named themeing the data as shown in Table 1. The author proposes an intermediate cycle, named transition coding cycle, whose goal is not to "take the researcher to the next level", but rather to cycle back to the first coding efforts so the researcher can strategically cycle forward to additional coding and qualitative data analytic methods. For this cycle, the author offers four possibilities of codes. The second cycle coding methods, according to (SALDAñA, 2013), are advanced ways of organizing and reanalyzing data coded through first cycle methods. The author explains that the primary purpose during this cycle is to develop a sense of categorical, thematic, conceptual, and/or theoretical organization from your array of first cycle codes. He proposes six types of coding for this cycle that can be used whenever the researcher deems necessary.

During the first cycle coding processes the portion of data to be coded can range from a single word to a full paragraph. It could be an entire page of text or a stream of moving images. This means that the data to be coded can vary in terms of length and its sources. In the second cycle coding processes, the portion coded can be the exact same units, longer passages of text, analytic memos about the data, and even a reconfiguration of the codes developed thus far. As mentioned, the author offers a repertoire of possible filters (coding techniques) to consider and apply to the researcher's approach to qualitative inquiry. The researcher's choices of coding will be directly associated to the study's goals. This process allows better systematization of the coding process, decreasing subjectivity as the steps and criteria are clearly defined (POCRIFKA; CARVALHO, 2019).

Table 1 – Coding Cycles

<table>
<tr><th colspan="2">First Cycle Coding Methods</th><th>Transition from First Cycle coding to Second Cycle coding</th></tr>
<tr><td>Grammatical Methods</td><td>- Attribute Coding
- Magnitude Coding
- Subcoding
- Simultaneous Coding</td><td>- Eclectic Coding
- Code Mapping
- Code Landscaping
- Operational Model Diagramming</td></tr>
<tr><td>Elemental Methods</td><td>- Structural Coding
- Descriptive Coding
- In Vivo Coding
- Process Coding
- Initial Coding</td><td rowspan="2">Second Cycle Coding Methods
- Pattern Coding
- Focused Coding
- Axial Coding
- Theoretical Coding
- Elaborative Coding
- Longitudinal Coding</td></tr>
<tr><td>Affective Methods</td><td>- Emotion Coding
- Values Coding
- Versus Coding
- Evaluation Coding</td></tr>
<tr><td>Literary and Language Methods</td><td>- Dramaturgical Coding
- Motif Coding
- Narrative Coding
- Verbal Exchange Coding</td><td rowspan="4"></td></tr>
<tr><td>Exploratory Methods</td><td>- Holistic Coding
- Provisional Coding
- Hypothesis Coding</td></tr>
<tr><td>Procedural Methods</td><td>- Protocol Coding
- OCM (Outline of Cultural Materials) Coding
- Domain and Taxonomic Coding
- Causation Coding</td></tr>
<tr><td>Themeing the Data</td><td></td></tr>
</table>

Font: (SALDAñA, 2013).

During the first cycle of this research, we used a First Cycle Method named "themeing the data", which belongs to its own subcategory. In this first step, the goal was to determine the design of what was going to be proposed. Whereas, in the second step, we intended to analyze the impact of what had been proposed in more detail, therefore, we resort to more detailed analytical strategies, using both the transition and second cycle of analysis. During the transition cycle, we used the eclectic coding. Finally, we used both pattern and elaborative coding during the second cycle of analysis as they were the most suitable to answer our research questions. In the following chapters, we detail each of these steps as well as present and discuss their results.

6 ANALYSIS OF PRACTICAL PROBLEMS BY RESEARCHERS AND PRACTITIONERS IN COLLABORATION

The analysis of practical problems has been conducted in four steps. First, the author reviewed the literature related to AR for education, language teaching and AR authoring tools, whose findings have been presented at chapters **Chapters 2 to 4**. Also, three more steps have been conducted with users: (1) interviews with teachers who used technology in the classrooms; (2) interviews with teachers and pedagogic coordinators who used AR in the classrooms and (3) online survey with teachers.

6.1 STEPS INVOLVED IN THE ANALYSIS

The first stage of a design-based research consists in an “analysis of practical problems by researchers and practitioners in collaboration”. In this stage, we aimed to characterize teachers use of technology in order to contrast the needs of teachers who used AR to the ones presented by the teachers who used other types of technologies for pedagogic purposes. To achieve that, teachers were interviewed either online (through programs, such as Skype or Google Hangouts) or face to face according to their availability. The main criterion for participation in these interviews was to have experience using technology in education. Participants were requested to read and sign a consent form as can be found in appendix C.

In case they agreed to participate in this research, the researcher also asked their permission to record the audio of the session. Since this first stage was exploratory, we aimed to recruit participants that represented a broad cross-section across teaching levels and subjects. Participants were recruited from social media communities related to education and technology as well as previous connections to the researcher. Additionally, the participants were requested to invite teachers they knew used technologies to participate, a method known as snowball or chain sampling. Snowball sampling is an efficient and cost-effective non-probability sampling technique to access people who would otherwise be very difficult to find. In this method, the researcher asks the first few samples, who are usually selected via convenience sampling, if they know anyone with similar views or situations to take part in the research. Sampling continues until data saturation is reached (NADERIFAR; GOLI; GHALJAEI, 2017).

The questions for this interview were:

1. What is the teacher's profile?
2. How is their planning process?
3. What is the role of technology in their schools?

The interview protocol covered three themes:

1. Teacher's background;
2. Teacher's planning process;
3. Role of technology in the school.

Also, we aimed to characterize the teachers who currently use AR and understand what are their needs, expectations and limitations. To achieve that, teachers and pedagogic coordinators who have experience with AR were interviewed. The main criteria for participation was to have previous experience with AR technology. Online semi-structured interviews were conducted using programs, such as Skype or Google Hangouts. Similar to the interviews with the teachers who did not use AR, participants were requested to read and sign a consent form. It is worth noticing that it was difficult to find participants who used AR in education. Therefore, many techniques were used to recruit participants. During this Ph.D., we had access to the Google Innovator community to recruit participants. Participants were also recruited from social media communities of users interested in AR for education as well as news reports involving such uses. Additionally, we used snowball or chain sampling (NADERIFAR; GOLI; GHALJAEI, 2017).

Our questions were:

1. What are the profiles of the teachers who currently use AR?
2. How is their planning process?
3. What are teachers experiences with AR for education?
4. What are teachers experiences with content creation for AR?

The interview protocol, as displayed in appendix A, covered three themes as detailed below. The main difference is that AR related questions were added in this questionnaire.

1. **Teacher's background:** questions aimed to characterize the user's educational background and experience;

2. **Teacher's planning process and its impact in AR use:** part aimed to understand teacher's planning and resource selection process;

3. **Use of AR:** part aimed to characterize teachers experiences using AR.

Finally, it was also conducted an online structured survey with teachers to understand why we do not see more of AR schools, in other words, we aimed to understand what are the current limitations for AR use in schools. Thus, we investigated the use of AR in schools and reflected on ways AR technology can evolve and adapt to support more meaningful and effective learning practices. The main questions for this step were:

1. What is the current maturity level of AR adoption in schools?;

2. What are the constraints blocking AR to be used in the classrooms?.

The online survey aimed to gather information about these questions as shown in appendix B Based on the future classroom model, as detailed in **Chapter 4**, we have designed four questions to assess the levels on the dimensions described in the model. Other questions were related to participant's experience using and creating AR content. These questions aimed to capture some of the factors known to influence teacher's adoption of technology as discussed in Subsection 3.3.2.

This form was shared with English and Portuguese speaking teachers from different countries, levels and areas of expertise as well as to mailing lists and social media groups of teachers interested in innovation and AR use in education. Participants were requested to acknowledge their consent in participating in this research, fill out the form and share it with their colleagues. Since this first stage was exploratory, we also aimed to recruit participants that represented a broad cross-section across teaching levels and subjects. Once more, it was difficult to find participants who used AR in education. Many techniques were used to recruit participants. They were recruited from social media communities of users interested in AR for education as well as news reports involving such uses. Additionally, snowball or chain sampling was used (NADERIFAR; GOLI; GHALJAEI, 2017).

6.2 DATA ANALYSIS

We carried out a qualitative approach to analyze the data generated from the interviews. This data was treated using thematic analysis which "is a type of qualitative analysis. It is used to analyze classifications and present themes (patterns) that relate to the data" (ALHOJAILAN, 2012). Phrases and sentences, called codes in the thematic analysis methodology, were created and grouped by themes. Coding means highlighting sections of the unprocessed data and creating shorthand labels or "codes" to describe their content, for instance:

- Participant's comment: *"(I chose to use AR) I found it awesome when I saw that body floating in front of me (in the anatomy 4D) and I wanted to use it to learn that way because it is different."*.
- Theme: Rationale for AR use.
- Code: Positive initial teacher evaluation.

This step corresponded to what (SALDAñA, 2013) labels as "themeing the data". For him, a theme is an outcome of coding, categorization and analytic reflection, not something that is, in itself, coded. It is an abstract entity that brings meaning and identity to a recurrent (patterned) experience and its variant manifestations. Thus, a theme captures and unifies the nature or basis of the experience into a meaningful whole.

These codes and themes were made by the Ph.D. researcher and revised by the two doctoral advisors. The themes and their subdivisions were organized in tables as will be shown in the following subsections.

All the phases of the thematic analysis are displayed below (BRAUN; CLARKE, 2006). The unit of analysis was all teachers' responses considered together.

1. **Familiarize yourself with the data:** The interviews were read and re-read. Initial notes were taken during this phase;
2. **Generate initial codes:** Interesting features of the data were collected from the entire dataset. Codes were generated;
3. **Search for themes:** Codes were collated into potential themes;

4. **Reviewing themes:** Themes were checked in relation to the coded extracts and the entire dataset, which generated a thematic map of the analysis;
5. **Defining and naming themes:** The specifics of each theme were refined to generate clear definitions and names for each theme;
6. **Producing the report:** A report of the analysis has been produced.

Based on these results, personas of our end users were created along with storyboards that depicted user's journeys using AR in their classrooms. These tools were used as input in future ideation sessions with teachers, engineers and designers. These sessions aimed to generate the initial requirements for an authoring tool prototype. In a later stage, we aimed to propose an authoring tool that would make sense to teacher's needs, abilities and constraints they might face following the steps previously described.

6.3 INTERVIEW WITH TEACHERS WHO USE TECHNOLOGY IN EDUCATION

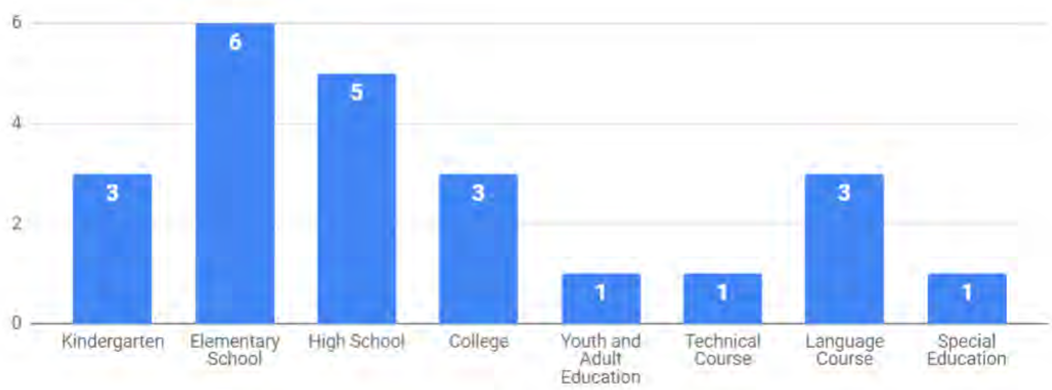
This subsection aims to characterize teachers' use of technology to contrast their needs to those of teachers who used AR for pedagogic purposes. To achieve that, fifteen teachers were interviewed either online (through programs, such as Skype or Google Hangouts) or face to face according to their availability. The semi-structured interviews were conducted from September, 2016 to March, 2018. The shortest one lasted 20m10s and the longest one lasted 1h21m46s. Their average length was 46m26s. Data analysis followed the process detailed in the Subsection 6.2. Also, personas that represent them as well as storyboards depicting the problems they face were created as detailed below.

6.3.1 Participants' Background

Fifteen teachers who used technology in their lessons were interviewed at this point. They were identified by T (teachers) and their corresponding numbers. We aimed to recruit participants that represented a broad cross-section across teaching levels and subjects. Thus, they teach in a variety of scenarios and subjects. There are twelve females and three males. Overall, they had the following characteristics:

1. Have been teaching for 13.7 years (on average);
2. 35 years old (on average);
3. Have undergraduation and an additional specialization (7 teachers) or master degree (4 teachers);
4. Brazilian (most of them located in Recife). Other nationalities included are Austrian (1);
5. Most work in elementary or high school, as detailed in Figure 23;

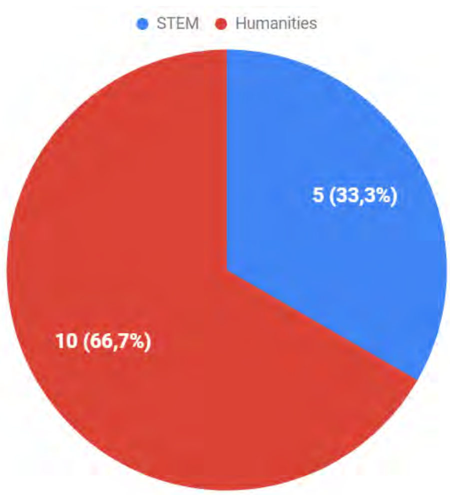
Figure 23 – Levels taught by the teachers.



Font: Image elaborated by the author.

They teach humanities (10 teachers) and STEM (5 teachers) as illustrated in Figure 24.

Figure 24 – Areas taught by the teachers.



Font: Image elaborated by the author.

6.3.2 Teacher's Planning Process and its Impact in Technology Use

Through the analysis, we identified two types of planning process as shown in Figure 25.

Figure 25 – Planning for technology use.

Planning for technology use	Planning technology use	Classroom advance planning
		Planning in action (adjustments during class)
	How to choose content	Official document
		Textbook
		Established own curriculum to follow
		Use of internet and specific websites
		Content related to institutional exams
		Workbook
	Support network	Sporadic exchanges with co-workers
		Exchanges with coworkers
		Lonely planning
		Assistance/feedback in the practical classes
		Collaborative construction

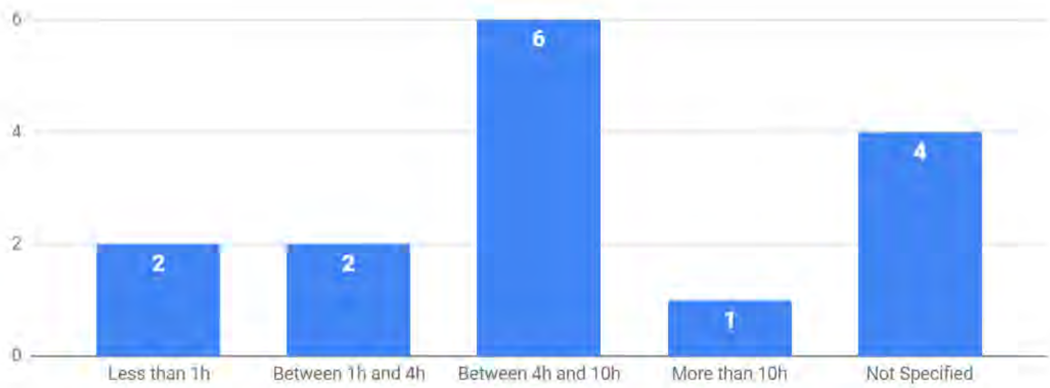
Font: Image elaborated by the author.

Most teachers planned their lessons in advance. Nevertheless, seven teachers mentioned the need to adjust those plans throughout the lessons due to classroom management, technical issues or even to welcome student's suggestions or feedback as mentioned by T4 who claims to make last minute adjustments in the lessons to accommodate student's suggestions. Another example is mentioned by T9 who explained that in one of her lessons about social movements they decided to have a field class in order to investigate social movements that were happening at the time due to student's input. This teacher also argued that in one of the universities she teaches she needs to have a plan B in case the projector is not working.

This category also revealed that most teachers choose the content to be thought based on official documents (11 teachers) and textbooks (6 teachers). Other factors that influence teacher's choice of content were: internet and specific websites (2 mentions); content related to exams (2 mentions) and workbook collections (1 mention). Two teachers mentioned that their schools did not offer a curriculum to be followed so they had to choose one by themselves. This situation happened to T7 who teaches computing. She explained that she chose a British curriculum to work with the children because "*the school did not direct me. I took this curriculum because I have knowledge* *about this field (...).*"[1] T2, an English teacher, had a similar experience. She explained that "*(...) the bilingual program is poor in relation to the curriculum so as I work with the year one since last year I established a curriculum to work with the class.*".

Another important aspect is teacher's planning time. The results revealed that teachers spent a considerable amount of time planning lessons per week as shown in Figure 26. Some teachers were labeled as "not specified" as it was not possible to determine how many hours they spent planning per week.

Figure 26 – Teacher's planning time per week.



Font: Image elaborated by the author.

Figure 26 reveals that most teachers spent between 4 to 10 hours per week planning lessons. Planning time was mostly done with sporadic exchanges with colleagues (7 teachers) or regular exchanges with colleagues (5 teachers). 2 teachers reported to plan lonely, 2 teachers reported to receive help or feedback related to their practice and 1 teacher revealed that they built the plan collaboratively. These results revealed that peer support is an important aspect related to teacher planning. Even support among teachers from other classes. The lack of this type of support may make it difficult to align content properly and might hinder students' performance in national exams. As T3 explains: "*(...) there is no dialogue between the sixth year teacher with the ninth year for example or the seventh year and eighth year in order to achieve this alignment (referring to content alignment that would enable better performance in the exams).*".

Little support from the coordination has been reported in this research. As summarized by T4 when asked if she has help for planning: "*(...) teacher-teacher depending on the*

[1] All quotes in this thesis were translated by the author. Details that might identify participants have been purposefully omitted.

year and who the teachers are, it is possible. Teacher-coordination and teacher-management, no.".

The level of support teachers receive is an important aspect that might also impact technology use as we will discuss in the following sessions.

It is important to highlight though that some teachers mentioned more than one aspect in their choice of content and planning style especially the ones that worked in more than one institution.

6.3.3 Rationale for Technology Use

First, it is important to mention that the technologies used varied widely as described in the list below. This list is not extensive but rather a sample of the most mentioned ones. These resources varied according to the schools where participants teach and the resources available to them.

- Presentation slides;
- Videos;
- Computers;
- Projectors;
- Interactive boards;
- Smartphones and tablets;
- Websites;
- Digital games;

In this work, we use the term technology to refer to digital technologies or the so-called "new technologies". (KENSKI, 2007) explains that the term new technologies refers to: "*(...) processes and products related to knowledge from electronics, microelectronics and telecommunications. These technologies are characterized by being evolutionary, that is, they are in permanent transformation. They are also characterized by having an immaterial basis, that is, they are not technologies materialized in machines and equipment. Its main area of action is virtual and its main raw material is information.*".

Five main reasons were identified as a justification for technology use: (1) methodological or pedagogical facilities; (2) improvement of student learning, attention and engagement; (3) structural conditions; (4) demand for technology use; and (5) other. Each of these reasons were subdivided as detailed in Figure 27.

Figure 27 – Rationale for technology use.

Rationale for technology use	Methodological or pedagogical facilities	Facilitate visualization, display of content
		Facilitate contextualization, discussion, exploration and understanding of a certain concept or theme
		Practice concepts interactively
		Explore previously worked content
		Replace experiences that are not possible in practice
	Improvement of student learning, attention or engagement	Increased student engagement
		Student creation
		Attract student's attention
	Structural conditions	More traditional class
		Institutional limitations (cultural and physical)
		Program or equipment requested/offered by the school
	Demand for technology use	Expected use/implicit
		Mandatory
		Voluntary use
		Does not know how to inform
		Student's demands
	Other	Does not see much need for use

Font: Image elaborated by the author.

One important reason for using technology was methodological or pedagogical facilities. This aspect was subdivided in five categories. First, it was the ability to facilitate visualization or display of content. Eight teachers mentioned the use of technology such as presentations or YouTube videos to present content to students. For instance, T12 used slides with 3D animations to present Chemistry concepts to his students. He explained that "*(...) the use of visualization technologies started to make my life easier as a teacher, and I was pleasantly surprised that such technologies also facilitated students' learning*.". It is interesting to note that T2 mentioned the use of videos to present content to students as a replacement for an activity that would not be feasible to do in real life. This was the case when she was teaching the unit about games to be played outside. She mentioned that "*(...) It would be nice to do this (referring to the game hopscotch) in the classroom in practice but there are too many children*.". Four teachers used technology to facilitate contextualization, discussion, exploration and understanding of a certain concept or theme. For instance, T9 used social media discussions to encourage students to explore topics outside the classroom walls. They were exploring strong and weak links in social networks and organized a fund raise to test those and help the community. T3 used the application WhatsApp in her Portuguese lessons in order to have students reflect about the degrees of formality in the language. Two teachers mentioned the use of websites to have students practice different concepts interactively on the internet. T7 mentioned she uses online digital games as a way to review content previously worked with students in the classroom.

Another important rationale for technology use was an improvement of student learning, attention and engagement. This aspect was mentioned in the speech of some teachers. For instance, we can identify this aspect when T5 explains that "*I always put a lot of images in motion, a lot of videos inside my slides to attract students and to keep them always attentive.*".

Other aspects are related to structural conditions and demand for technology use. As regards to structural conditions, we found that most teachers (7 in total) teach predominantly in a traditional way, which means exposing the content followed by a set of exercises in order to practice it. This is even more evident when T3 explains that she does not see much need for technology as displayed in Figure 27.

She explains that "*I use the whiteboard and whiteboard marker often. I cannot think of other resources for Portuguese language teaching.*". She occasionally mentioned the use of technology such as videos or smartphone applications. Other aspects that played an important role in technology use were the institutional limitations either cultural or physical, such as lack of internet access (T6, T8, T10, T11, T14), physical resources such as paper, glue or brushes (T6, T8, T15) or even incentives for innovation (T5). On the other hand, some schools had software or equipment that was offered or requested to be used. Nevertheless, sometimes the conditions for use of these programs or software were not ideal as can be seen in T2's speech: "*we have to use flashtrack once a week. This flashtrack is mandatory. It comes with the content and it has to be used twice a week. It has a theme and sometimes it is very disconnected. For example, it talks about Egypt when we are working on the alphabet then there is no way for us to relate those topics.*". T10 comments that her school received tablets that they will be able to use, but she mentions that she has not used them yet because there are 20 children in her classroom and she is alone to handle the children and the 20 tablets. T10 mentioned that she preferred when they had the computer room where she used to take the students and each had a computer to work on.

As regards the demands for technology use, results have shown that in most cases teachers acknowledged there is an implicit demand or at least the use of technology is expected. The demands for technology use were expressed in varied ways. T2 mentioned that in one of the schools she teaches there are Google and Lego rooms that teachers must take students to periodically. T3 explained that "*Even though it is not mandatory (the use of technology) I realize that there is the speech of 'look... here it is the videoconference room... the projection room... the computer room... the auditorium has a mobile projector and no one uses it... ' This type of speech appears when you have a negative result because if the teacher has a traditional class... whiteboard marker and whiteboard and has good results no one will comment on this...*". Other schools tried to motivate and encourage teachers to use those resources by indicating possible resources in the syllabus or textbooks adopted (T13, T15), promoting training (T9) and encouraging teachers to share their materials with others as well as giving prizes or medals in order to motivate them to use technology (T6). Five teachers mentioned that the use of technology was mandatory in their schools. T14 even mentioned that "*the discipline that does not use these resources is pointed out very firmly by the coordination*.". Two teachers mentioned they used technology voluntarily as they were free to prepare their lessons the way they preferred. Although T8 was free to prepare her lesson the way she preferred, she mentioned that her students demanded games as they associated language lessons as being more playful. One teacher did not know if there was an official demand for technology use. It is important to point out that some teachers may be categorized in more than one category depending on the different institutions where they work.

6.3.4 Maturity Level of the Practices Proposed

These results suggest that the use of technology described by most teachers lie in the initial levels of maturity as described in the future classroom model (Future Lab, 2014). Most of these practices could be described in levels 1 (10 entries) and 2 (9 entries), which describe a narrow range of technology use. The first level is named exchange and consists in a narrow range of technology effectively used in less than 5% of lessons. In level 2, named enrich, technology is effectively used in 5-25% of lessons. It sometimes replaces more traditional approaches for learning and teaching. Many teachers used slides or videos to replace traditional approaches of presenting content in a more interactive way. They also described the use of online web pages to replace more traditional exercises. Technology was sometimes seen as something extra, which was done only when there was time available as illustrated in T2's speech "*this semester I have to use three books. By the end of the year I managed to finish one. Then I am already in the second one, but there is still another one. We are almost in October so I will have to rush. I will have to explore the book more and I will have to leave other resources aside, do you understand? But at the same time it gets exhausting and the students complain. Then you feel like you are limited and it is not the case. It is something you have to rush.*".

As regards to school support, data suggested that many teachers worked in schools with little or no training and support for teachers regarding digital learning (characteristic of level 1), and some of them in schools that encouraged technology use, but, school leaders were commonly reactive to change (characteristic of level 2). This latter case was noticeable when we observed some teachers comments reporting that schools had a variety of technology (tablets or brand associated technology rooms), but teachers did not receive appropriate support in order to integrate those technologies into the curriculum effectively.

As concerns learner's roles, most practices also reflected levels 1, in which learners use digital learning materials occasionally (usually alone) provided or presented by the teachers; and 2, in which they use digital resources a few times and are able to use it both individually and in collaboration in a pre-defined task. In the second level, students are able to communicate clearly using technology to present ideas. Nevertheless, we found some examples of more advanced levels. T9's experience was classified as level 3, in which the learner is able to learn more independently and be creative, supported by technology providing new ways to learn through collaboration. For example, she reported to take students outside the classroom to record interviews with subjects for a research about a given topic. Learners were also more involved in the decision of learners goals. The teacher mentioned she made changes in the syllabus based on students previous knowledge and background. It is also important to point out that in some cases, such as reported by T13 and T14, the experiences have characteristics of more advanced levels, nevertheless one aspect that is commonly missing regards learning assessment as the model states that in level 3 learners are involved in deciding learning objectives, which include higher order thinking skills and progress through the task being tracked. The learning goals in these cases were usually decided by the syllabus. Nevertheless, T13 mentioned her main concern was to expose students to a lesson that promotes student's cognitive development.

6.3.5 Strategies for Technology Use

The strategies for technology use were divided into three categories: (1) learning objectives; (2) infrastructure conditions; and (3) resource management, as illustrated in Figure 28.

Figure 28 – Strategies for using technology.

Strategies for using technology	Learning objectives	Experience, discuss and/or practice content
		Introduction
		Review
		Evaluation
	Infrastructure conditions	Presence of technology department
		Absence of technology department
		Training in the use of technology
		Does not know how to inform
	Resource management	Available in the room
		Out-of-room equipment generally available by appointment
		Access to internet
		BYOD
		Availability of specific laboratories (e.g: science, languages)
		Brings own equipment
		Not informed

Font: Image elaborated by the author.

As regards to learning objectives, most teachers (8) used technology to allow students to experience, discuss and/or practice content. For example, teachers might use videos to encourage further discussion or use digital games so students can explore concepts in practice. Eight teachers mentioned the use of technology for content introduction. This usually happened through the use of presentation software, such as Power Point. One teacher mentioned the use of technology to review content previously worked (T7) and another (T13) used smartphone applications so students can self-evaluate their pronunciation.

As concerns infrastructure conditions, most teachers (8 or 53.3%) reported the presence of a technology department in their schools, whereas 7 (46.6%) teachers reported not having this department in their schools. It is important to highlight that 2 teachers mentioned that although they did not have a technology department in their schools, there was a department in the city hall that promotes training. The technology department was usually responsible for managing, maintaining and repairing equipment. T5 explains about the staff of this department: "*They are very technical. Sometimes, I meet someone very new who arrived a little while ago and suggests something, some application for example. But, most of them are very technical.*". Only 2 teachers mentioned the presence of training or support for technology use. Nevertheless, the training offered was not always satisfactory. In this regard, T6 mentioned the following: "*There is an attempt to create support for the use of technologies through 'multiplier teachers', whose role is to give support to the school in terms of training and assistance to teachers for the use of technology. There are training courses for the use of technologies, but they are very weak because in reality those who are at the head of the training also have no training in the sense that it is, for example, a teacher who has just left the classroom who often coordinates this training. So, they are in the same condition as the teacher who they are going to support. They also did not experience the use of these technologies in the classroom. In fact, they are learning together.*".

Resource management is another aspect that is very influential in technology use since it might interfere with classroom management itself. Most teachers reported to have access to technology available in their own classrooms. The equipment available consisted mostly of projectors and computers. Two teachers reported access to interactive whiteboards (T8 and T13). Six teachers reported to have access to equipment in other rooms, which they had access usually by booking it previously. The booking process as well as the antecedence needed depends on the school and its context is as explained by T5: "*The technical courses I teach have a protocol for scheduling everything. I've never had to share the labs with other teachers but we always request them beforehand. In higher education, we always have to schedule. When we deliver the plan for the semester, we already let them know the days we will teach in the laboratory. In the specialization courses, we have to schedule beforehand because there is much dispute for all the laboratories especially the computer room, which is more general and everyone uses.*". As observed in this quote, the process of booking the laboratories demands teacher's previous planning and organization to schedule the equipment beforehand. T10 explained that in her school the projector is installed in the library and that there is an assistant to organize everything for the teachers, but she is not in the school everyday. Nevertheless, in some schools more flexibility is reported. For instance, T14 describes what happens in her school: "*(...) when I need something specific in the laboratory, I can send a message to the department via classapp and they prepare what is requested. Also, when I realize that students are having difficulties I can also ask if the laboratory is free and I can take them there so I can work with students.*". Although the process of taking students to other rooms might be time consuming, T3 found this change of environment beneficial as can be seen in her speech: "*(...) the school has thematic rooms. I have access to a mobile projector upon request. I think it is better to take students out of the classroom because the lighting here does not help much either. The room is every bright... you have a lot of heat... I don't know... I prefer to take them to another environment. It changes their minds and their moods...*".

As regards to access to internet, five teachers reported to have no access to it in their schools. Three teachers reported to bring their own device or use students own devices for the activities. T13 explained that her school "*(...) especially encourages the use of mobile learning from the perspective of bring your own device.*". T4 mentioned she brings her own notebook to the classroom. One teacher did not mention how is the technology management in her school. As happened in previous categories, it is important to point out that some teachers may be categorized in more than one category depending on the different institutions where they work.

6.3.6 Authorship with Technology

As regards technology authorship, three categories have been created: (1) content creator; (2) purpose; and (3) conditions to facilitate technology authorship, as can be seen in Figure 29.

As regards the category of content creator, the data revealed that most teachers (9 in total) worked more as content curators. As exemplified by T11 who explained that: "*I take a topic, for example sports in English or Family and friends, outdoor activities. I look for pictures, for songs, the social web as well as some special links to work on the computer, online learning. I collect all around for one topic and then I work it through with my students.*". T15 mentioned that "*I have a collection of more than 2 TB of images, videos, documents, ready-made classes, tests, things that I managed to accumulate*

Figure 29 – Technology authorship.

Technology authorship	Content creator	Teacher as a content curator
		Teacher
		Student
		Teacher creates to share with colleagues
	Purpose	Content Introduction/Make it easier to visualize
		Experience, discuss and/or practice the content
	Conditions to facilitate technology authorship	Institutional support and infrastructure
		Lack of time
		Lack of knowledge
		Does not mention

Font: Image elaborated by the author.

throughout this digital experience.".

Among the teachers that reported to have created content, five teachers created content by themselves. Usually the content created are presentations or worksheets for students to practice. T12 even created presentations and shared with his peers upon request. T13 maintains a blog to share her experiences with Virtual Reality and other technologies with other teachers. Five teachers reported to also use technology for students to create their own web pages or content for the school's web page as well as games. T3 mentioned she is advising her students to create YouTube videos and blog posts for their science fair project.

It is important to note that some teachers might use multiple strategies such as creating content themselves and also have students create it depending on the student's needs (T9).

The future classroom model states that from the third level onward, the learner can work more independently and creatively supported by technology. As exemplified previously, some teachers managed to use technology creatively so students could create content independently and share it online. Nevertheless, we can observe many examples of teacher-centered authorship, in which technology creation is enabling educators to show content to students and direct content practice in more interactive ways.

The data revealed that the purpose for content creation is usually to introduce content to students or to make it easier for them to visualize it or to experience, discuss and/or practice content. As an example, T9 explained that "*I usually prepare a presentation whether it is a prezi or a powerpoint, a video or some images for them to see and problematize. We use this to have a debate or some discussion.*".

As conditions to facilitate technology authorship, we observed the need for institutional support and infrastructure. T5 missed institutional incentives to innovate, whereas, T12 he payed for resources he wanted to use. He explained that "*If I wanted something at the time and could afford it, I saw it as an investment. In addition to the programs, I bought short courses and books to learn skills that I thought were necessary*.". Three teachers mentioned the lack of time to prepare lessons and share with colleagues. T1 mentioned the lack of knowledge: "*I would like to have more technological knowledge to be able to be creative, to prepare classes with a program that maybe gives more three-dimensional view or to be able to do virtual experiments*.". Only one teacher did not mention any aspect that would facilitate technology authorship.

6.3.7 Personas

A persona is a fictional description of a typical target user of a product. It is an archetype rather an actual person. Personas are described as real people and their creation should be based on real data that can be collected through field studies, questionnaires, interviews, workshops, observations, among other methods of user research. This is done to ensure they are accurate and representative of actual users of the product. The aim to create a persona is to help designers empathize with the users and, thus, develop something that will work for them (HARLEY, 2015).

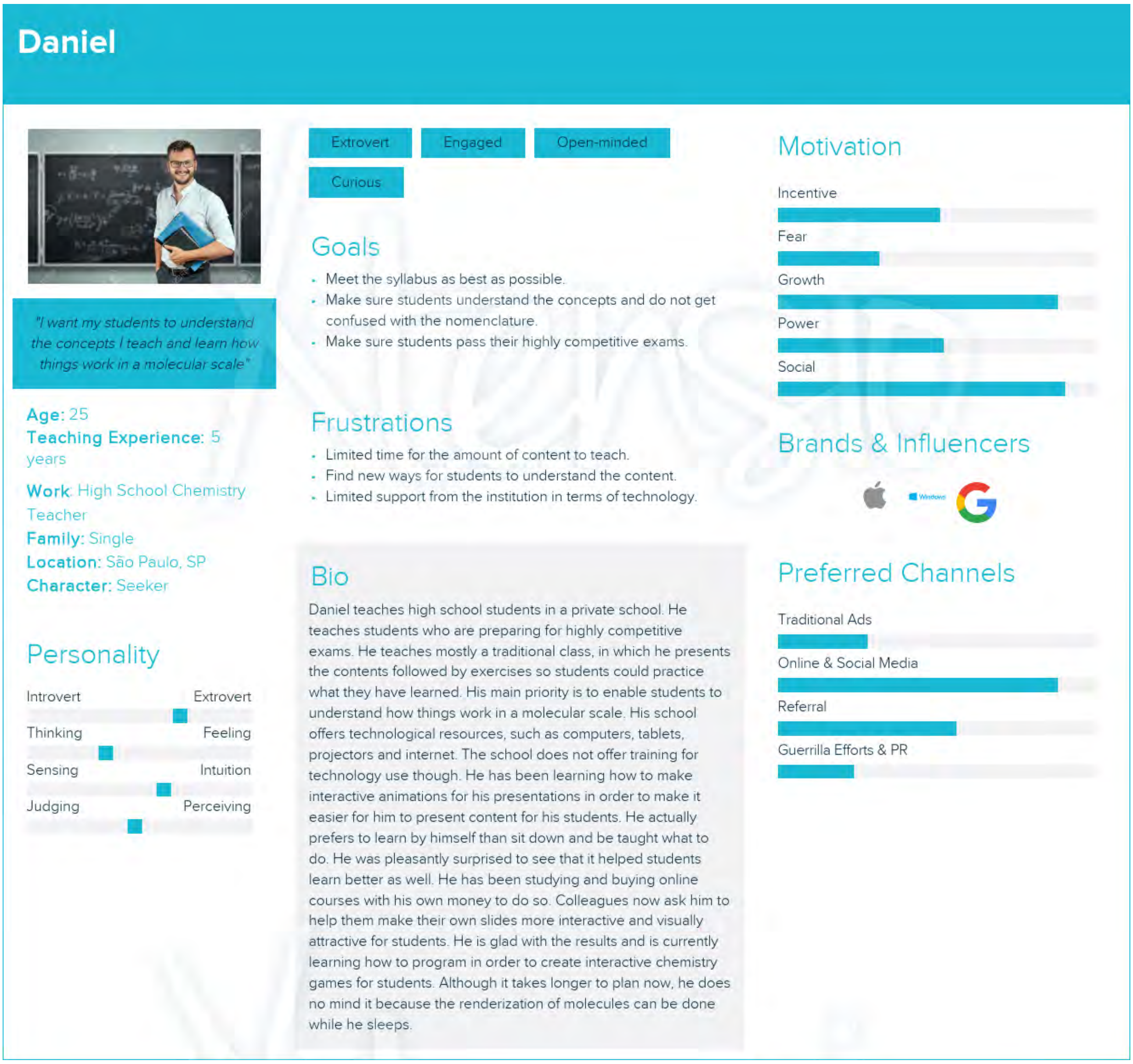
(MARTIN; HANINGTON; HANINGTON, 2012) explain that a persona is typically presented in page-length or shorter descriptions. They contain a name for the person, a photograph (usually a stock photography to prevent connection to a real identity) or sketch, along with a narrative story describing key aspects of his or her life situation, goals, and behaviors relevant to the design inquiry.

In order to ensure the confidentiality of our participants, the personas created were given fictitious names. They represent different teachers in varied contexts as revealed in our interviews. These personas were created using the software Xtensio[2]. This software was chosen since it allows non-designers to create visual appealing content easily. We divided them in two areas they teach: STEM and humanities. Three personas that teach STEM have been created to represent three main different realities found in our data. The first persona is named Daniel. He is a high school chemistry teacher as can be

[2] Available at <https://rb.gy/nsjnvj>.

seen in Figure 30. As described in the persona, he teaches high school students who are preparing for highly competitive exams. The school where he works provides basic technology, but does not provide proper training for its use. He is very independent and has been investing in his own learning in order to add 3D animations in his slides to help him better explain and show the students content. He is satisfied with learner's feedback from his lessons and he has been creating more materials to share with his colleagues.

Figure 30 – Daniel is a high school chemistry teacher preparing students for exams. He is very independent and invests in his own learning to create materials for his students and colleagues.

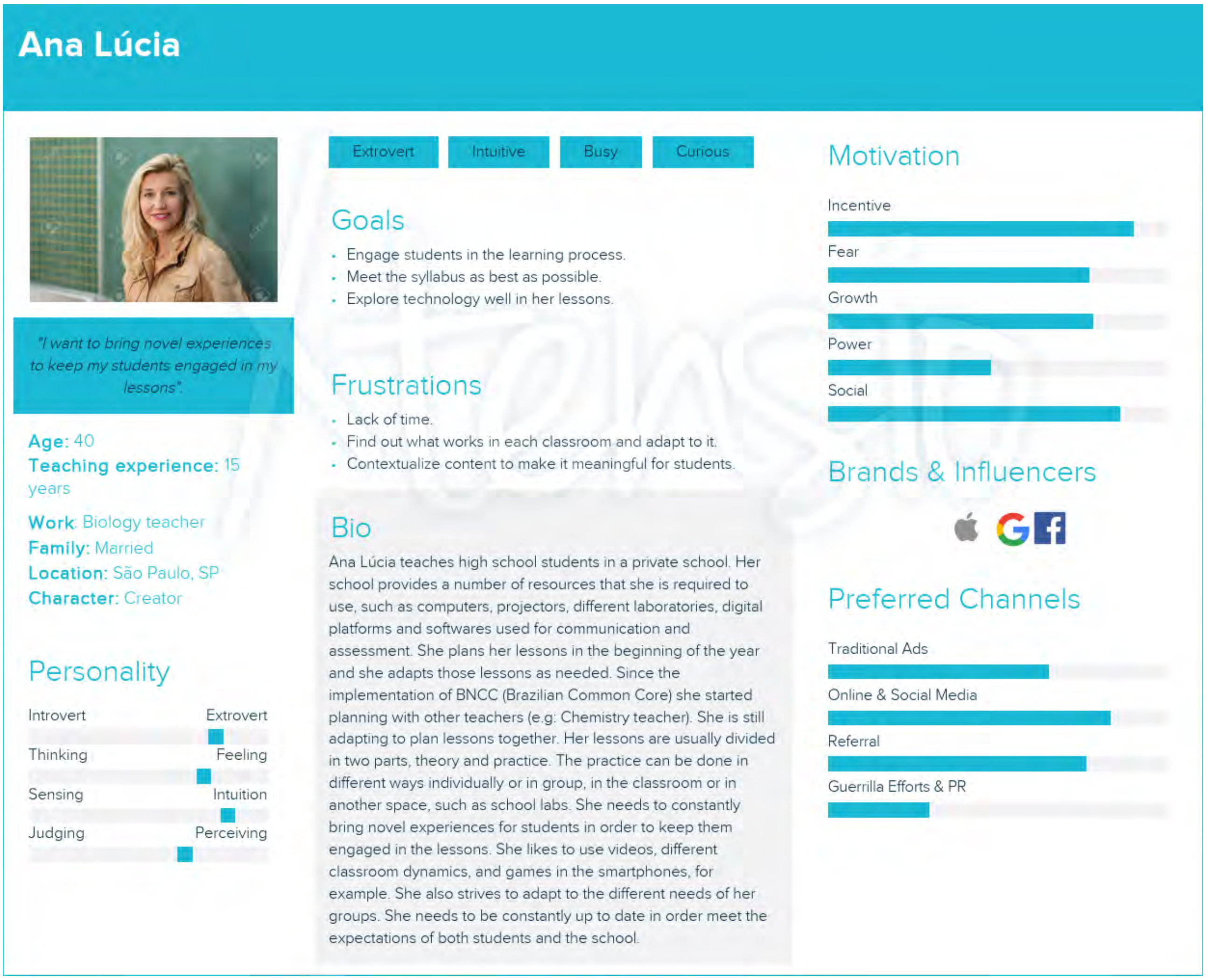


Font: Image elaborated by the author.

The second STEM teacher is named Ana Lúcia as shown in Figure 31. She is a

Biology teacher in a private school. Her school invests a lot in technology and its use is mandatory for teachers. She uses a wide variety of technology with her students in order to keep them engaged and learning.

Figure 31 – Ana Lúcia is a Biology teacher in a private school. Technology use is mandatory in her school. She uses a wide variety of technology with her students.



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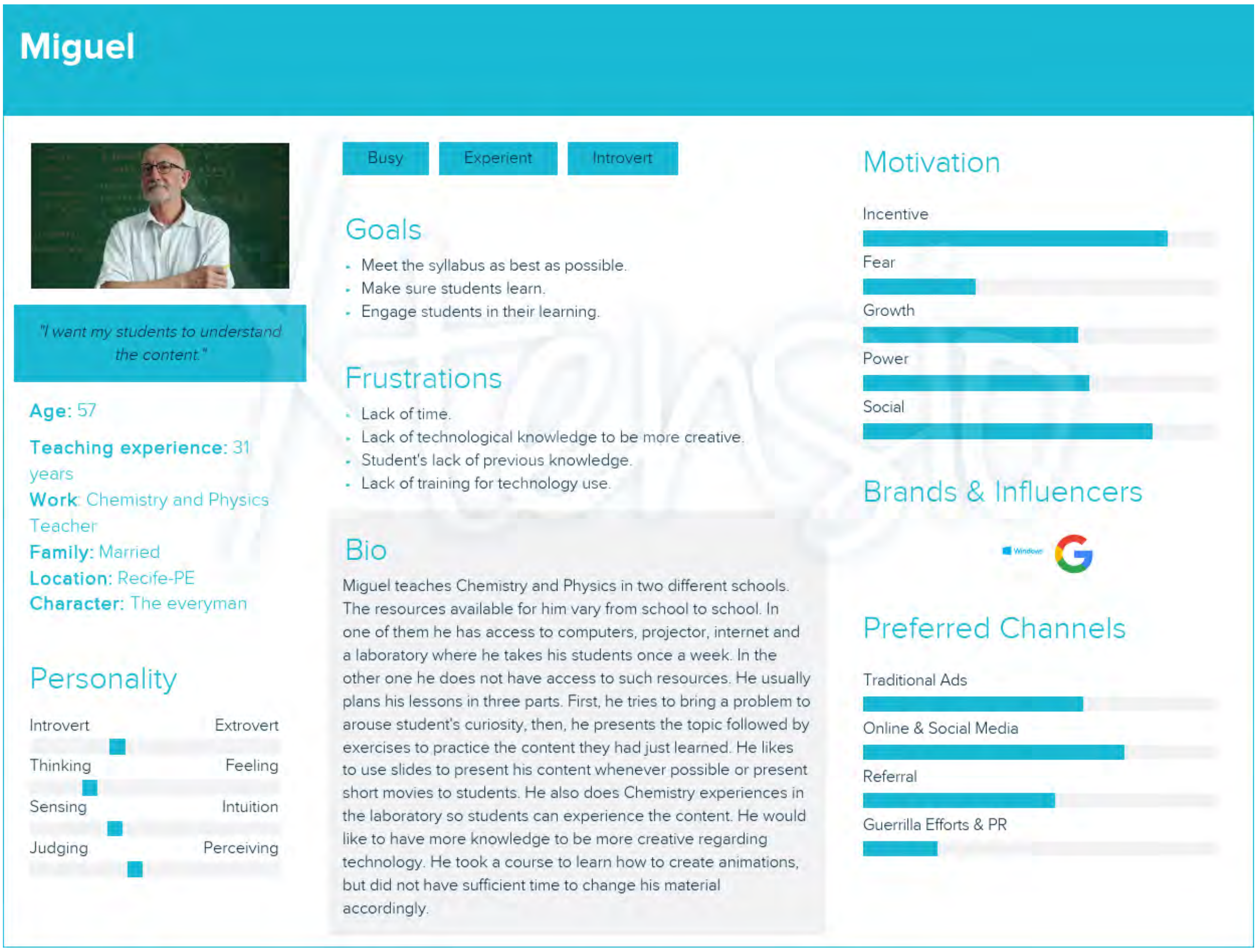
Finally, the last STEM teacher is named Miguel as can be seen in Figure 32. This teacher works in two different schools and each of them has a very different reality. In one of them he has access to basic technology (projectors and internet) and laboratories where he takes his students weekly. Similar to Daniel's school, this school does not provide training for technology use. This teacher misses technological knowledge in order to be more creative. He also suffers from a lack of time due to his large workload. He uses presentations and videos to help him better show and explain content to his students. In the other school, however, he does not have access to these types of technology, therefore, he teaches without it.

Figure 32 – Miguel works in two different schools with very different realities. He misses technological knowledge in order to be more creative. He also suffers from a lack of time due to his large workload.



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As regards the humanities teachers, two personas were created to represent the main situations found among the participants. The first one is a language teacher named Diana as can be seen in Figure 33. She works in a school that is very well-equipped regarding technology. She strives to bring a lot of variety to students and to foster their cognitive growth as well as exposing them to a sequence that makes sense. She is very independent and enjoys learning about new technology to introduce it to her students, such as Virtual Reality. Similar to Daniel, she likes to share what she learns with other colleagues. She maintains a blog and social media profiles in order to do so.

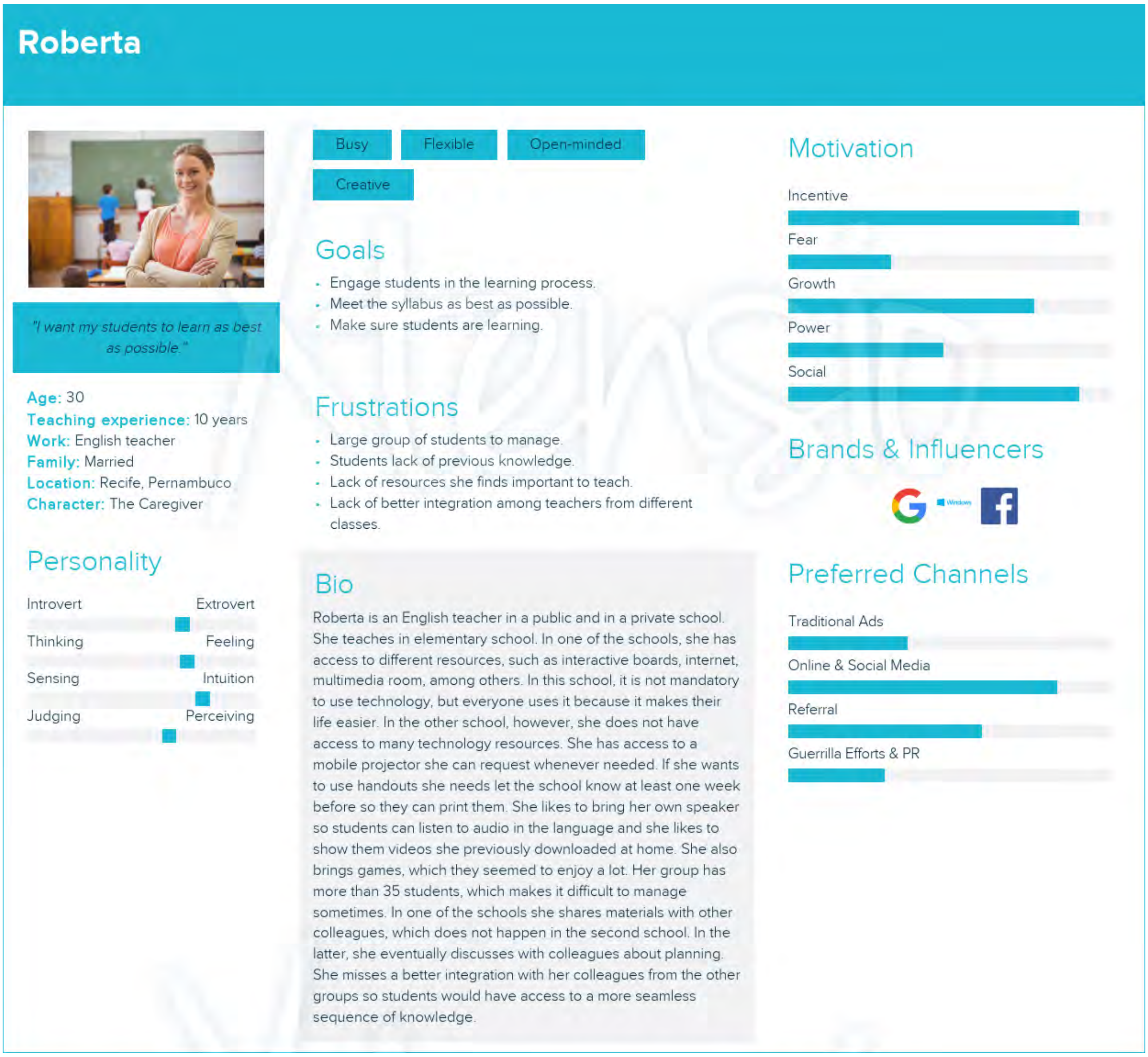
Finally, the last language teacher is named Roberta as illustrated in Figure 34. Similar to teacher Miguel, she works in two schools that have very different access to technology. Although in her case, in one of the schools she has access to a projector

Figure 33 – Diana works in a well-equipped school. She is very independent and enjoys learning about new technology, such as Virtual Reality.

Font: Image elaborated by the author.

she can request whenever needed. The school does not provide internet access. If she wants to print any handouts, she needs to inform the school one week before, which makes it difficult for her to make last minute changes. She downloads previously digital content to show to her students and brings her own speaker to class so students can practice listening. She also brings games for students. In the second school, she has access to a wide range of resources including an interactive board in her room, which allows her to explore many different activities with her students. She misses those resources in the other school as well as better integration with her colleagues so students could have access to a more seamless sequence of knowledge.

Figure 34 – Roberta works in two very different schools. She misses technology resources in one of them as well as better integration with her colleagues.



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These personas were be used in order to compare them with the ones of the teachers who used AR in order to understand their similarities and differences. This helped us better understand the target audience for our system as well as their needs.

6.3.8 Storyboards

Another tool that can help explore solutions to UX issues is the storyboard, which can also aid the communication of these issues and solutions to others. Storyboards are defined as illustrations that represent a story. It's a sequential art, where images are grouped to help visualize the story[3].

According to (MARTIN; HANINGTON; HANINGTON, 2012), storyboarding can help visually capture the important social, environmental, and technical factors that shape the context of how, where, and why people engage with products. Through the use of contextually rich narratives, it can be used to build empathy for end users, and consider design alternatives in the early phases of the design process.

Storytelling makes personas work, by distilling information and analysis into a character and a narrative that ignite the imagination and bring the persona to life (PRUITT; ADLIN, 2005). (MARTIN; HANINGTON; HANINGTON, 2012) explain five design principles common to storytelling as described below:

1. Degree of artistic or photo-realistic detail - this refers to a common misconception that storyboards should be done by designers with artistic capabilities. However, authors argue that simple, abstract drawings of stick figures are oftentimes more effective at focusing the attention of the storyboard audience on a specific detail or message;

2. Text-based narration or explanations - authors advocate for the use of text in the storyboard when it would otherwise take too much effort to illustrate a concept or idea;

3. Emphasis on people, products, or both - authors advise to illustrate characters in emotionally charged situations in order to elicit emotional impact. However, when the goal is to elicit technical or evaluative feedback regarding the concept, it is acceptable to leave characters out of the panels and focus attention on design details;

4. The right number of storyboard panels - authors argue that experts tend to use between three to six panels to communicate an idea. Each storyboard should

[3] Available at <https://rb.gy/ray82h>.

be focused on one salient concept or idea. They advise the creation of multiple storyboards to illustrate different concepts;

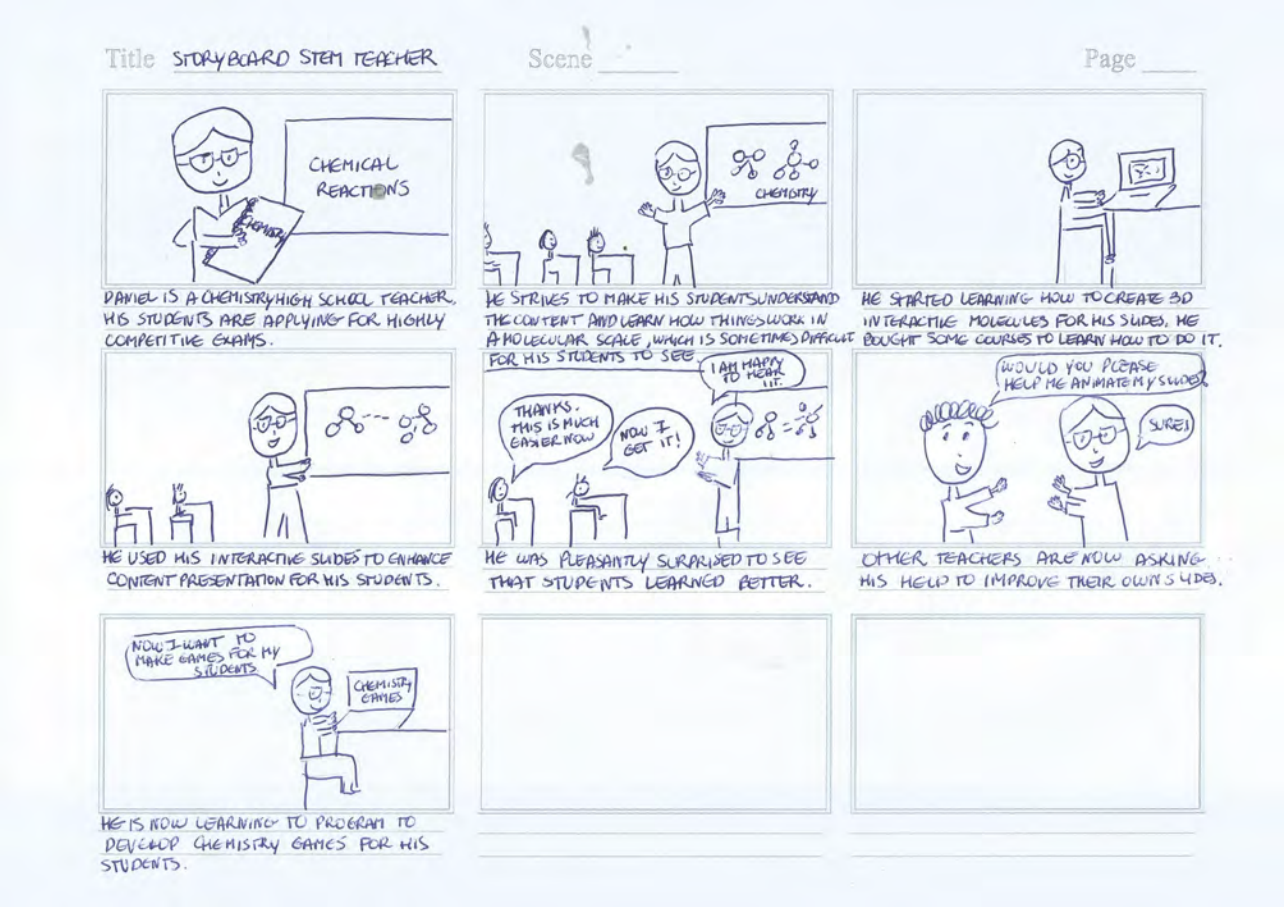
5. Depicting the passage of time - authors argue for the use of time as a design element in order to show large time lapses in a scene.

Based on the results from the interviews, we created two storyboards to represent one STEM teacher and one language teacher who uses technology prolifically as they were two distinct groups in our sample with specific characteristics. The first storyboard shows a story about Daniel, a STEM teacher who uses technology to help students visualize chemistry content better, as seen in Figure 35. Although we understand he used technology in a predominantly teacher-centered scenario, it is noticeable that he is an independent learner and likes to share his discoveries with fellow colleagues. He was also motivated to see that students were able to understand content better through the use of such technology. For ethical reasons, the name of the tools illustrated in the storyboard are not mentioned. As classified by (PRUITT; ADLIN, 2005), this is a “key scenario” story, which starts to move into concrete illustrations of how personas (and real people) interact with the product. In our case, we are depicting how personas work with products they have at their disposal, what is their rationale for using them and how its use impacts their work.

In the second storyboard it is shown the story of a language teacher, Diana, who uses varied technologies to teach her students a foreign language, as shown in Figure 36. She displays a more student-centered approach. Her students are encouraged to create content by themselves and to self-evaluate using technology. This teacher uses technology to her benefit and the students. She adopts a low-tech approach when needed. She also shares her practices with fellow educators through the internet.

Through the storyboards, it was noticeable that although teachers differed in terms of approach to technology used. In other words, the STEM teacher presented a more teacher-centered approach while the language one a more student-centered approach, they both valued sharing their knowledge and practices with colleagues. Also, we noticed that they both needed to customize the technology to their particular contexts, the STEM teacher studied to learn how to do it himself and the language teacher also encouraged her students to do it. While the first teacher used the technology to present content in a visible way to learners, the second also used it as way for students to

Figure 35 – Daniel, a chemistry teacher, uses technology to help students visualize content better. Although the use is in a predominantly teacher-centered scenario, he shares his materials and positive results with fellow teachers.



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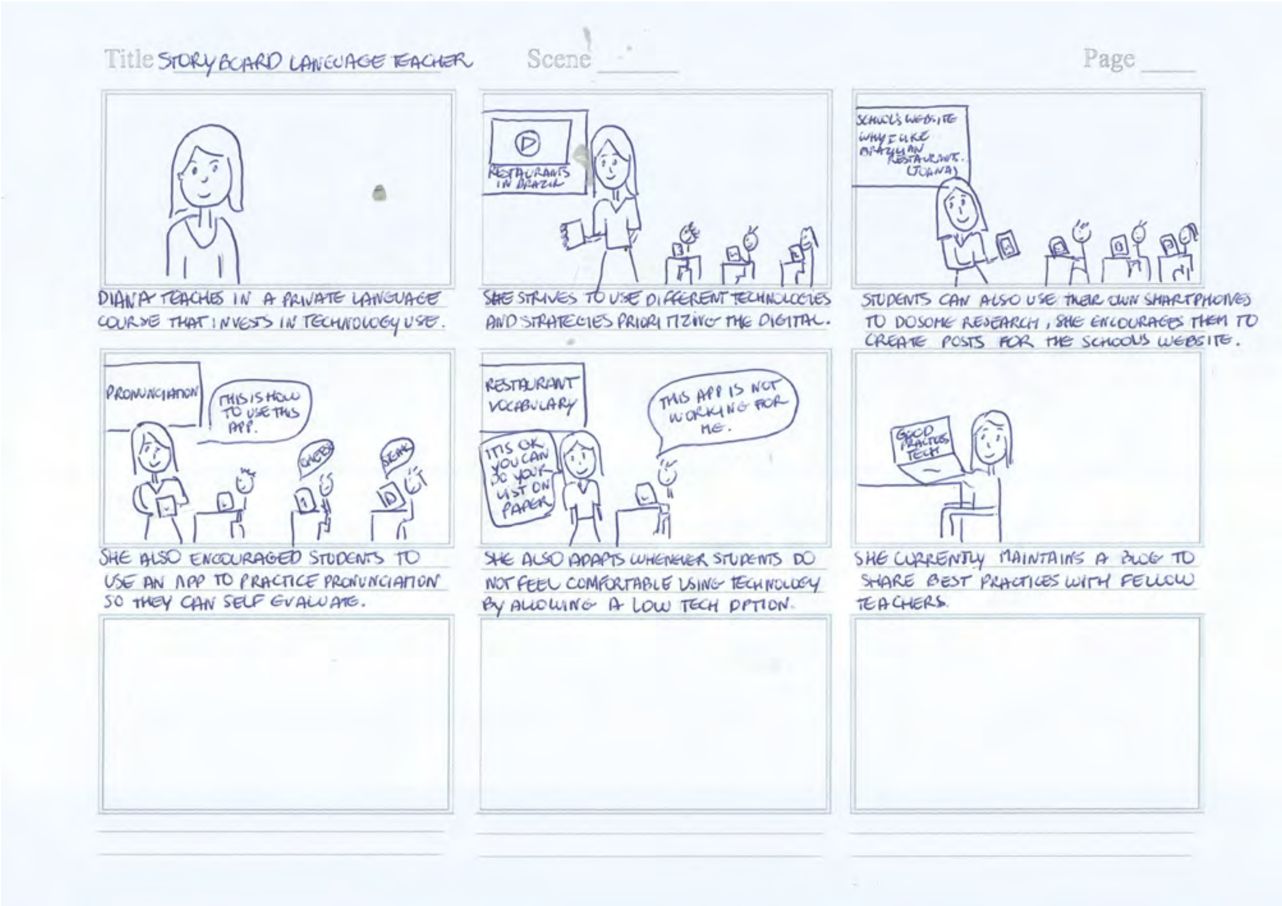
share knowledge and self-evaluate, thus, expanding its possibilities in the classroom. As previously mentioned, along with the personas who used technology in education, these storyboards were used throughout the design and development process especially to compare them with the teachers who used AR and understand their main differences and similarities. These data helped better understand the real context of our users and factors that might help or hinder prolific use of technology, especially AR, in education. It also helped to keep the users and their contexts in mind throughout the development process.

Figure 36 – Diana, a language teacher, uses varied technologies in a student-centered approach. She needs to adapt to low-tech approaches when needed. She also shares her knowledge through a blog.



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6.4 INTERVIEW WITH TEACHERS WHO USE AR IN EDUCATION

This subsection aims to characterize the teachers who currently use AR. This was achieved through interviews with end users, the creation of personas that represented them as well as storyboards depicting the problems they face as detailed below.

For these interviews, seven teachers and two pedagogic coordinators who have experience with AR in formal educational environments were interviewed. The online semi-structured interviews were conducted from November, 2017 to March, 2018 through programs, such as Skype or Google Hangouts. The shortest one lasted 34m06s and the longest one lasted 1h17m15s. Their average length were 49m13s. The results of this interview were discussed in (SILVA et al., 2018), and details are provided in the next subsections.

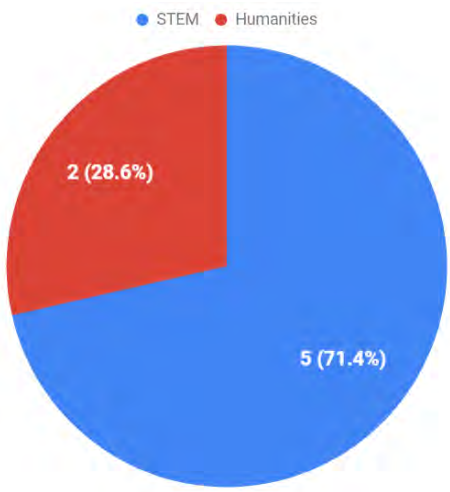
6.4.1 Participants’ Background

Seven teachers and two coordinators who used AR were interviewed. They were identified by T (teachers) or C (coordinators) and their corresponding numbers. They taught in a variety of scenarios and subjects. There were five females and four males. Overall, they had the following characteristics:

1. Have been teaching for 14.8 years (on average);
2. 37 years old (on average);
3. Have undergraduation and an additional specialization or master degree;
4. Brazilian (most of them located in São Paulo). Other nationalities included are North American (1) and Swedish (1);
5. Work in elementary or high school.

Apart from the coordinators, they taught STEM (5 teachers) and humanities (2 teachers) as shown in Figure 37.

Figure 37 – Areas taught by teachers who used AR tools.



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The data revealed that the teachers who used AR were usually well-experienced and mature. All of them had additional studies, either specialization or master degree. They also taught mostly nature and sciences, which might be due to what C9 noticed in her experience. She observed that most of the AR tools are related to this area.

6.4.2 Teacher's Planning Process and its Impact in AR Use

Through the analysis, we identified three types of planning processes as detailed below.

1. **Early planning:** this means the teachers plan their lessons in advance;
2. **Planning in action (adjustments during the lesson):** it refers to adjustments reported during the lessons;
3. **Unplanned lesson:** it reflects situations in which teachers do not plan in advance.

However, the same teacher can plan in different ways depending on the context. For instance, T1 revealed that she has two types of planning: the ideal and the rushed one. "*Here are two forms (of planning): the ideal and the rushed one. The ideal form is usually what I can do at the beginning of the first and second semesters... I think about what is the goal I have... the goal in terms of behavior and ability... then I get the content that I have to work with (...) and then I'm going to see what material I think is appropriate for that class and then prepare the lesson.*".

Although this quote shows an example of early planning, T1 also needed to adjust her planning to meet the institutions' demands: "*From the middle to the end of the semester both in the first and in the second semester I can't do that planning anymore. There is already the pressure to fulfill the content and to have material to be able to make a written test because this is compulsory. The school requires to have a written test with ten questions...*".

The planning process was an important issue to consider when adopting new technologies such as AR since this process required planning time from the teachers and possible planning in action since adjustments sometimes needed to be made on the go, impacting on classroom management and student's evaluation. These adjustments could be due to different reasons, such as technical issues or even student's emotions as will be detailed below.

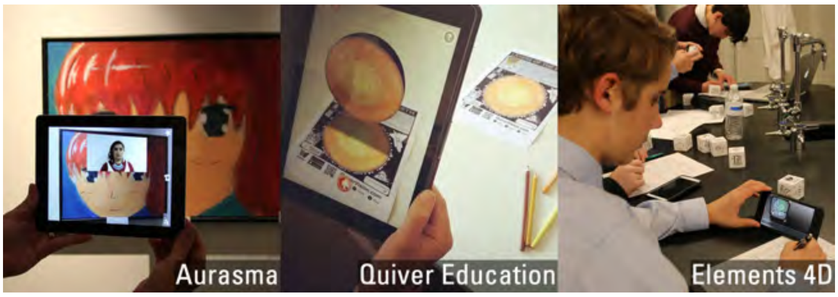
6.4.3 Use of AR

This category intended to characterize teachers experiences using AR.

6.4.3.1 AR Tools Used

The most mentioned tools were the Aurasma (mentioned by 44.4% of the teachers), which was later renamed as HP Reveal[4], Elements 4D[5] (22.2%) and Quiver[6] (22.2%) as seen in Figure 38. Other tools mentioned (11.1% each) were: Pokémon Go[7], Metaverse[8], 4D Mais[9], The Cell[10], Anatomy 4D[11], Treasure Hunt App (TAVARES; LIMA; CARVALHO, 2015), Lifeliqe[12], and Google Expedition with AR[13]. These tools are detailed in Table 2.

Figure 38 – Mostly used AR tools.



Font: Image elaborated by the author.

6.4.3.2 Rationale for AR Use

Three main reasons were identified as a justification for AR use: (1) improvement in students' learning; (2) positive initial teacher evaluation and (3) continuing education. Each of these reasons were subdivided as detailed in Figure 39.

Two teachers based their decision in scientific research. T1 discovered AR tools during her master course. T4 was researching about the topic and learning to develop apps in that format. T5 mentioned scientific findings showing that: "*students have longer retention and they also show better understanding when they get to work with something.*".

[4] Available at <https://rb.gy/xrudwg>.
[5] Available at <https://rb.gy/wixkv0>.
[6] Available at <https://rb.gy/etuv5g>.
[7] Available at <https://rb.gy/6u4hzr>.
[8] Available at <https://rb.gy/qysdk0>.
[9] Available at <https://rb.gy/msrxul>.
[10] Available at <https://rb.gy/rgdecf>.
[11] Available at <https://rb.gy/wo6mxq>.
[12] Available at <https://rb.gy/uhf6oh>.
[13] Available at <https://rb.gy/msrxul>.

Table 2 – AR tools used.

Tool used	Description
HP Reveal	It enables users to create AR contents and associate them to printed material.
Elements 4D	This app allows users to interact with AR content using either paper or wood blocks that are inscribed with the symbols of 36 elements from the periodic table. It is also possible to combine two elements together and see how they interact.
Quiver	This app associates AR contents to coloring pages.
Pokémon Go	It enables users to locate, capture, battle, and train virtual Pokémons, which appear as if they are in the player's real-world location.
Metaverse	It enables users to create different AR experiences, such as games, scavenger hunts, memes, and educational experiences.
4D Mais	This app associates AR content to printed cards.
The Cell	The Cell is a 3D model of cell in scale.
Anatomy 4D	It associates 3D human body parts to image triggers. Thus, enabling students to interact with the human body using AR.
Treasure Hunt App	It is an AR treasure hunt game for mobile devices.
Lifeliqe	It provides K-12 science curricula enhanced with interactive 3D contents.
Google Expedition with AR	It allows 3D objects to be brought into a shared space and viewed through individual phones and other larger screens.

Font: Table elaborated by the author.

Another reason for using AR was a positive teacher's initial evaluation. For instance, T7 thought the Anatomy 4D was a great application. "*I found it awesome when I saw that body floating in front of me and I wanted to use it to learn that way because it is different.*". Two teachers found Aurasma easy to use. T1 mentioned that it allowed her to work without programming knowledge while C8 highlighted its user-friendliness.

C9 mentioned that in her experience "*Specialist teachers will seek according to the resource...*". In other words, she believed those teachers chose the resources based on the possibilities offered by the tool.

T6 chose to use Pokémon Go because it was a trending app. "*Pokémon go was a*

Figure 39 – Rationale for AR Use.

Rationale for AR use	Continuining education	Scientific research
		Scientific Journal
	Positive initial teacher evaluation	Enchantment
		Ease of working
		Possibilities offered by the tool
		Possibility of sharing
		Trending app
	Improvement in student's learning	Motivation
		Works well with certain concepts
		Engagement
		Access to expert

Font: Image elaborated by the author.

choice because it was very trendy (...) so this makes it much easier because when the student is very inserted in the context he starts to understand just because I'm talking about something he already knows.".

Another reason observed was through improvement in student's learning. This was evidenced in different ways, such as improvement in motivation and engagement. Also, some teachers mentioned that AR worked well to teach certain concepts, specially, abstract ones. "*The first thing is 3D visualization from the point of view of biological sciences, why? when you can see what is on top of something and what relates to what and you can draw a map of the body in your head (...) when they see it in school it's already a way for them to understand what anatomical relationship they're going to have in medicine or in the biological sciences they're going to do, in other words, it already gives a topographical notion and in a book you do not have it.*".

6.4.3.3 Strategies for AR Use

The strategies for AR use were divided into six categories: (1) AR content; (2) learning objectives; (3) infrastructure conditions; (4) support network; (5) demand for resource use and (6) AR differential. Each of these categories and its subdivisions are illustrated in Figure 40.

As regards to the type of content worked with AR technology, we observed that five participants worked with contents they considered easy. Whereas, six participants used it to work with contents they considered difficult. T3, on the other hand, chose AR because this is something that his students have never been exposed to. He taught

Figure 40 – Strategies for AR Use.

Strategies for using AR	AR content	Work with something the student does not know
		Difficult
		Easy
		Other
	Learning objectives	Review
		Introduction
		Exemplification (experience content)
		Evaluation
		Reflections on teaching possibilities
	Infrastructure conditions	School structure
		Presence of technology department
		Absence of technology department
		Teacher as leader of technology insertion
	Support network	Lonely planning
		Exchanges with coworkers
		Presence of continuing education
		Assistance in the elaboration of practical classes
		Collaborative construction
	Demand for resource use	Voluntary use
		Expected use/implicit
		Mandatory
		Student's demands
		Teacher's demands
	AR differential	Create something that represents student's learning
		Learning outside the classroom walls
		Gamification
		Visualization and spatial awareness of the content
		Exemplify content
		Emotional impact
		Allow students to manipulate contents
		Promote different lessons
		Develop 21st century skills
		Add layers of virtual information to objects

Font: Image elaborated by the author.

future chemistry teachers at the university. He explained that "*the schedule is always open. We set the schedule in the first class according to what they have not studied yet, as technologies are something they almost never studied during graduation we usually have a large block of content technologies.*". Thus, we understand that in this case the demand for the technology content came from the students lack of knowledge regarding this issue. The teacher believes it is important that his students learn how to integrate technology into their future work context (high-school teaching).

Four participants worked with contents labeled as other since they did not classify those as either easy or difficult. This was the case for the coordinators who chose AR to present it to teachers and to encourage its use as explained by C8: "*in our teacher training when we opened the first spot we had a role to make the use of augmented reality tangible.*". Likewise, C9 played a role in "*contextualizing the tool to the teacher.*".

Another category observed referred to the learning objectives of AR use. The data has shown that three teachers used it to review contents. Those teachers used different strategies to do so, such as: engage students in a scavenger hunt game (T1), engage students in AR expeditions (T4), or as one station during the lesson, in which students could explore an AR application (T7). The main aspect here was the novelty effect and emotional reactions that catch students attention and promoted their engagement and curiosity. Many teachers mentioned the ability of AR to promote student's curiosity and desire to go beyond what has been learned. This is an interesting aspect especially if we consider that studies have made the case that learner's success is more dependent on grit, curiosity and persistence than solely on IQ (BROWN, 2000). Only T2 used it to introduce new content by having students leave the classroom and search for posters with clues for the content to be worked in the lesson. She mentioned that one impact of this use was to break a paradigm and show that one can learn while having fun. Three teachers used AR to exemplify concepts as T5 mentioned that "*one that is the biggest (AR tool) is called lifeliqe and it shows the heart in AR. I used this one because it provides models of the cell parts (...)*". The effect of using AR to illustrate content is to help students visualize the content better and understand its spacial dimension as reported by T7. AR also enabled students to visualize content without the need to imagine it as emphasized by T6.

Three teachers used AR for evaluation. These teachers asked students to create presentations in order to demonstrate their learning, which was considered very positive for the teachers as T4 puts it: "*the way they learn best is that to create something that represents their learning so any way that we can create something that represents learning that's how I want to use it* .". Strategies were needed to help students create high quality presentations. T5 mentioned the use of rubrics. He also mentioned that activities could be time consuming for the teachers to the amount of students they teach. He reported that one solution for that is peer review. Three participants used AR to reflect on teaching possibilities. This included the coordinators and T3 who worked with undergraduate students studying to be teachers. These educators attempted to make the use of AR in classrooms tangible by exploring different applications available or exploring the applications in order to recreate the physical spaces. One challenge found in their work is the need to create stimulating activities for students that go beyond the initial “wow” effect and the content limitations of the tools available (T3, C9). C8 and C9 also mentioned difficulties regarding the costs of some of the options available.

Another aspect observed was the infrastructure conditions. The school infrastructure varied a lot from school to school. Only T1 reported to have access only to projectors, while the other teachers, in general, had access to a variety of resources from the basics (computers, projectors and WI-FI) to the more sophisticated, such as Virtual Reality headsets and digital boards. C8 stated that “*I am very privileged because I have access to all the resources that at the moment I consider indispensable resources for the progress of what we plan*.”.

As regards to the presence of technology department, five participants (55.5%) reported they had that in their workplaces, while three participants (33.3%) did not. T2, on the other hand, reported a peculiar situation since she was moving from the position of teacher to technology manager. She was also organizing online training for the teachers. She said: “*In fact the department of technology is me. This department does not exist. I felt we have this need so I ventured to get Google for education and I'm going from the position of teacher to the position of technology manager of the school so the whole department is still in theory with me (T2)*.”. Two other teachers also took the leadership role in their institutions. They work in institutions that do not have a technology department. T4 reported that “*everybody comes to me in terms of technology questions.*”.

As concerns the support network, the most common form of planning was solitary (6 mentions). Many teachers reported that although their planning occurs primarily alone, they had access to exchanges with coworkers (5 mentions), to continuous training (5 mentions) or assistance in the elaboration of practical activities (1 mention). “*When I have a practical class in the laboratory for example in one of the schools I have access to a professional who helps me because she is the laboratory technician. So, for the practical part, I give her the guidelines but she is the one who assembles everything. She also gives me advice during the experiments to answer students' questions (T7)*.” Two of them reported a collaborative construction of the plan. C8 posted her lesson plan but other teachers had access and were able to change it. C9 reported a similar process.

Six types of demands for resource use (not necessarily AR) were observed. Four teachers mentioned they were expected to use technology in education as T4 explained: "*(...) I think anytime a device is put in the classrooms you know they expect the use of it. I have not seen anything specific. My principle is a technology person so I think he wants us to use but there is nothing in writing or saying that we do x, we have to do this*.". The Swedish teacher reported that technology use is mandatory for him. "*I have been teaching in schools specialized in ICT*"[14] *and it is even written in our work conditions we should use digital tools as much as possible (T5)*." Three teachers reported no demand for it, thus, they used it voluntarily. Two participants reported demands from the students. C9 reported that nowadays the teachers are also demanding technology and that they are concerned if the textbook comes with an online platform where students can practice.

As AR differential, we have observed AR differential for the methodology, content and pedagogic objectives. The most frequent differential was AR's emotional impact on students. This impact was observed in terms of affection (T7), curiosity (T4, C9), attention (T2), engagement (T4, C9) and interest (T4, C9).

Other frequent mentioned differentials were learning outside the classroom walls (T1, T2, C8), visualization and spatial awareness of the content (T3, T5, T7). We considered learning outside the classroom walls whenever the teachers were able to take students outside the classroom and explore or reframe other spaces in the school. The visualization and spatial awareness of the content were specially important for STEM teachers. The teachers in our sample who mentioned this differential were all Chemistry and Biology teachers.

By analyzing their proposed work with learners, we observed other AR differentials, such as create something that represents student's learning (T1, T5); allow students to experience or manipulate contents (T4, T7); and promote different lessons (C8, C9). It is important to note though that only the use of a new technology such as AR will not guarantee innovative or different ways of learning as exemplified in T1's speech: "*They used aurasma as a way of doing things differently, but in the end the students gave an oral presentation and filmed themselves*.". This quote evidences that although she planned to have students show their learning in different ways without

[14] Information and communications technology.

close guidance they might default to what they are used to produce. The ability to enable students to manipulate content was also evidenced by the teachers as pointed out by T7: "*(...) the student can manipulate that body projected on the tablet or cell phone (using anatomy 4D), placing and removing systems, activating and removing cardiac contraction, changing the individual's sex to see the differences. They are able to rotate the body so it becomes very palpable and students love it when they see that body that didn't exist before floating in front of them.*". As for the coordinators, we observed the opportunity to promote different lessons using AR. Other AR differentials were: the use of gamification as proposed by T2 who used AR in a game she created for students; and exemplify content as proposed by T6 who used Pókemon Go as a way to exemplify the use of GPS in a way students could easily relate to the content. Finally, AR was used to promote the development of 21st century skils, such as autonomy and creativity (C8) and also as a way to add layers of virtual information to objects (C8). The latter is particularly interesting for language learning.

It is important to note that some of these aspects represent an undeniable impact in the classroom management. For instance, teachers might take students out of the class to allow learning outside the classroom walls. They usually mentioned that they organized learners in small groups so they were able to visualize and manipulate content.

6.4.4 Maturity Level of the Practices Proposed

We also evaluated the maturity level of the practices proposed according to the future classroom maturity model (Future Lab, 2014).

Our results have evidenced that when it comes to the use of technology in classrooms, most practices reported by these teachers (5 in total) lie in level 2 of the model named enrich. In this level, the learner becomes the user of digital technology, which improves learning and teaching practices. Three participants reported practices that lie in level 3, in which the learner is able to learn more independently and be creative, supported by technology providing new ways to learn through collaboration. Interestingly, when asked about what could be done differently regarding the use of AR, T7 mentioned he would like to work with AR for problem solving. This shows that this teacher reflected on ways to make his practice more student-centered, which is aligned with more mature practices. Only the Swedish teacher reported practices that lie in level 5, empower. According to the maturity model (Future Lab, 2014), this level concerns the capacity to extend learning and teaching through ongoing whole school innovation, with teachers and learners empowered to adapt and adopt new approaches and tools. Through his speech it is evident that the whole school is involved in the innovation process since he mentioned to receive support and planned lessons together with teachers from other areas of knowledge. “*(...) what we do in Swedish curriculum is that we are trying to integrate our subjects with other teachers (T5).*”

6.4.4.1 *Evaluation of AR Use in the Lessons*

The evaluation of AR use was subdivided in (1) planning effectiveness, (2) student’s learning and (3) future uses of AR, as illustrated in Figure 41.

Figure 41 – Evaluation of AR Use in the Lessons.

Assessment of the use of AR in classes	Planning effectiveness	Complete
		Underutilization
	Student's learning	Difficulty in using the tool
		Low pedagogical gain
		Initial impact
		Reflection on limitations
		Change in student's behavior
	Future uses of AR	Novelty
		Positive
		Negative
		Attention to the time destined for activity
		Play pedagogically
		Use more
		Work more with the problem situation

Font: Image elaborated by the author.

As regards to planning effectiveness, the data have shown that seven participants achieved complete effectiveness in their lessons using AR. Two of them were considered as an underutilization of AR. As exemplified in T1’s speech: “*AR has a very cool potential to bring extra information, but I did not get it. I could not get it in it. After all I used it as... almost an accessory like this ... in a very ugly way which I used it because I did not use it in its potentiality.*”. No one reported failure regarding their planning objectives.

In the student’s learning category, many aspects were highlighted by the teachers.

Although no teacher reported failure regarding their lessons planned some issues have been found. T1, for instance, mentioned that students had difficulty using both tools used in her lessons. Her students had difficulties to understand what worked as a marker, which led to frustration among them. T1 also used the treasure hunt app in which students followed QR codes to answer questions related to the content. They had to follow arrows to go to the next question. However, T1 mentioned that "*these arrows were COMPLETELY difficult to interpret and they had a problem also in the font size for reading. Bigger cellphones, tablets and iPads were able to read everything but the phones with small screen... this is very frustrating, right?*". It is very important that teachers and students are able to set up accounts and have the technology function reliably within the constraints of school networks. (SOUTHGATE, 2020) explains that there is nothing more demotivating for a teacher than having to spend considerable time trouble-shooting technology failure when they should be facilitating learning. She adds that students can become demotivated when the technology is consistently unreliable. Thus, this is an aspect that must be carefully considered by developers.

Two teachers reported that the types of questions proposed in the applications used promoted low pedagogical gains. T1 reported that the Treasure Hunt app proposed multiple choice questions, which in her words "*(...) pedagogically speaking I think the gain of a treasure hunt with multiple choice question is minimal.*". Likewise, T3 points out similar issues with the application The Cell. "*(...) even though it has been thought with the pedagogical function (...) it still presents very mechanical questions. Questions that do not make the student think so much. More direct questions like which molecule fits within that metabolic pathway that will generate a given product. So, a very conceptual knowledge question. It is not a question that makes the student think about an action he could do... no... concept... so it is either molecule a or molecule b... it doesn't really matter why is that.*"

T3 and T7 reported the effects of the initial impact of AR in their students. "*the first reaction is a very positive surprise, it looks fantastic (...).*" T7 also mentioned this impact and explained that the emotion can disturb students' focus. "*The first contact with a novelty is mesmerizing to you but that's it. It is difficult sometimes to delve into the content because they think it is so cool so beautiful and then you have emotion disturbing sometimes. Having too much fun and thinking that it is awesome decreases a little student's focus to understand that.*" Studies have shown that emotions play an important role in learning. Positive emotions have been positively correlated with memory retention and learning (PEKRUN, 1992; UM et al., 2012; TYNG et al., 2017). (ZULL, 2006) goes even further and states that emotion is the foundation of learning. Nevertheless, in some cases immersive technologies can become too distractive for students, especially when combined with teachers inability to directly supervise activities (SOUTHGATE, 2020). This can be caused by what researchers understand as cognitive overload in which learner's intended cognitive processing exceeds the learner's available cognitive capacity (MAYER; MORENO, 2003). Such issues highlight the importance of pedagogy. It is important to carefully plan lessons in order to leverage the positive effects of these technologies as well as avoid or diminish negative ones. (BROWN; ROEDIGER; MCDANIEL, 2014) present empirical evidence that space out retrieval practices, interleave the study of different problem types and reflection, among other techniques, can be effective for long-term memory retrieval and learning. These authors also emphasize the importance of providing feedback for students in order to promote learning. Besides constant feedback, (SOUTHGATE, 2020) argues that systematically developing metacognitive and regulatory behaviour in students as part of curriculum could also ease student's high demand for teacher supervision in immersive virtual environments. (MAYER; MORENO, 2003) also recommend these techniques mentioned by (SOUTHGATE, 2020) as a way to reduce cognitive load in multimedia environments. Thus, we understand the same recommendations might also be applied to AR.

T3 used AR with his graduate students. He encouraged his students to think about teaching possibilities for the AR tools. His students reflected on the limitations of the tools. "*First reaction the students have is of surprise. It is a very positive impression. (...) So the time comes to think of an activity to use this application and then they begin to see the limitations, as an example, the Elements 4D has a set of elements with a set of reactions and it is over. So the first impression is really cool, it is known that the student will be impressed, but that will not last more than half an hour in the classroom, because the application has a very big limitation*."

Finally, T4 and C9 observed a change in student's behavior since the AR tools raised student's interest in the content and in learning more. As mentioned in the rationale category, other aspects related to student's learning were reported such as improvement in engagement and motivation.

In the category future uses of AR, we observed a myriad of aspects that could impact future uses as well as understand what could be maintained and what could be improved in their experiences. Something that was relatively controversial was the novelty effect. While T1 considered it a "*poor factor*" arguing that novelty is not novelty for long, T7 considered the neuroscience regarding this topic: "*(..) from the moment you use this tool, to the student it is a new tool. When you have a novelty in learning this releases a series of substances in the brain of that child ... that teenager... that strengthen the formation of that memory so it is not a matter of being fun*.". This teacher also expressed his concern with the overuse of digital tools, which makes it lose its novelty appeal. He believes the best way is to promote varied lessons with different types of low and high technology, such as whiteboard and even 3D models of cells built by students using modeling clay. The importance of having sufficient variety in techniques to keep lessons lively and interesting has already been shown in the literature (BROWN, 2000; BRINTON, 2001).

The impact of novelty in learning has been investigated in the literature. (SCHOMAKER; MEETER, 2015) point out that "*a variety of studies have suggested that transient increase in arousal and/or attention due to novelty can indeed have a range of positive effects on task performance*.". In order to support long-term learning, it is important to extend well beyond giving students a novelty experience and leverage the positive impacts of the technology. Research has shown that the use of brainstorming techniques and pre/re-training pedagogic technique, where learners are scaffolded towards constructing a mental model of the components to-be-learned or utilised in a digital application can keep students on-task, making it less likely that they would experience cognitive overload and, thus, encourage students to go beyond the novelty effect of iVR (immersive VR) towards a more metacognitive framing of its efficacy for learning (SOUTHGATE, 2020). Although we hypothesize that these techniques could be used effectively for AR as well, further studies are needed to investigate the effectiveness of those strategies or other possible strategies applied in an AR context.

Another important aspect that affects performance is related to the learners themselves. Studies have shown that how students see themselves and their own abilities matter a lot for learning (DWECK, 2006; BROWN; ROEDIGER; MCDANIEL, 2014). Although we recognize the importance of aspects such as student's learning styles and strategies (OXFORD, 2001) as well as their mindset, these aspects are not in the scope of this work.

Different positive aspects were raised by teachers, such as: (1) evaluating students previously, (2) raising students curiosity, (3) enabling students to visualize abstract concepts, among others. Two teachers mentioned explicitly they would like to use it more while others implied that.

On the other hand, some negative aspects raised were: (1) diverse bugs, (2) possibility of losing lesson's focus, (3) tools that are too specific or limited, (4) costs and (5) connection issues. Due to the limitations of the tool, T3 reported that his students intended to use the Elements 4D to "*play pedagogically*.". In his words, they would use it to demonstrate something to students and to grab student's attention to chemistry.

T2 and T7 revealed specific changes they would make in their next practices. T2 reported she would pay more attention to time allotted to the activity and T7 would like to work more with a problem situation.

The data evidenced that teachers who adopted AR usually have access to different technologies in their workplace. In our sample, they seemed to have more access than the teachers who did not use AR. Another factor is that they usually had a positive initial evaluation of the tool before using it with learners either by the possibilities offered or easiness of use or because it works well with specific concepts they need to work with. Teachers revealed to have plenty of support either academic or in their workplace. This result supports the literature in the sense that circumstances at the workplace, such as access to up to date infrastructure and supportive culture as well as teachers personal skills and experience with technology play a considerable role in teachers technology adoption (VERMETTE et al., 2019). Nevertheless, we understand that some can be considered pioneers of this use in their workplace. Three participants were responsible for sharing AR use with other professionals or training teachers. Some teachers even invested their own money to buy resources they need, such as T2. The majority of the participants used it in regular schools mostly to review content, exemplify it or assess student's knowledge. It is important to understand teacher's use to propose tools that would meet those needs.

Nevertheless, although we can understand that the majority of the teachers effectively achieved their objectives in the lessons they used AR, this use was still something specific for particular situations. Data has evidenced that in order for teachers to incorporate it more often there must be a way for them to customize the contents and types of activities proposed.

6.4.4.2 AR Authorship

The AR authorship process is summarized in Figure 42. Four participants (T1, T2, T4, C8) reported to have created something using AR.

Figure 42 – AR authorship.

AR authorship	Content creator	Student
		Teacher
	Purpose	Evaluation
		Content introduction
		Reflection about teaching possibilities
	Tools used	Aurasma
	Conditions to facilitate AR authorship	More intuitive interface
		Better conection
	Support	Institutional

Font: Image elaborated by the author.

As Figure 42 shows, the content creators were the students (2 cases) and the teacher or coordinator (2 cases). All of them used Aurasma. Two teachers used it for evaluation purposes, one for content introduction and the coordinator as a way to aid teachers reflection about teaching possibilities. In her work place, teachers were provided with institutional support.

The contents worked in these experiences were: (1) the sugar economy, Brazilian history and First World War (T1); (2) future tense (T2); (3) solar system, digestive system and math problems (T4); and (4) make AR use tangible (C8).

The creation process varied from teacher to teacher. T1's students created contents in pairs. T2 created content by herself. C8 created an experience for the teachers. T4's students created something that represented their learning.

The category conditions to facilitate AR authorship refers to what participants reported as difficulties in the process. These conditions were: a more intuitive interface (3 mentions) as T4 explains: "*with the aurasma there is that challenge of sometimes it is quirky and it is difficult to use (...)*". C8 mentioned better connection. These findings suggest that it was not the pedagogical imaginations of teachers or students which acted as a barrier to smooth classroom implementation, but rather issues related to the technology itself. These findings resonate with research on iVR (immersive VR) use in education (SOUTHGATE, 2020; LAINE, 2019).

The data show that these experiences were limited as only four participants were able to achieve it and through the same tool, HP Reveal (formerly known as Aurasma). Nevertheless, it was evidenced that one issue for them concerns the need for more intuitive interfaces and infrastructure issues, such as better connection. The data also revealed that both teachers and students can author AR educational experiences.

6.4.5 Desire to Create Content

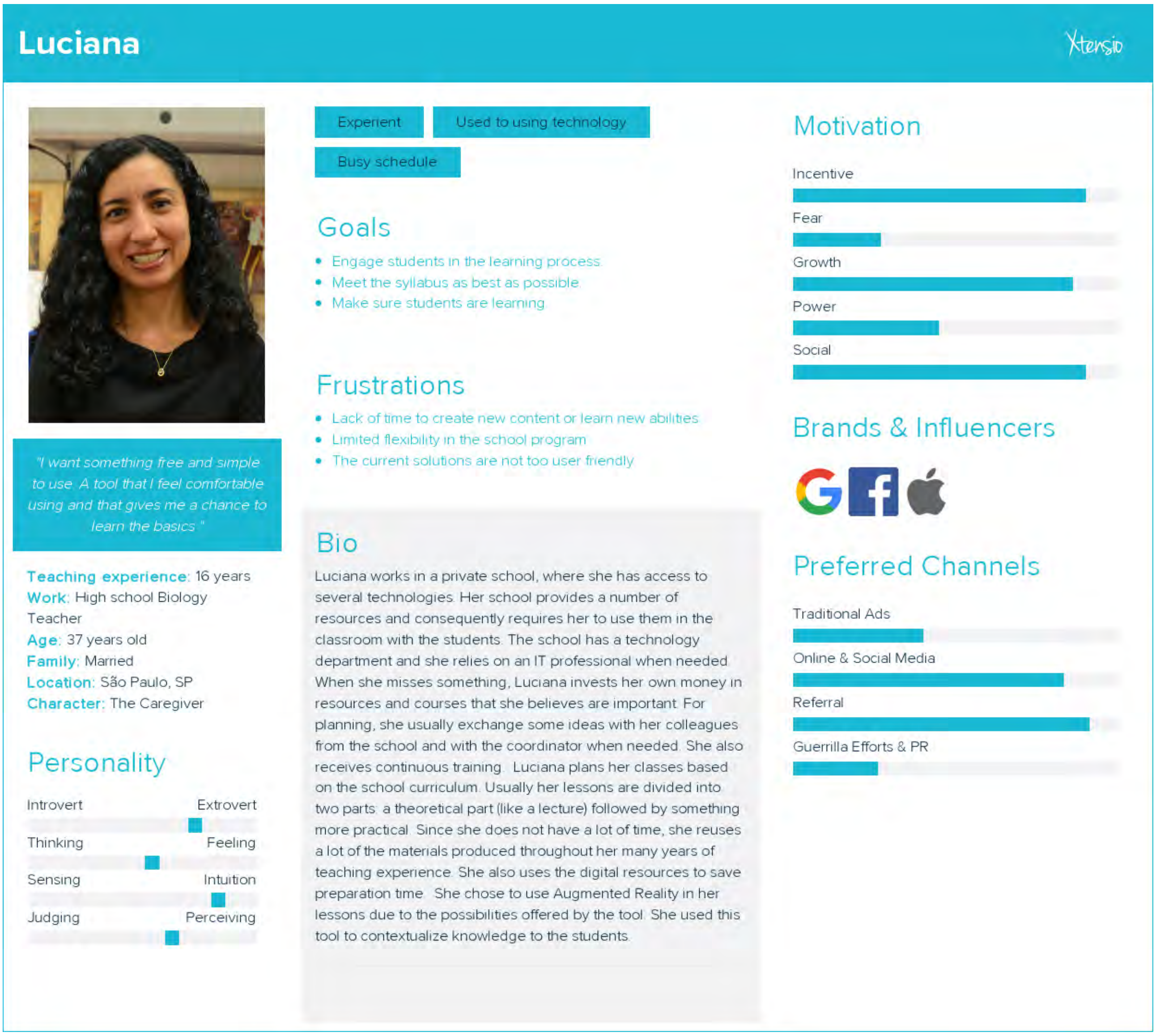
When asked if they would like to create content for the tools, four teachers (44.4%) reported to be interested in creating content for AR. T3 explained that he partnered with programmers to create an AR tool to teach chemistry. Only one teacher (11.1%) did not express interest in creating AR content. He mentioned he was exploring Virtual Reality headsets and how to use them in his classroom. It is important to highlight that four subjects (44.4%) have already created content using AR. One of them, C8, mentioned her focus was to give the tools for the students so they could create content themselves. This result suggests that although these teachers are not specialized in content creation they are mostly interested in having some degree of autonomy in order to explore AR content creation in their lessons either by themselves or with the students.

6.4.6 Personas

As previously explained, to ensure the confidentiality of our participants, the personas created were given fictitious names. They represent different teachers in varied contexts as revealed in our interviews. Similar to the teachers who used technology in education, we divided the personas according to the areas they teach: STEM and humanities. The first one is named Luciana, a high school biology teacher as can be seen in Figure 43. Her school invests considerably in technology and requires its use. She also uses her own money to buy anything she deems necessary for lessons. She is an experienced teacher who reuses a lot of materials she has produced over the years. She used AR as a way to contextualize content for her students.

The second persona is named Paul, a Chemistry upper secondary school teacher in Sweden as shown in Figure 44. The school where he works is very well-equipped and requires the use of technology. He uses AR to help students visualize content, but for him the most interesting part is when students use the 3D models to explain and

Figure 43 – Luciana is a high school biology teacher in a well equipped school. She invests her own money in technology and reuses materials produced over the years.

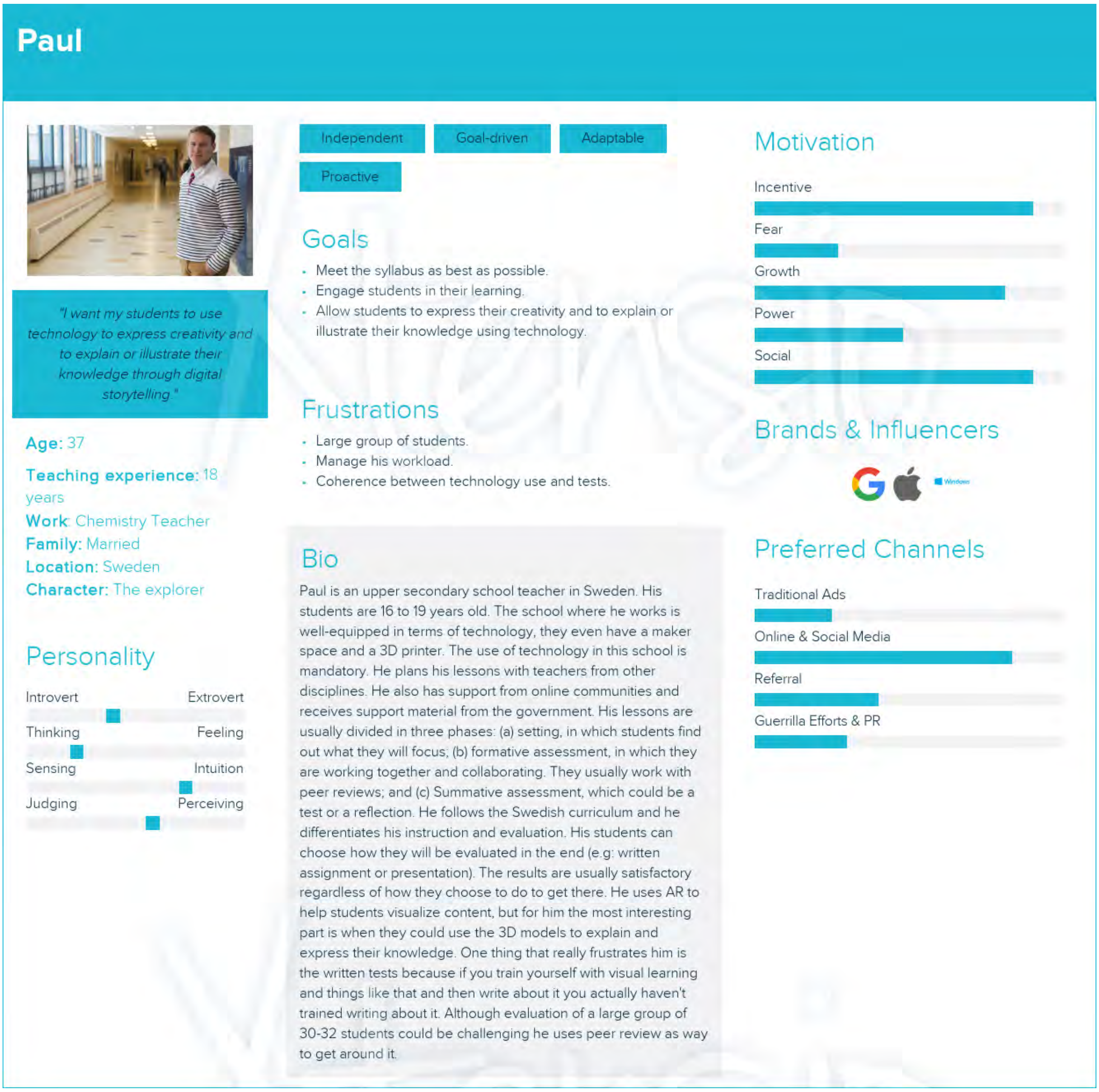


Font: Image elaborated by the author.

express their knowledge. Also, it is very important for him that students are able to express creativity through technology and digital storytelling.

The third persona is named Julia, an English teacher who works in a private school as shown in Figure 45. Her school is in the early stages of technology adoption. She is a leader regarding the use of technology. She is currently migrating from working as a teacher to assuming the role of technology manager. She likes to reuse materials created by herself and her students. She chose to use AR due to the possibilities offered by the tool as a different way to explore and share contents as well as occupy the spaces in the school.

Figure 44 – Paul is a Chemistry upper secondary school teacher in Sweden who works in a very well-equipped school that requires the use of technology.



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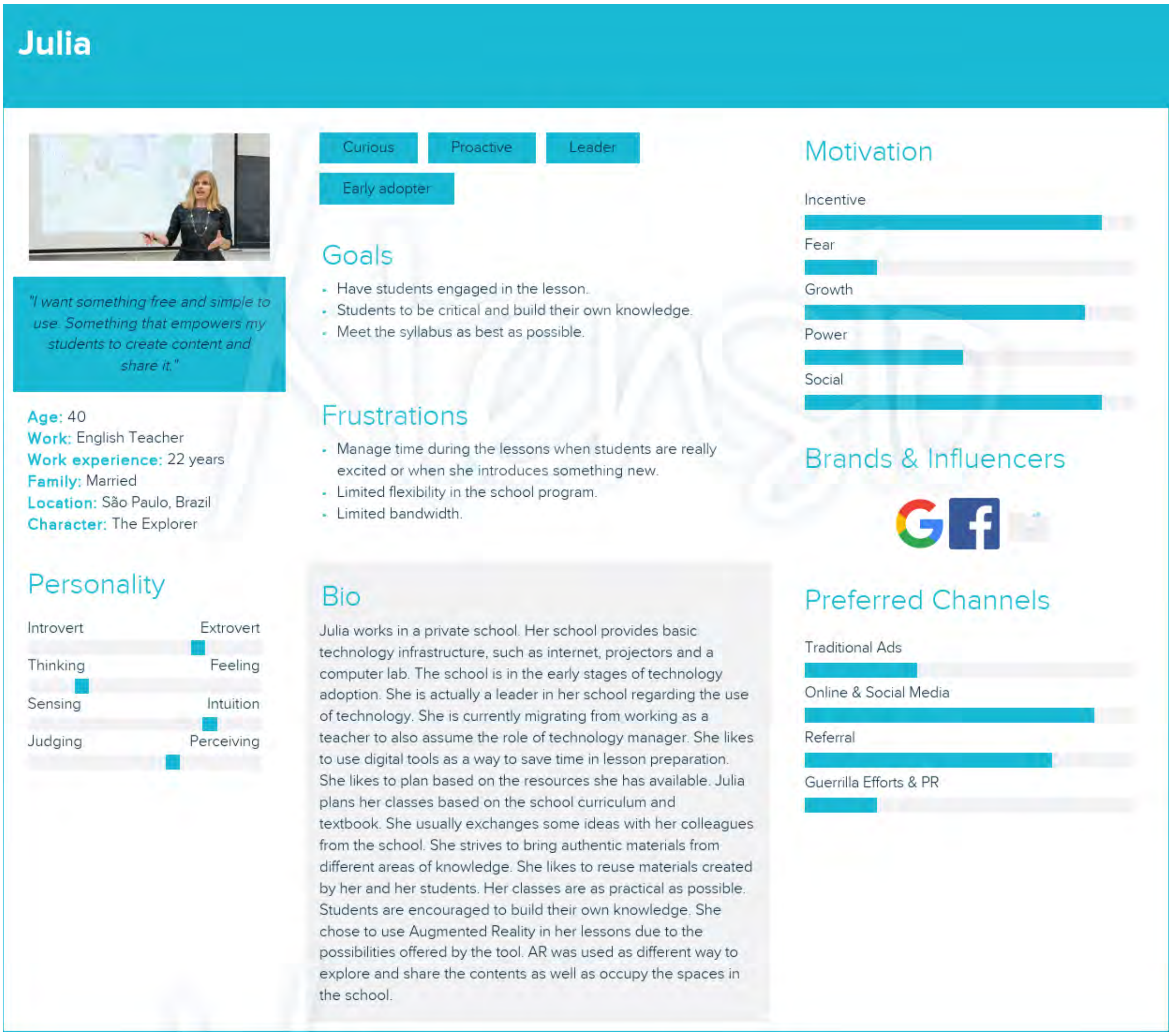
Similar to the personas of teachers who did not use AR, these personas were created using the software Xtensio[15]. These personas were used in the follow-up ideation sessions with multidisciplinary groups of engineers, designers and teachers in order to promote empathy and a better understanding of the end users. According to (PRUITT; ADLIN, 2005), personas can be used more generally in non-structured ways throughout the entire development cycle. They can help by answering difficult questions and by

[15] Available at <https://rb.gy/nsjnvj>.

Figure 45 – Julia is an English teacher who works in a private school. She is a leader regarding the use of technology and likes to reuse materials created by herself and her students.



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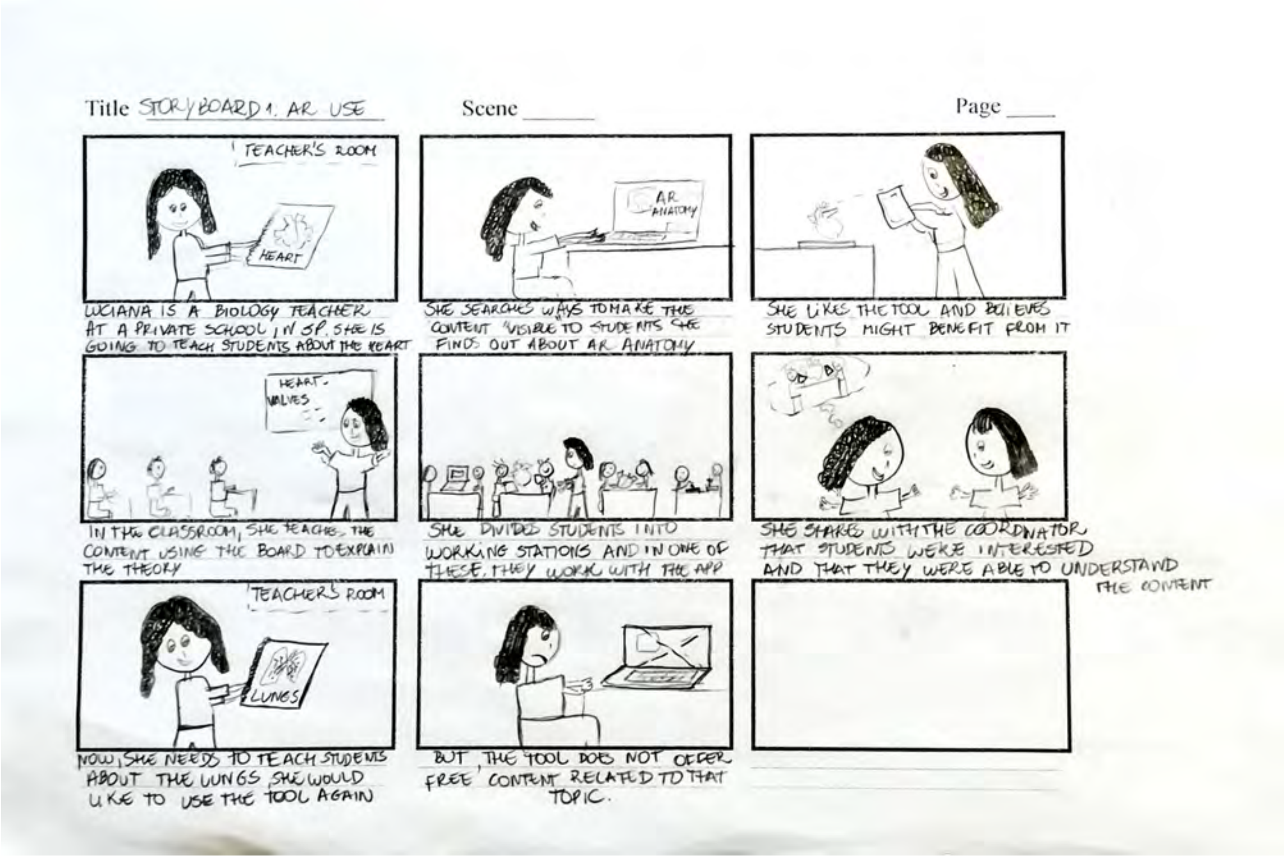
focusing activities in a way that takes the guesswork out of making customer-driven decisions. These authors add that personas can help a product team be user centered. They can take part in those decisions to make the implicit become explicit. They can help move an entire team in a user-focused direction.

6.4.7 Storyboards

Based on the results from the interviews, we created two stories that represent common problems teachers face when using current AR solutions in their lessons. Thus, we created a storyboard to represent the use of AR in the classroom by one of our personas, Luciana, as shown in Figure 46. For ethical reasons, the name of the tools illustrated in the storyboard are changed. In this storyboard, we illustrated how our persona might find out about AR, familiarize herself with the tool and use it in the classroom with students. We also depicted the problem identified in the interviews that happens when the persona wants to use the tool for other contents and there is no solution available that meets her needs. As classified by (PRUITT; ADLIN, 2005), this is a "point of pain" story, which illustrates problems, and often can point forward to possible solutions that could be part of a new design. According to the authors, they help to create a vivid view of the problem from the point of view of the persona. As previously described, this persona has a busy schedule and may not have time to completely plan the entire course ahead of time, adjusting the lessons according to tools she might find interesting as well as student's interest and feedback throughout the lessons. This story reveals that a point of pain for teachers is to want to show some 3D content to students using AR and finding out there is no such content available and they need to find a way to create it.

Additionally, we also created a storyboard to represent the process of creation using an AR authoring tool, as can be seen in Figure 47. For ethical reasons, the name of the tools illustrated in the storyboard are also changed. In this storyboard, we illustrated how our persona might find out about an AR authoring tool, familiarize herself with it and use it in the classroom with her students. We also depicted the problems identified in the interviews that happen when the persona wants to use such a tool with the students and strategies used to alleviate the problems faced along the use. Similar to the previous story, this is another "points of pain" story. In this story, it is possible to understand different points of pain in the process of creating content using AR experienced by our persona in her lessons as well as to understand a bit better the classroom dynamics involved in the process. As points of pain, we highlight the following: (1) the need for extra support for students in order to help them understand how to use the tool properly; (2) technical limitations, such as poor connectivity that forces her to make last minute changes during the lessons. We can also observe that our persona might feel frustrated after the experience when faced with so many problems. Although our future solution might not be able to solve all these problems, it is important to understand the real context where the future tool proposed will be used and think about ways to mitigate possible problems and avoid leaving the user feeling frustrated. Finally, another

Figure 46 – Storyboard about AR use. Luciana, a biology teacher found an AR tool and used it with students. She wanted to use the tool for other contents, but there was no solution available that met her needs.



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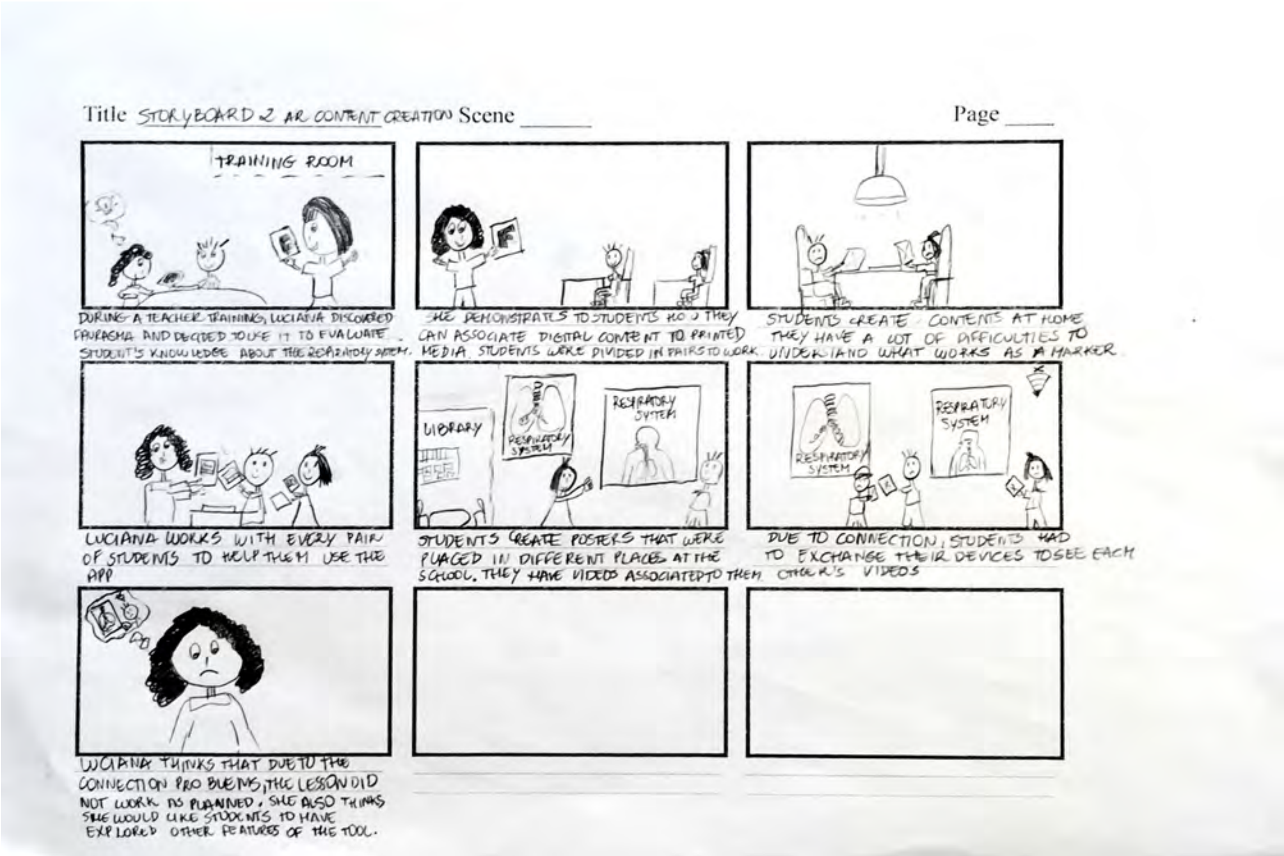
important aspect depicted in the story is the classroom dynamics involved in using tools such as AR that might be different from a more “traditional” lesson. In this story, our persona worked with small groups of students and also explored other spaces in the school rather than just the classroom itself, which is also important information to keep in mind during the future design and development phases.

Along with the personas, the storyboards were used throughout the process of design and development in order to “create a vision of the user’s worlds and invite others to enter it” as argued by (PRUITT; ADLIN, 2005). According to these authors, personas and their stories have a power of persuasion. They allow to reach many people and help to ignite the imagination of an entire development group. The authors add that they are more effective than argument because they are memorable and can be easily repeated. This way they should contribute to the design of a more appropriate solution to the user’s needs.

Figure 47 – Storyboard about AR content creation. Luciana, a biology teacher, found an AR authoring tool and used it with her students. She made adjustments in her lessons, but faced problems during its use.



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6.5 ONLINE SURVEY WITH TEACHERS

This subsection aimed to understand what is the current maturity level regarding AR use in schools, as well as what is preventing schools to reach higher levels of maturity. We also aimed to discuss the current use of AR in schools and reflect on ways AR technology can evolve and adapt to support more meaningful and effective learning practices.

In order to achieve that, we used an online structured survey to gather information about schools' current maturity level regarding AR use in education; and what are the constraints blocking AR to be used in the classrooms. Based on the future classroom model, we have designed four questions to assess the levels on the dimensions described in the model. Other questions were related to their experience using and creating AR content. These questions aimed to capture some of the factors identified above in Subsection 3.3.2.

We have collected 106 responses from this form and we analyzed them in order to answer the research questions. We aimed to recruit participants that represented a broad cross-section across teaching levels and subjects. Thus, this form was shared with English and Portuguese speaking teachers from different countries, levels and areas of expertise as well as to mailing lists and social media groups of teachers interested in innovation and AR use in education. Participants were requested to fill out the form and share it with their colleagues. All the answers were provided in June, 2019. The results of this interview were discussed in (SILVA et al., 2019b) and are detailed below.

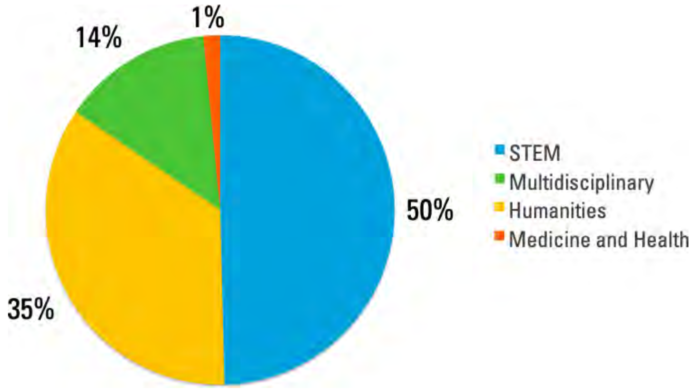
6.5.1 Teachers' Profile

Most of the teachers who participated in this research were female. On average, they were 41.1 $\pm$ 10.6 years old, have been teaching for 15.5 $\pm$ 10.0 years and 78% of them know what is AR. As regards to their education, the majority of teachers had a master degree or a specialization course. These results show that most of these teachers were relatively older and had more teaching experience and education. Through the analysis, it was not observed a clear relation between their age or teaching experience and the use of AR.

Most of them taught in regular public schools, followed by universities and regular private schools. Although we have a limited sample, this result suggests that we are going towards inclusion of students through the use of new technologies, such as AR. As regards to their teaching segment, the data show that most of them taught in the graduation level, followed by high school and middle school teachers. Post-graduation, pre-school and technical school were the segments with the least number of teachers.

When we consider the teachers who have used AR, half of the subjects taught are STEM related, followed by humanities and multidisciplinary contents as can be seen in Figure 48. It is important to note that one participant can teach more than one subject. Only one teacher used AR to teach medicine and health topics. This result corroborates existing literature, which shows that teachers usually find more abundant AR applications related to STEM subjects (SILVA et al., 2018; RADU et al., 2021).

Figure 48 – Subjects taught for each area by teachers that used AR.



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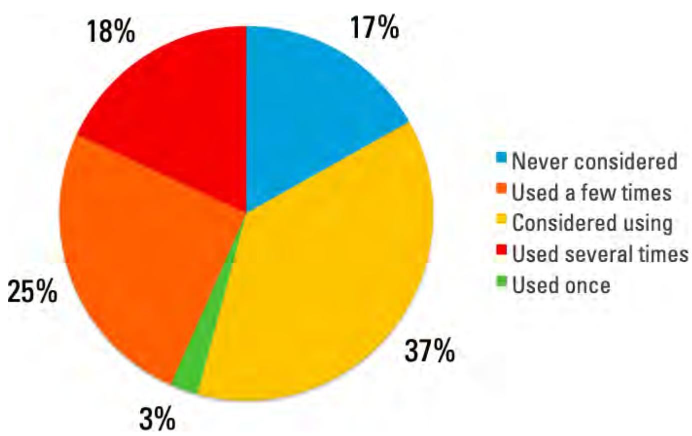
6.5.2 Teachers' Knowledge of AR and Barriers to AR Adoption

Figure 49 shows that 54% of the teachers have never used AR. However, from this group, most teachers claimed that they have considered using it. This group of teachers were asked what they would like to know before using AR in their lessons. Most of them claimed they would like to learn more about pedagogic strategies. As one teacher put it, he would like to *"determine if it is pertinent or not"*. Secondly, they would like to learn more about tools available, and, moreover, which tools are accessible in their particular context. This is exemplified in this speech of a teacher who wants to *"learn more about it as there are very limited resources for adult students who are English language learners"*. Also, they would like to make sure they have technical support to use AR. These results suggest that teachers still need more time, training and support to feel more confident to use AR.

Figure 49 – Distribution of teachers according to the use of AR.



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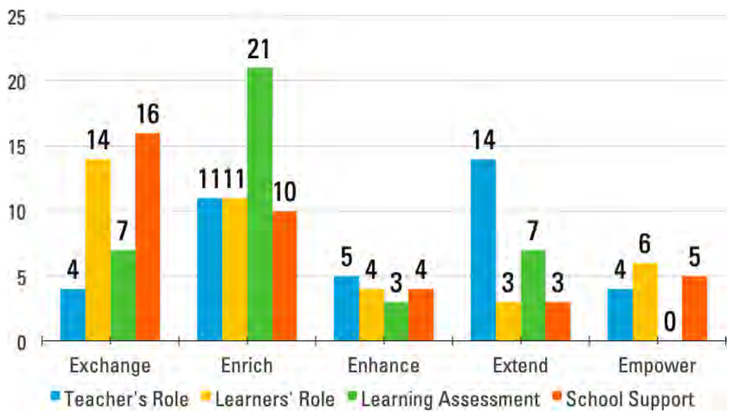
21 teachers argued that they used AR in classroom more than one time, but, not much. Followed by teachers who used AR in many of their lessons. In this research, we considered it to be more than five uses. Only 2 teachers used AR just once. This result evidences that most of the teachers who used AR are still in an exploratory phase as they claimed to have used it less than five times.

6.5.3 Teachers' Maturity Level Regarding AR

As previously explained, we had four questions in the survey that intended to assess schools' use of AR technology, as previously explained in Subsection 3.3.1. These questions considered four of the five dimensions: (1) teachers' and (2) learners' role, (3) learning assessment, and (4) school support. We did not focus on tools and resources because we are interested on AR as a tool.

As regards to the teachers, most of them classified themselves as levels 4 (extend), 2 (enrich) and 3 (enhance). The same number of teachers were classified as levels 1 (exchange) and 5 (empower), as illustrated in Figure 50. When it comes to all other dimensions, most of them classified themselves more in levels 1 (exchange) and 2 (enrich). However, there were some particularities. 6 teachers considered that students use the technology in level 5 (empower) and 5 see the school support in the same level.

Figure 50 – Distribution of teachers over the five maturity levels grouped by dimensions.



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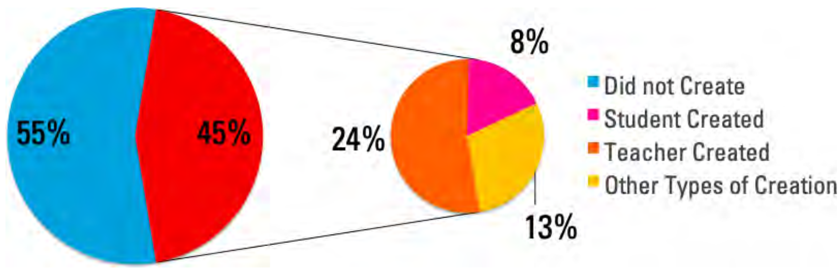
The Future Classroom toolkit shows that innovation in a school usually starts as an initiative of one or more individual teachers. However, in order to upscale the innovation process, we need to involve different stakeholders. Thus, school involvement is very important not only to provide infrastructure, but to provide support and promote a culture of innovation and collaboration.

Concerning assessment, they classified themselves in level 4 (extend) as much as in level 1 (exchange) and no one were considered as experiencing level 5 (empower) in that dimension. This result evidenced that there is still some difficulties to incorporate new forms of assessment in school. This might happen due to many reasons such as fixed models of assessment or even lack of technology tools that support more innovative forms of assessment. For instance, our work (SILVA et al., 2018) shows that teachers considered multiple choice questions as a limited way to evaluate students in AR tools. Thus, it is noticeable that time is needed to integrate AR into the curriculum and develop alternative forms of assessment.

6.5.4 AR Content Creation

55% of the teachers did not experience AR content creation. From the teachers who created AR content, most of them did it by themselves (24%), as shown in Figure 51. In only 3 cases, the students were responsible for content creation. Five cases were classified as others. This means that 4 teachers reported AR content creation in partnership with the students; and one teacher created it with the help of a colleague.

Figure 51 – Distribution of teachers according to the creation of AR content and who created it.



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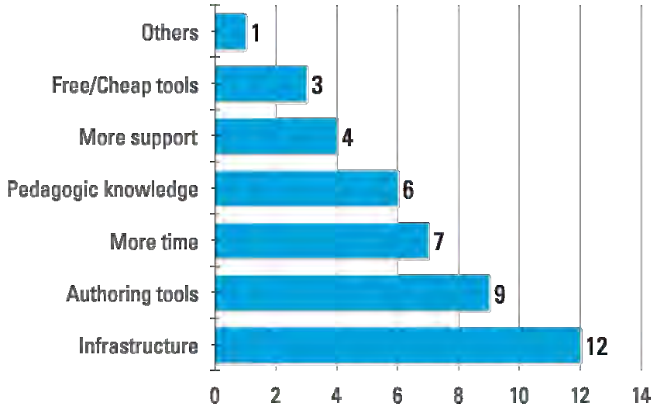
6.5.5 Factors Blocking Teachers to Use AR More Effectively

Participants reported many factors that hinder their ability to use AR more effectively in their classrooms. These factors are illustrated in Figure 52. The most critical was poor infrastructure, which encompasses a variety of issues, such as poor internet connection and lack of devices. Besides, problems related to compatibility among devices were also mentioned.

When asked about the biggest problems faced when using AR, one teacher answered as follows: *"The type of devices of my students that sometimes didn't let them access the content"*.

Figure 52 – Factors that prevent teachers from using AR in the classroom more often.



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The second most mentioned problem by the teachers was the lack of authoring tools as illustrated in this statement: *"I prefer that my students create AR rather than use pre-created programs"*. This problem evidences that the technology itself needs to become flexible by allowing teachers and students to create appropriate learning content that is aligned with the pedagogic goals for the lessons. This is an important factor if we want schools to progress to higher levels of maturity regarding AR use. The future classroom model shows that, from the third level onward, *"technologies are used for collaboration, communication, to solve real-world problems and creativity (authoring tools, creating games, modelling and making)"*.

Teachers also pointed out the lack of pedagogic knowledge or AR applications. Pedagogic knowledge, in this context, means the knowledge of how to integrate AR effectively into teaching and learning. As can be illustrated by this statement: *"I would use AR more if I received more training and could use AR to redefine my lessons"*. Also, two teachers reported students got distracted with AR use. This indicates they had difficulties to coordinate the use of AR to achieve their learning objectives. In other words, data indicated that teachers need more guidance for using AR purposefully in the classrooms as can be seen in these words: *"I would use AR more if I saw other example lessons to get new ideas"*.

The absence of support from school, the lack of time for planning the lessons using

AR and also to use it in the classroom were other important factors preventing teachers to use AR more often.

The lack of these important aspects may lead to a decrease in teachers' confidence to explore this new technology as can be seen in this statement: *"I am not trained enough to feel confident using AR"*.

Another aspect mentioned was the cost involved in AR adoption. This is an important factor since without support it is difficult for teachers to adopt a new technology such as AR. One teacher reported that he tried to use AR, but,*"it still did not work, because I had to use my own materials"*. Other teacher reported to have used his own device and internet connection.

These results evidenced that although teachers were interested and eager to learn more about AR technology, its use has not reached higher levels of maturity in schools yet. Most of the teachers have been experimenting with it in their classrooms, but, they still need things like better infrastructure, tools that support content creation, and time to adopt it more effectively for learning. As one teacher put it: *"learners are not used to the technology so they have trouble getting used to it. After 3-4 lessons they become more competent in using the equipment which facilitates learning"*. In other words, they need to explore this technology much more in order to feel confident in using it.

Different aspects were related to that, such as lack of infrastructure, authoring tools and time. Results have also shown that teachers need more guidance and support in order to better connect AR use with their pedagogic goals. Price of the tools were also a concern for them.

Additionally, the need for AR tools to support collaboration, creativity through content creation (authoring tools) and ability to assess students in more flexible ways are also related to more mature uses of technology. Thus, these would be interesting features to be provided by AR tools. In the following subsection, we discuss the relationship we found between AR application features and the maturity model.

It is important to address as much of these issues as possible so teachers can be more confident in AR use and feel confident enough to explore it in the classrooms and promote effective learning. Finally, it is important to mention that the goal is not just to use more of AR, but use it effectively, connected to the learning objectives and integrated to other technologies available in schools as advocated in the maturity model.

6.5.6 Relationship Between AR Application Features and the Maturity Model

Based on our understanding of the maturity model, we point out some aspects that might be considered when developing AR applications.

1. **Exchange:** in this level, students usually work individually and activities and assessment are usually carried out by the teacher. It is interesting for the tool to enable assessment (usually done in more traditional ways at this stage) of students. It does not necessarily need to enable collaboration;

2. **Enrich:** in this level, there is some sharing of useful apps and tools between teachers and technology sometimes replaces more traditional approaches for learning and teaching. Thus, we might infer that tools might need to enable some collaboration and it might also allow more innovative experiences;

3. **Enhance:** in the third level, learning objectives are more personalised. Teachers work with a range of assessment approaches. Students receive quality feedback and their progress is tracked through the task. The need for authoring tools start to appear at this level because technology should enable personalization and intelligent content. It would also be interesting if the tool allows different assessment approaches to be used and progress track throughout the task;

4. **Extend:** in this level, besides the other aspects previously mentioned, tools might enable collaboration beyond traditional subject boundaries, thus, including interdisciplinary skills and collaborative problem-solving;

5. **Empower:** in addition to the aspects previously mentioned, learning objectives are continually reviewed and revised, are wide-ranging, ambitious, and balance the needs of assessment with the importance of developing skills, which are less easily or not formally assessed. Hence, it might be interesting the combination of AR and sensors that could help teachers to assess students more holistically. Learners receive feedback quickly, usually instantaneously.

6.6 IMPLICATIONS

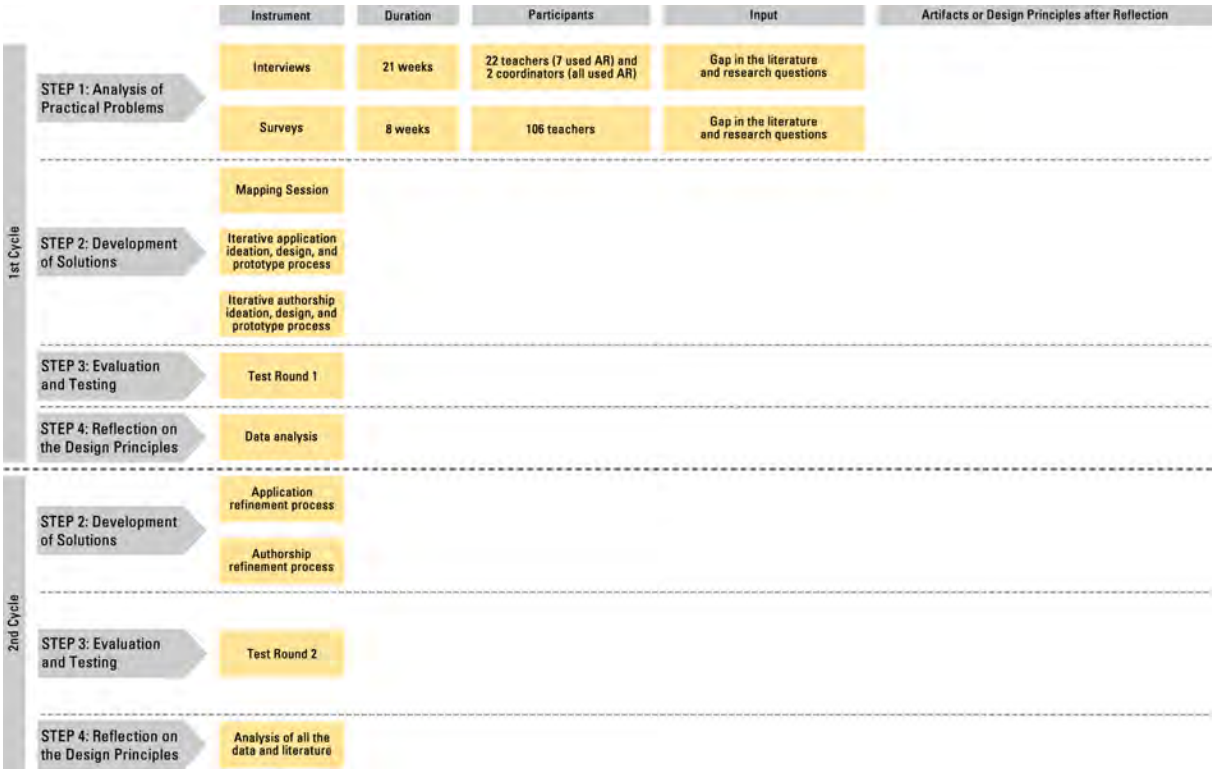
From the identified aspects that are currently hindering AR adoption in classrooms, we believe some of the most interesting for the AR community are: (1) the need to be careful to avoid a lot of effort and frustration for teachers since they are still getting used to this technology. Excessive effort or frustration might hinder their confidence, and prevent future uses; (2) the need for authoring tools, since, these tools would allow more flexible and innovative exploration of AR content in the classroom; (3) the need to support compatibility to many types of devices which may be present in various classrooms; (4) the need to provide collaboration channels among students and also among teachers. It would be beneficial for AR technology platforms to stimulate cooperation among professionals, thus, building a sense of community and helping them advance in terms of maturity regarding AR use.

As regards to authoring tools, some valuable features might be: (1) not relying on internet connection for the AR experience; (2) possibility to create experiences compatible with a variety of devices; (3) possibility to share and reuse content created; (4) possibility to create content collaboratively.

Our results support the literature in the sense that circumstances at the workplace, such as access to up to date infrastructure and supportive culture as well as teachers personal skills and experience with technology play a considerable role in teachers technology adoption (VERMETTE et al., 2019). Results have shown that overall AR use has not reached higher levels of maturity yet as defined by the (Future Lab, 2014). However, the presence of good infrastructure, and a supportive culture combined with teachers personal skills are correlated with more mature practices. Although it is not in AR designers' hands, it is important to understand aspects such as access to infrastructure and teaching support, as well as learning what kinds of resources are usually available in typical classrooms. For instance, it is noticeable that internet connection is not always available as well as access to 1:1 devices. Thus, it is important to design tools that work around such limitations.

Finally, in the Figure 53, we detail the methods involved in the first step of this research.

Figure 53 – Method overview of the first step of the research.



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7 FIRST CYCLE OF DEVELOPMENT, TESTING AND REFLECTION TO PRODUCE DESIGN PRINCIPLES AND ENHANCE SOLUTION IMPLEMENTATION

This chapter details the first cycle of development of an AR tool, Virtual Playground, which allows the creation of augmented storytelling collaboratively, as well as its authoring tool, Virtual Playground Creator. Theses tools have been conceived, prototyped and tested with users through a series of interactions and two iterative cycles of testing and refinement of solutions. The first iteration cycle comprises the conception, development and testing of low-fidelity prototypes of the proposed tools.

As regards the development of solutions informed by existing design principles and technological innovations, we adopted guidelines central to graphical user interface for learners (PETERS, 2014), such as provide feedback; recognize the agency of learners and the locus of control; include the teacher as a local designer and learner, too. The complete list of those guidelines is presented Subsection 7.2. The design principles for AR for education found in the literature such as the ones proposed by (VERT; ANDONE, 2017) were also taken into account. For example, collaboration between end-users, and between authors, as well as offline version. The complete list of the design principles proposed by (VERT; ANDONE, 2017) is presented in in Subsection 4.1.

We were inspired by the Design Sprint method, which offers a step-by-step approach teams can use in one week (KNAPP; ZERATSKY; KOWITZ, 2017). Since it was not feasible in this research to have a team of designers, engineers and teachers for an entire week, we applied some of its design and creative techniques whenever needed. The description of the techniques used are detailed in the following sessions, in which we describe the protocol followed in each step of the process. Our decision of the techniques used were based on our research questions and the time available for each session. We outline below the 6 sessions conducted, in which the first 5 contribute to DBR's Development step and the last one to the Evaluation step. The six sessions were:

1. **Mapping session:** this session occurred on November 12, 2018 and it aimed to map the problems faced when planning and using AR in a lesson. The output of this session was a map that illustrates the use of AR in the classroom to be used in the next sessions;

2. **Sketch Workshop 1:** based on the map of the problems generated in the previous

session, we proposed a challenge so that participants could identify problems and benefits in the proposed scenario and sketch solutions on how AR could help solving those problems. The challenge proposed was: “How might we design a learning sequence using AR to help students understand ELA concepts in small groups?". After the challenge exposure, they came up with positive points that help to teach in small groups and negative points that can get in its way. After that, each participant had a short time to sketch in a paper eight possible solutions for the problems mentioned. Following that exercise, participants chose one of the ideas to sketch in more detail. All the sketches were exposed at the wall. Finally, the participants voted for the sketches and a discussion about them was encouraged. This session occurred on April 4, 2019;

3. **Sketch Workshop 2:** its structure was similar to workshop 1 and it occurred on April 25, 2019;

4. **Decision session:** nine possible solutions were generated in those previous sessions, therefore a more thorough analysis had to be made to choose a solution to implement in the time frame available. Therefore, a decision session was conducted on May 3, 2019. The goal was to analyze the ideas from previous phases and decide which solution would be implemented, all sketches were analyzed. Participants mapped the potential of AR technology and how each solution used this potential to solve the problems mentioned. The objective was to facilitate the visualization of which idea was the most appropriate considering its AR potentials and what listed problems it could solve;

5. **Sketch iteration and development:** the goal of the sketch iteration session was to give more details to the chosen solution. It occurred on June 19, 2019. The result of this session, a more detailed sketch, was passed on to the developers’ team to be implemented;

6. **Evaluation and testing:** we tested the prototype of the authoring tool and the tool itself with language teachers in two different rounds.

In parallel to these sessions, the Ph.D. researcher worked with 2 engineers and 2 designers to decide the requirements for the authorship process. The goal was to define the requirements for authorship based on what teachers wanted to create using AR. This process was collaborative and happened through a series of meetings. Its input was the understand of teacher's creation desires and its output is the paper prototype of the Virtual Playground Creator.

At first, we considered the use of an HMD (head mounted display) device, such as Hololens. However, we decided to use mobile devices since they are portable and usually present in schools, thus, more accessible to our end users. Our initial results (detailed in Chapter 6) demonstrated that infrastructure is an issue for schools and teachers. Our goal was to define the minimal requirements for the AR authoring tool and build its first prototype. The prototype was developed following as many requirements as possible as described in Subsection 7.1.4.1.

7.1 DEVELOPMENT OF SOLUTIONS

The five sessions to develop the solution included a diverse team of participants (i.e: teachers, engineers, designers and the Ph.D. researcher). Based on the AR potential for language learning found in the literature and through the interview with users, the Ph.D. research personal background and availability of participants, we decided to focus on language learning. Therefore, we recruited language teachers to participate in the following stages of the research. Participants were recruited from the university and in online teacher communities for all the iterative sessions.

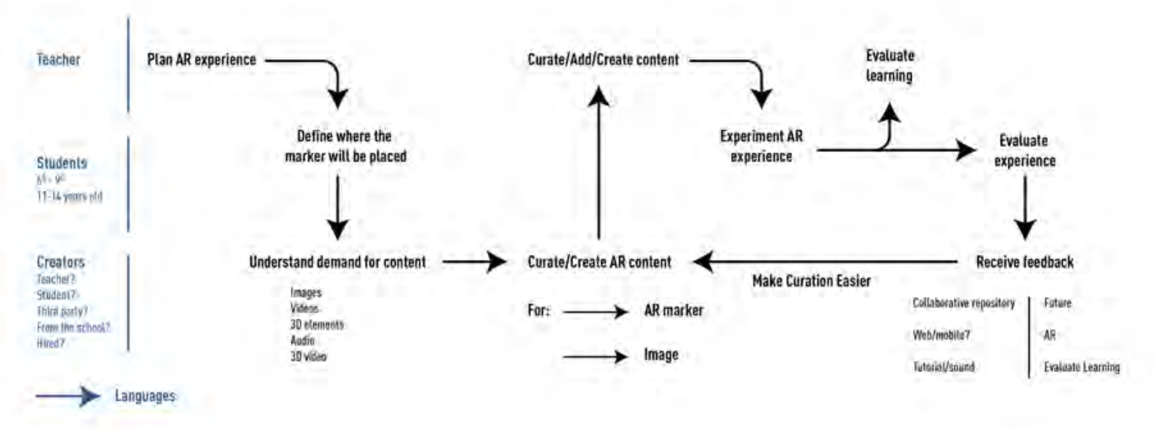
7.1.1 Mapping Session

The mapping session aimed to better understand the problems found in the previous interviews and surveys and provide more details with situations and challenges that happen in classrooms. Among the issues found in the previous steps were the need for classroom management, assessment flexibility and support for teachers. For instance, we observed that teachers usually made classroom arrangements to use AR different than the "traditional ones" where students sit down and listen to the teachers' explanations. Teachers used small groups and rotation among different stations of work, or even had students leave the classroom to engage in the AR experience. We also observed the need to offer an offline version and a mobile version of the tool proposed since these are common constraints in schools. In the mapping session, the participants were a language teacher, two designers, two computer engineers/scientists and the Ph.D. researcher. Furthermore, a map that illustrates the use of AR in the classroom was created to be used in the next sessions.

The map that resulted from this process was a flowchart, as illustrated in Figure 54, so we could better understand the use of AR applications. The map was a visual representation of teachers' user journey (HOWARD, 2014). This journey included choosing an application, understanding the demands of contents and creating/curating them, applying the experience in the classroom and evaluating the learning experience of the students. This journey also included the process of receiving feedback after the experience. Many ideas were generated regarding this aspect, such as a collaborative repository that could be on the web or mobile; and the use of tutorials or sounds. This would serve as input for future experiences and for learning evaluation. It was clear from this map that the ideal tool should be very easy to use to save time, flexible for content creation and reuse, and also enable flexible evaluation.

This session helped us identify demands for types of content, possible target group and the demand for collaborative content creation. The target group used on the map was students in years 6 to 9 (11-14 years old). These groups were chosen since they are able to read and write, are more independent and could benefit from storytelling practices to improve their language skills. We found several challenges we could tackle using AR, such as student's lack of understanding of the topics and the necessity of working together in small groups. The data also reinforced the demand for evaluation of the experience and the use of this feedback to improve both curation and creation processes. Besides reinforcing the some of the Vert's design principles (VERT; ANDONE, 2017), some of the principles proposed by this author differed from the data found through the interviews and survey with teachers. For example, the principle personalization proposes to identify students themselves to keep track of their activities. Our research has shown that teachers focused more on group work. The assessment principle, on the other hand, argues for the possibility of allowing educators to insert assessment items such as quizzes, which was not deemed by teachers as the best way to assess students learning in AR (SILVA et al., 2018). the data collected suggested the need to offer a content library as teachers did not demonstrate interest in creating 3D objects themselves. Also, it was observed the need for content curation since this would help teachers to analyze the content quality as well as save their time. Finally, the data revealed the need for sharing AR experiences as a way to provide students with a real audience for their work and the possibility to build a portfolio.

Figure 54 – Map produced during the mapping session. It presents an overview of the steps taken by teachers from choosing an AR application to planning the experience and executing it.



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7.1.2 Sketch Workshops 1 and 2

The first workshop had one language teacher, two computer engineers/scientists, two designers and the Ph.D. researcher. Participants were presented to a challenge based on the data previously collected throughout this study. The challenge was: *"How might we design a learning sequence using AR to help students understand ELA (English, Language and Arts) concepts in small groups?"*. Participants had to propose solutions for this challenge in a collaborative manner. After the challenge exposure, they came up with positive points that help to teach in small groups and negative points that can get in its way. After that, each participant had a short time to sketch in a paper eight possible solutions for the problems mentioned. Following that exercise, participants chose one of the ideas to sketch in more detail. All the sketches were exposed at the wall. Finally, the participants voted for the sketches and a discussion about them was encouraged. The second workshop followed the same structure of the first one, but it was held in the United States with different participants: three language teachers, two computer engineers, one designer and the Ph.D. researcher.

The goal of the two workshops was to develop ideas to overcome the proposed challenge. For that to happen the difficulties involved were listed and the ideas were developed based on these problems.

The first workshop revealed problems regarding the challenge of using AR to help students in small groups. A sample of the main problems reported by the participants are listed below:

- Listening difficulty;
- Student dependency of the teacher;
- Student's lack of understanding of the topic/task;
- Behavior management when working in groups (when students behave unproductively during group work, such as excessive competitiveness, attention seeking and bullying);
- Presentation of group work (when many groups reach the same conclusions. It may become repetitive);
- Some activities do not work well in small groups.

This workshop also generated five different possible solutions, all idealized by the participants. The solutions were demonstrated using a 3 frame storyboard, illustrating with simple drawings the application being used by students and teachers and a few characteristics of its interface as shown in Figure 55. It was noticed that many solutions involved collaboration between students or storytelling.

Figure 55 – Storyboard of Word Translator.

Font: Image elaborated by one of the participants.

The list of every sketch from the first workshop is presented below:

- **Guardian Angel**: a student that can see some virtual elements through a device would give instructions to another student that can not see these same elements.

The author of the idea illustrated the concept by sketching an interaction in which a student with the device can see a virtual snake and give instructions so the other student can escape or survive.

- **Interactive Director**: students would produce a story so each one will take care of one part (e.g: production of the scenario, sound edition, image edition, costumes, production of space). They will be able to insert characters in the story and interact with them. The system can also help students to produce the language appropriate to the situation. However, it is not an AR application. Therefore, we eliminated this solution.
- **Kit Media AR**: an AR multimedia kit to substitute the textbook, which could be composed of a whiteboard with markers so the system can understand what it is. The teacher can decide what content appears on the board. It could be a virtual character explaining the virtual content or an interactive video or image. There would be an editing tool for the teacher to change the content presented.
- **Word Translator**: a student can use it as a treasure hunt game to build sentences, once he/she identifies an object, he/she can create a sentence about it. For example, a student can point a device camera to a table and the system identifies a characteristic of the table, helping the student to create a sentence. It can also be the opposite. Given a sentence, the student needs to use the camera to find something in the real world whose meaning is related to the sentence.
- **Yellowstone Treasures**: the teacher can set up an expedition in the park and work with students to find things in the environment, such as the tallest/oldest tree. Some clues in the form of virtual content would appear in the environment. The students with devices would see this virtual content and help others to find the tips and there could be a prize for students who reach the goal.

It can also be noticed that all AR solutions tackled the problems of lack of understanding. This evidenced that teachers were aware that an AR application can be used to promote understanding by enabling students to interact with the topic in different and meaningful ways.

The second workshop had the same pattern of results as the first one, problems related to the challenge and possible solutions, which can be seen in the sample of the main problems reported:

- Difficulty to create momentum in the class when the group is too small;
- Less diversity in terms of ability and thoughts because of the limited number of students;
- Groups could be dominated by one or two students;
- There is a risk of unequal contribution among students unless you have set some rules;
- It is really hard for teachers to know every student unless there is a final debrief in the whole class;
- It is quite difficult for the teacher to manage all the small groups and students could be distracted and out of control.

This workshop generated four solutions. These solutions were presented using the same methods as the first one, simple sketches and illustrations of the idea. The solutions of the second workshop were more related to changing and reframing everyday experiences using AR, as can be noticed in the list of ideas below:

- **Expert Reader**: this application would serve as a reading aid for the student. If the student has trouble with reading then when he/she moves the device along the text some virtual content would pop up showing the main idea, the vocabulary, the evidence of the paragraph along with some questions asking students what they noticed and understood about it. There would be different levels of support: easy (maximum support), medium (medium support) and high (minimum support).
- **La Receta**: the student would follow a set of instructions to do a very specific task. The application would guide him/her to follow the instructions by pointing the cellphone to the real objects. For instance, the user would have the cooking instructions by pointing to the pot or the ingredients.

- **Story Every Day**: students can take pictures of objects in their surroundings to learn different vocabulary. The teacher can ask them to create stories based on this vocabulary. They could either do it in English or in their native language and the machine would translate it. They would share their stories with the other classmates.
- **Virtual Playground**: in this application, the user would use everyday objects like a soda can or a coffee mug to be scanned and transformed into virtual objects. The soda can could possibly be an astronaut and the coffee mug could be a monster. The visualization of these virtual content would occur through the device camera. The user would tell stories using the enhanced objects.

7.1.3 Decision Session

Many different possible solutions were generated in those previous sessions, therefore a more thorough analysis had to be made to choose a solution to implement in the time frame available. Therefore, a decision session was conducted composed by a computer engineer, the Ph.D. researcher and two doctoral advisors. As mentioned, the goal was to analyze the ideas from previous phases and decide which solution would be implemented; all sketches were analyzed. The group also mapped the potential of AR technology and how each solution used this potential to solve the problems generated and described in Subsection 7.1.2. The result of this mapping process is summarized in Tables 3 and 4. The objective was to facilitate the analysis of which idea was the most appropriate considering its AR potentials applied and what listed problems in Subsection 7.1.2 it could solve.

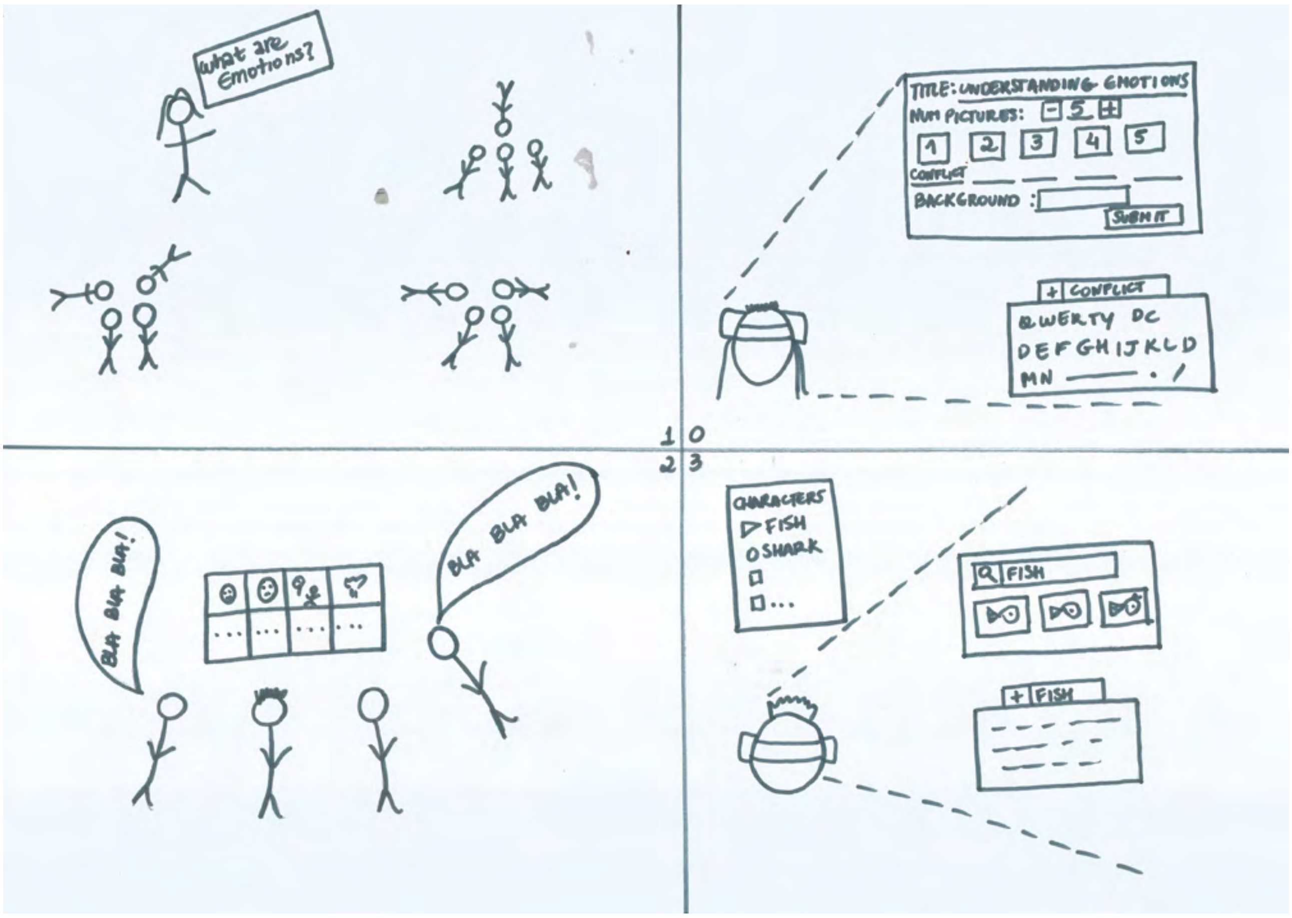
In the decision session, participants produced a map relating AR potentials (visualization, instruction and guidance, interaction, physicality, decreased abstraction, and context), problems listed from the workshops sessions as described in Subsection 7.1.2 and the solutions created during the workshops as well. The list of AR potentials were drawn from the Ph.D. knowledge based on the literature (PORTER; HEPPELMANN, 2017; RADU, 2012). After that, participants chose the idea that tapped into more AR potentials and solved most of the observed problems: Virtual Playground (VP). This solution was the one that made the best use of AR potentials. Also, Virtual Playground was the sketch that could solve most of the problems stated by teachers. Therefore, for the next steps, the chosen idea gained more details and was implemented.

7.1.4 Sketch Iteration and Development

The sketch iteration session was composed of a language teacher, two computer engineers/scientists and the Ph.D. researcher who acted as the facilitator. The goal was to give more details to the chosen solution: Virtual Playground. The participants had already participated in the previous sessions, during the ideation, therefore, they were very familiarized with the research, the methods and the objectives. The map of the problem was presented to participants. The facilitator also highlighted the problem we wanted to solve and AR features. The problem we focused was to reduce students dependency of the teacher. The technology focus was determined by feasibility (3D objects, animations, images). Some constraints regarding the technology were presented to participants such as: (1) they are able to associate a 3D avatar to an image and (2) the interactions are based on proximity of the objects. The facilitator also presented the sketch of the Virtual Playground. She drew 10-15 panels on the board for the storyboard. One participant was invited to be the “artist” (the person who drew the storyboard), participants generated ideas together for the storyboard that detailed the solution (Virtual Playground). The ideas were connected into a coherent story. The facilitator constantly emphasized the need to focus on the problem.

The result of this session, a more detailed sketch, was passed on to the developers’ team to be implemented. The sketch iteration session aimed to detail the idea chosen in the previous one as shown in Figure 56. The concept of the Virtual Playground was detailed in-depth. As previously mentioned, at first, the use of an head-mounted display (HMD) device was considered. However, the concept was adapted to a mobile device format. This choice was made due to the easy access and portability of mobile devices in schools as well as difficulties faced by teachers in terms of infrastructure as revealed in our previous results. In summary, it enables students to create, tell, record and share stories using virtual 3D scenarios and characters.

Figure 56 – Sketch of the solution prototyped - Virtual Playground.



Font: Image elaborated by one of the participants.

7.1.4.1 Virtual Playground

Before developing an authoring tool, it was necessary to have an AR application since the users need to author content for a given application. As mentioned, the chosen solution is named Virtual Playground, which is an application that tries to combine the creative effort in storytelling and the educational potential in AR technology. The process of creating a story involves all the language skills: writing, speaking, listening and reading. In addition to that, AR technology can expand information in an object with virtual content. It can also help the learning process due to its capability to give a visual representation of abstract and difficult concepts through virtual 3D models. These features of AR technology combined can provide a more interactive and engaging experience using real and virtual objects. Through the combination of the educational potential of storytelling and AR, this application could be used as a tool for English teachers and students, in which stories can be created and told for the purpose of learning and practicing English and this whole process can engage and promote collaboration between students.

The concept was designed to be very simple. It was intended to be used without any difficulties by students and teachers, following some well-known principles of intuitive navigation and design (KRUG, 2005). In a classroom environment, any technology to be introduced must be easy and intuitive, because teachers have limited time for class preparation (SILVA et al., 2019b). A complex technology would create barriers to be adhered to. The flexibility of story creation is also a feature designed to address common classroom necessities. With the same scenario and characters, many stories can be told, and many topics can be explored.

Virtual Playground can be experienced by one single player or by a small group of two to four students. In a multiplayer case, the players have to enter a virtual room in the application to have a shared experience. Each room is identified with a unique number, therefore players have to join the same room using the same identifier to have a shared experience. These rooms are just abstractions to make the connection between players. After this stage, the AR experience can begin and the camera is turned on so the application can receive data. The finding and tracking of the images using the camera are handled by Vuforia[1]. The application uses markers, that is, printed images to be tracked and augmented. The experience consists of several character's markers equal the number of players in the room interacting all together. Every interaction that happens can be recorded by a player for later editing and sharing.

A simplified step by step of using the application can be summarized as follows:

- Step 1: run the Application;
- Step 2: join a virtual room to have a shared experience;
- Step 3: place the markers;
- Step 4: tell a story using real and virtual elements using your device.

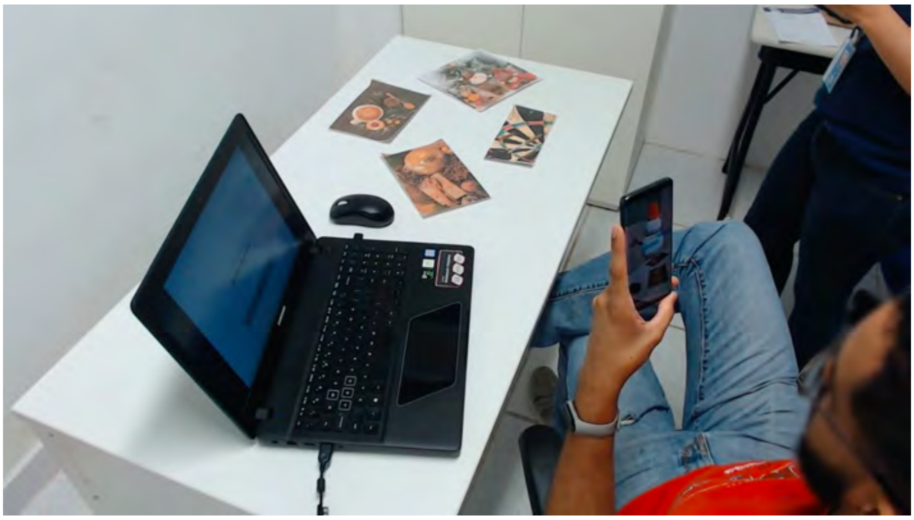
7.1.4.1.1 Virtual Playground Development

Virtual Playground uses printed images as targets to place the 3D objects, a feature that came naturally during the Sketch Iteration. There are markers for the characters,

1 Available at <https://rb.gy/nqzviy>.

which can be moved by the student to explore the scenario and interact with other characters. This experience is shared through different devices, which means that everybody can see the same scene at the same time. Figure 57 shows one teacher using the Virtual Playground.

Figure 57 – A user testing the application.



Font: Image taken by the author.

Before beginning the implementation, it was necessary to choose the tools to do so. Unity Game Engine (HAAS, 2014), Vuforia and Photon Unity Networking (PUN) [2]were the ones chosen. Unity is a good option because it is free, relatively easy to use and has great support. Vuforia, as a Unity extension, has compatibility with the engine, it is also free and by using it a programmer can implement AR features in an application very easily. PUN, another Unity extension, was used for making the networking communication between devices. Mobile devices were the targeted platform, because of its great presence in the classroom environment. The prototype was developed targeting low-end Android phones (starting from version 6.0).

The developers' team was able to prototype an application version in which users were able to associate printed images with virtual content and to implement shared AR experiences. They could also choose which virtual object would be associated with each printed image. This information would be sent to all connected devices through the PUN network. The choices of features to implement were based on what are the minimum requirements that have to be met in order to plan a test with teachers as

[2] Available at <https://rb.gy/2djbyt>.

soon as possible: virtual content associated with printed images and shared experience between multiple devices.

7.1.4.2 Virtual Playground Creator

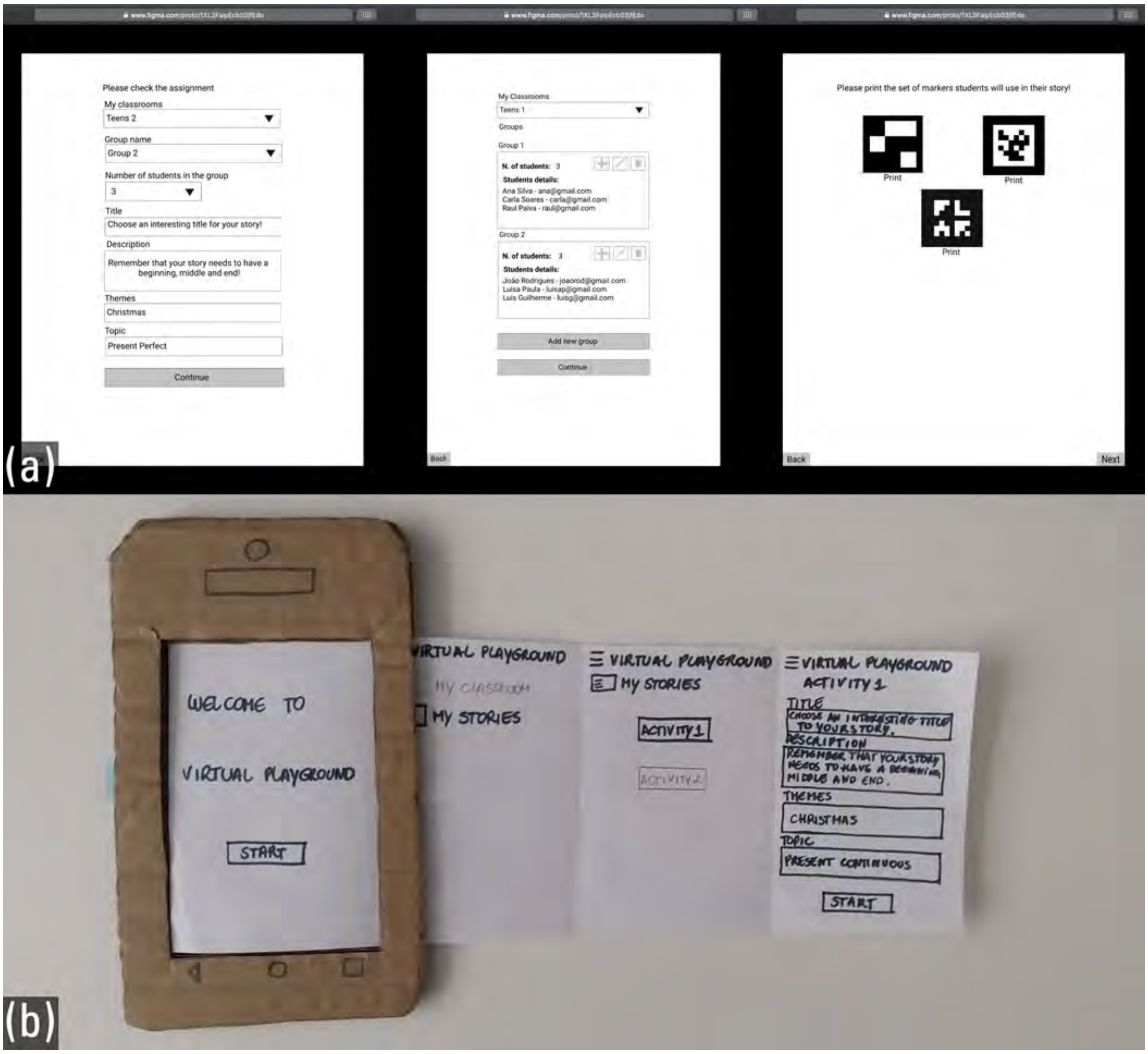
In order to develop the authoring tool, we worked iteratively with engineers and designers. We created wireframes, which are low fidelity pen and paper sketches of the user interface, to help visualize the functionalities of the tool. These wireframes were refined through discussions with 2 engineers and 2 designers, until we found a version that met the teacher's needs found in the research, detailed in Subsection 7.3.2. This first prototype focused on the pedagogic features because they are not commonly found in the AR authoring tools available and in validating the concept of the prototype as a whole. The features included provide classroom management, co-creation of activities, the use of content library, and sharing AR experiences. The prototype was conceived to work in a mobile and offline environment.

The authoring tool is called Virtual Playground Creator (VP Creator) and it has two modules, one for teachers and one for students. First, we developed a low-fidelity prototype using Figma[3] and a cardboard and paper prototype for the teacher and student modules, respectively. The teachers' module allows them to understand how they will assign activities to students using the Virtual Playground. The students' module allowed teachers to understand how the students would access the activity they created and how students would create collaboratively and share their own augmented stories. Figure 58 shows this prototype.

In the teachers' module shown in Figure 58 (a), from left to right, the assign screen where teachers can set items, such as the story theme and the topics students will practice; the list of each student group; and the markers they will need to use. In the student's module shown in Figure 58 (b), from left to right, the initial screen, where students log in, choose the activities assigned to them and check teacher's instructions.

[3] Available at <https://rb.gy/4suokk>.

Figure 58 – Teacher (a) and student (b) modules of the Virtual Playground Creator first prototype.



Font: Image elaborated by the author.

Table 3 – Summary of the Decision Mapping of the solutions proposed in the Sketch Workshop 1.

	Guardian Angel	Interactive Director	Kit Mídia AR	Word Translation	Yellowstone Treasures
Visualization	■		■		■
Instruction and Guidance					■
Interaction			■		■
Physicality			■		
Reduce Abstraction					
Context			■	■	
Energy level management					
Inadequate materials					
Dependency of the teacher	■			■	■
Less diversity					
Listening difficulty					
Students can get out of control					
Individual dominance	■				
Students lack of understanding the topic	■		■	■	■
Unequal contribution					
Difficulty to know every student					
Conclusion redundancy					
Nature of the task					
Competitiveness	■				
Dictatorial leadership	■				

Font: Table elaborated by the author.

Table 4 – Summary of the Decision Mapping of the solutions proposed in the Sketch Workshop 2.

	Expert Reader	La Receta	Story Every Day	Virtual Playground
Visualization				
Instruction and Guidance				
Interaction				
Physicality				
Reduce Abstraction				
Context				
Energy level management				
Inadequate materials				
Dependency of the teacher				
Less diversity				
Listening difficulty				
Students can get out of control				
Individual dominance				
Students lack of understanding the topic				
Unequal contribution				
Difficulty to know every student				
Conclusion redundancy				
Nature of the task				
Competitiveness				
Dictatorial leadership				

Font: Table elaborated by the author.

7.2 EVALUATION AND TESTING

The goal of this test iteration was to validate the concept of the prototype. The tests occurred on November, 2019. Three prototypes were tested in this first iteration. First, a prototype of the teacher's module of the AR authoring tool created using Figma. Second, a prototype of the student's module of the authoring tool created using a paper prototype. Finally, we also evaluated the application that was built based on teacher's input from previous sessions. The application chosen, Virtual Playground, is intended to be a "case study" for the authoring tool proposed.

In order to test these three prototypes, an interview in five acts was conducted inspired in the Sprint Method (KNAPP; ZERATSKY; KOWITZ, 2017). The tests were conducted with language teachers who had previous knowledge about AR applications. They all taught in language courses, which means they normally had more access to technology and were more likely to innovate in the classroom environment. (KNAPP; ZERATSKY; KOWITZ, 2017) suggest that the whole sprint team watch the interviews live and take notes. In our case, one student watched it and took notes that later were shared with the Ph.D. researcher. The authors also suggest that interviewers avoid yes/no question. The interviewer should use neutral expressions such as OK. He/she can also ask incomplete questions such as: "So, it is..." The interview protocol is described below:

1. **Warm greeting and welcome the participant:** the researcher welcomed participants and made sure they felt comfortable. Amenities such as coffee, water and candies were provided. The Ph.D. researcher highlighted that the prototypes were being tested not the teacher and that it is important to understand any errors they noticed in the prototypes to fix them. Participants were also requested to read and sign the consent form, as shown in appendix D, in case they agreed to participate in this research.

   The Ph.D. researcher also asked their permission to record the video of the session;

2. **Participants contextual questions:** the Ph.D. researcher asked questions about participant's lives, interests and activities. This section was conducted as a natural conversation. The questions were: How long have you been teaching? What level do you teach? Do you usually use technology in your lessons? If yes, which

ones? Do you usually use technology in your private life? If yes, which ones? Do you know AR? Do you usually create content using AR? If yes, please provide examples;

3. **Present the prototypes:** the Ph.D. researcher asked participants to test the prototypes. She reminded them that the prototype was being tested not them and that they should expect things to fail and whenever that happens they would be warned. They were reminded that there was no right or wrong answer. Participants were asked to think aloud while they tested the prototypes;

4. **Detailed task for the participant to react to the prototype:** the Ph.D. researcher presented the prototypes for the participant in the following order: application, teacher screens and students screens. She asked participants to do the task: *Let's say you came across this application, Virtual Playground, how do you create content for it?* As the participant conducted the task, he/she was encouraged to talk aloud, using the thinking aloud protocol, a method with which the users "verbalize what they are doing and thinking as they complete a task, revealing aspects of an interface that delight, confuse, and frustrate" (MARTIN; HANINGTON; HANINGTON, 2012). The following questions could be made in order to encourage this process: What is it? What is it for? What do you think about this? What do you think this will do? What do you think when you look at this? What are you looking for? What would you do next? Why? These questions are supposed to be easy and not intimidating;

5. **Quick debriefing to record participant thoughts and general impressions:** the Ph.D. researcher asked questions to support the conclusions. The questions were: What do you think about this product compared to what you already have? What did you like about this product? What did you not like? How would you describe this product to a friend? If you had three wishes to improve this product what would it be? Would you use this application? Why? What for? Would you recommend it to another teacher? Why? What would you recommend?

The data collected was transcribed and analyzed using the thematic analyses as described in Subsection 6.2. This method is used to analyze classifications and present themes (patterns) that relate to the data (ALHOJAILAN, 2012). The unit of analysis is the interview. Phrases and sentences, called codes in the thematic analysis, were created and grouped by themes. Coding means highlighting sections of the unprocessed data and creating shorthand labels or "codes" to describe their content, for instance:

- Participant's comment: *"I do not know what to do in this screen, I think instructions would be nice."*
- Code: difficulty to understand the home screen.

These codes and themes were made by the author and revised by the advisors to reduce bias.

In order to validate the concept of the prototype in terms of teaching practices, we used the framework for structuring media lessons proposed by (BRINTON, 2001). The author divided the typical lesson into 5 stages as appropriately detailed in Subsection 3.1. Although this author proposed the framework for the students. We adapted it since in our work we investigate the perspective of the teacher. We understand teachers as apprentices. Thus, teachers need to understand and use the technology before they use it with the students. We based our analysis regarding the interface on (PETERS, 2014). This work presents some guidelines central to graphical user interface for learners. It helped us to extract the categories used to code our data. The complete list of the categories used are listed below and were also considered in the iterative development process of the tool.

1. Provide Feedback;
2. Focus on cognitive goals;
3. Automate routing or irrelevant tasks;
4. Have a "theory of learning" or a model of the learner;
5. Provide multiple representations and links between them;
6. Use multiple formats and media types to address diversity;
7. Include subject matter content;
8. Recognize the agency of learners and the locus of control;

9. Include the teacher as a local designer and learner, too;
10. Include ways to see the history of interactions and use progress;
11. Recognize that learning occurs not just in schools;
12. Consider the prior knowledge of users;
13. Recognize the students are diverse culturally, linguistically, motivationally and developmentally;
14. Facilitate mobility from screen to floor;
15. Design for prior knowledge and diversity.

7.2.1 Results of the First Test Iteration: Concept Validation

This round of tests was conducted with 5 teachers. Participants were recruited through online teaching communities. They were also requested to indicate fellow teachers that qualified for the study. (NIELSEN; LANDAUER, 1993) show that 5 users is enough to find out major usability problems. The participants were all experienced language teachers who were familiar with AR and had used it at least for personal use. Some of them participated in the previous steps of the research.

The most straightforward result of this step was the validation of the concept. Every participant of the test stated that he/she would use the application. The feedback from all the testing sessions was divided into three themes, following the thematic analysis method (ALHOJAILAN, 2012):

- UI (User Interface) and UX (User Experience);
- Technical;
- Teaching practices.

UI and UX feedback were very predictable. The first prototype had a very simple design. Therefore, some participant's comments were about simple aspects of the UI: *"the letter could be bigger"*; *"the screen is very white"*. Many UX comments were about the lack of some brief tutorials or instructions guiding the user on what to do for the first time using the applications: *"the instructions could be better"*; *"can I go on doing or await your instruction?"*. It is important to reinforce that it was a development choice to implement this way for the first testing phase because the core of the concept had to be tested before any further development regarding UI or UX design. This design decision proved to be useful because this way the concept could be validated with little development time. After the problems related to how to proceed at first were overcome, participants found the applications very practical and easy to use.

The technical feedback was all about some strange behaviors of the connection between devices through WiFi. Sometimes it was not clear if the users were connected or not. On other occasions, some virtual objects were duplicated. During the analysis of these errors, the developers' team realized that the lack of flexibility of the network was an issue. In other words, trying to adapt the built-in functionalities of the PUN network to the application's purposes caused many errors. It was clear for the developers' team that although the PUN networking is very sophisticated, the project needed its own networking, not a third party one, much simpler and flexible, a simple UDP/TCP connection between devices. This is because although it seemed easier to use an already built network, the errors during development and testing evidenced that trying to adapt a general purpose network for a very specific purpose can generate unexpected errors.

For the last category, teaching practices, the participants gave some insights about how and when the use of this application could be interesting taking to account the five stages an ordinary class can be divided into proposed by (BRINTON, 2001) and detailed in the Subsection 3.1.

It was evident that the application could be used in different stages. As illustrated in the following quotes from participant's speeches: *"students could listen and try to put the story in order"* in stage 3; *"the students could work in small groups telling stories using the elements available"* in stage 4; and *"before moving on to the story part, the students could work on the vocabulary"* in stage 2.

Teachers suggested that student's language could be greatly developed if they were allowed to create stories based on their own experiences, which emphasizes the importance of personalizing content according to their own needs. They also suggested that the tool could guide students to create their stories, offering a checklist of steps they should follow to produce it (e.g: negotiate the script with the group). These requests show the importance of providing instructions to students as demonstrated in the following quote: *"the success of an activity depends on the quality of instruction given"*. Finally, one teacher mentioned that students should be able to share their video online only after the previous discussion with the teacher and the group. This request revealed the need for teachers to have some control by moderating content produced by the students.

Concerning the authoring tool, Virtual Playground Creator, we were able to understand how teachers want to co-create activities with their students as well as important features these professionals want to control. They emphasized the importance of a clear delimitation between teacher and student tasks. However, they mentioned the language used was considered misleading sometimes. Some of the teachers had difficulties understanding specific vocabulary, such as target and marker.

We identified two types of authorship: authoring by imitation and authoring by need (or desire). The former refers to suggestions based on their previous experiences with digital tools, such as Kahoot[4] (i.e: a game-based learning platform that enables the creation of multiple choice quizzes) and Google tools. The latter is whenever teachers expressed desire for features based on what they would like to do in the classroom.

Also, we identified needs that would produce new design features, such as the necessity to provide instruction of use in the interface. Teachers suggested that the tool could guide students to create their stories, offering a checklist of steps they should follow to produce it (e.g: negotiate the script with the group). Some suggested that students should be able to share their video online only after previous discussions with the teacher and the group. These suggestions are related to monitoring and content moderation. Also, the inclusion of statistics might help teachers to check student's progress and offer appropriate feedback for them.

7.3 REFLECTION TO PRODUCE DESIGN PRINCIPLES AND ENHANCE SOLUTION IMPLEMENTATION

Finally, the data gathered was reflected upon in order to generate design principles for the development of an AR authoring tool aimed at education. According to (ROGERS; SHARP; PREECE, 2019), design principles are "generalizable abstractions intended

[4] Available at <https://kahoot.com/>.

to orient designers toward thinking about different aspects of their designs". They are derived from a mix of theory-based knowledge, experience and common sense. Design principles are intended to help designers explain and improve their designs. Nevertheless, the authors highlight that "they are not intended to specify how to design an actual interface, for instance, telling the designer how to design a particular icon or how to structure a web portal, but to act more like triggers for designers, ensuring that they provide certain features in an interface".

(ROSALA, 2020) explains that to be effective design principles should have the following characteristics:

1. **Take a stand on which value is important:** this means that each principle should be clear on what value it advocates and why. Thus, avoiding ambiguity;

2. **Inspire empathy:** it is also important that a design principle mention the reason why that value is important to users. This helps designers keep users interest in mind while taking design decisions;

3. **Be concise:** design principles are meant to be short and to the point. This ensures they will be easily understood, referenced, and remembered;

4. **Be memorable:** this means it is important to pay attention to how many design principles are created. It is best not having too many design principles otherwise many may be forgotten;

5. **Not conflict with one another:** Each principle should be dedicated to one value only. Nevertheless, it is important to be careful that the principles do not conflict. If two important principles might conflict, its is important to clearly specify in which contexts one of these principles is more important than the other to avoid confusion among designers.

7.3.1 Documentation and Reflection to Produce Design Principles

The analysis of the results made some general principles very evident. These principles must be followed in future steps of development:

- Problems with internet connection and infrastructure available suggest demand for an offline version to enable AR experience without the internet;
- The initial difficulties concerning the UX suggest demand for an instructional interface in order to help teachers easily understand how they could use the tool;
- To give language teachers and students the power to creatively explore a topic, the application should offer a content library to enable them to access an ample variety of content;
- Teachers intentions to co-create activities with students suggest the need for co-creation and increasingly giving them responsibility for their learning and content creation;
- The need for monitoring and content moderation was evident in teacher's desire to provide feedback to student's work before sharing it with the wide public or the desire to guide students to create their stories, offering a checklist of steps they should follow to produce it;
- Teachers evidenced the need to keep track of student's progress and offer appropriate feedback.

7.3.2 What Design Principles are Important when Authoring for Education?

This study suggests that AR authoring tools for education should consider three aspects: the infrastructure to use AR in classrooms, the augmented reality content itself, and how it will be related to the educational content. We are presenting the design principles that new AR authoring tools should follow as well as ways to incorporate them as features in the authoring tool. These are the *Preliminary Design Principles (PDP)* because they can change in our second evaluation. We present them accompanied by a one-sentence description (AMERSHI et al., 2019). We also include one paragraph to each design principle to state its importance in the context of education.

7.3.2.1 Infrastructure Aspects

In this study, we observed that one of the main challenges school and teachers face when using AR for education are related to the infrastructure. While some schools are well equipped with recently released devices and internet connection, others do not have computers. When met, these design principles can help teachers deal with challenges most schools face related with the infrastructure to use AR in classroom.

[PDP1] Offer an offline version: enable AR experience offline.

- *Importance:* Schools often lack internet infrastructure, which is a major barrier for teachers in adopting technologies like AR (SILVA et al., 2019b). Only non-essential features are not available when there is no internet connection.

[PDP2] Provide mobile version: enable users to use the experience in a mobile version.

- *Importance:* Students often carry mobile phones with them so it is useful to design for these devices. In other words, devices massively used by the target audience, which are currently represented by smartphones and table It is important to notice that as technology evolves and becomes widespread, other types of technology become mainstream.

[PDP3] Provide an instructional interface: provide instructions for teachers to easily understand how they could use the tool.

- *Importance:* This is important because teachers usually have a limited amount of planning time, which can be a limiting effect when incorporating new technology (SILVA et al., 2019b).

[PDP4] Provide support for teachers: help the teacher understand what the AR system can do and how it could be used in their lessons.

- *Importance:* Teachers feel the lack of support as a barrier preventing them from adopting new technologies, such as AR (SILVA et al., 2019b).

7.3.2.2 Augmented Reality Aspects

Our research has shown that teachers are not necessarily the ones that will create the AR contents, such as the 3D objects that will be displayed due to restrictions of both knowledge and time. Therefore, the tool should provide easy access to a content library where they can select appropriate materials to use in their classes. Moreover, teachers could also have the possibility to share AR experiences among them. When met, these design principles empower teachers to create, or better still, to co-create richer AR experiences.

[PDP5] Offer content library: enable teachers and students to access an ample variety of content.

- *Importance:* This is important to allow teachers to use the tools purposefully in their lessons and also to empower students in their learning process. In future versions, we intend to provide access to a free online repository of 3D contents, such as Sketchfab[5], and also allow the students to capture their own drawings and use them as markers.

[PDP6] Enable sharing of AR experiences: enable sharing AR content among fellow educators.

- *Importance:* Our research with teachers has shown that sharing content is important to provide students with an authentic audience for their learning. As for teachers, sharing content can be a tool to foster collaboration among their peers and decrease the planning workload as evidenced in the results from the interviews. These results have shown that some teachers proactively share content with colleagues as way to promote learning and collaboration.

[PDP7] Enable content curation: enable teachers to find and use good quality content previously created by third parties.

- *Importance:* Our research with teachers has shown that they are interested in content curation as it can help them find and use content faster and more easily.

[5] Available at <https://rb.gy/zswc9v>.

7.3.2.3 Pedagogical Aspects

An important aspect that AR authoring tools for education should consider is to provide the means to integrate AR experiences with the pedagogical process. It means allowing teachers to manage their creations among the different schools or classes they teach and to integrate ways to evaluate the student productions. When met, these design principles help teachers to give educational meaning to AR and support learning.

[PDP8] Offer statistics: provide an overview of the usage of the AR experience which would inform educators concerning students patterns.

- *Importance:* This is important to aid teachers in the assessment process by enabling them to provide customized feedback for learners.

[PDP9] Include pedagogic features: enable teachers to co-create AR experiences according to their pedagogical goals.

- *Importance:* This is a significant issue to give more responsibility for the learners by sharing responsibility for learning and content creation with them. The tool also has one module for teachers and another for students where they can co-create the AR experience.

[PDP10] Enable monitoring: enable teachers to keep track of each student work with AR content.

- *Importance:* This is important especially in larger classes where it could be difficult to monitor a large number of groups and make sure that learning is effectively taking place.

[PDP11] Enable content moderation: enable teachers to monitor student's AR production.

- *Importance:* Teachers should not try to control everything, but rather share control of learning by giving students some responsibilities. Nevertheless, some degree of control is important for teachers to ensure students are meeting learning goals as well as avoiding inappropriate content to be published. Also, we intend to create a lock feature that enables teachers to decide what students should and should not be able to change in their task. This could be used to provide freedom to learners according to their development.

[PDP12] Enable classroom management: enable teachers to create and personalize the AR experience according to their own classrooms.

- *Importance:* This is significant because classrooms differ fundamentally from other workplace environments. Aspects such as classroom size, class management and control, discipline and noise as well as managing group work impact teacher's work and decisions.

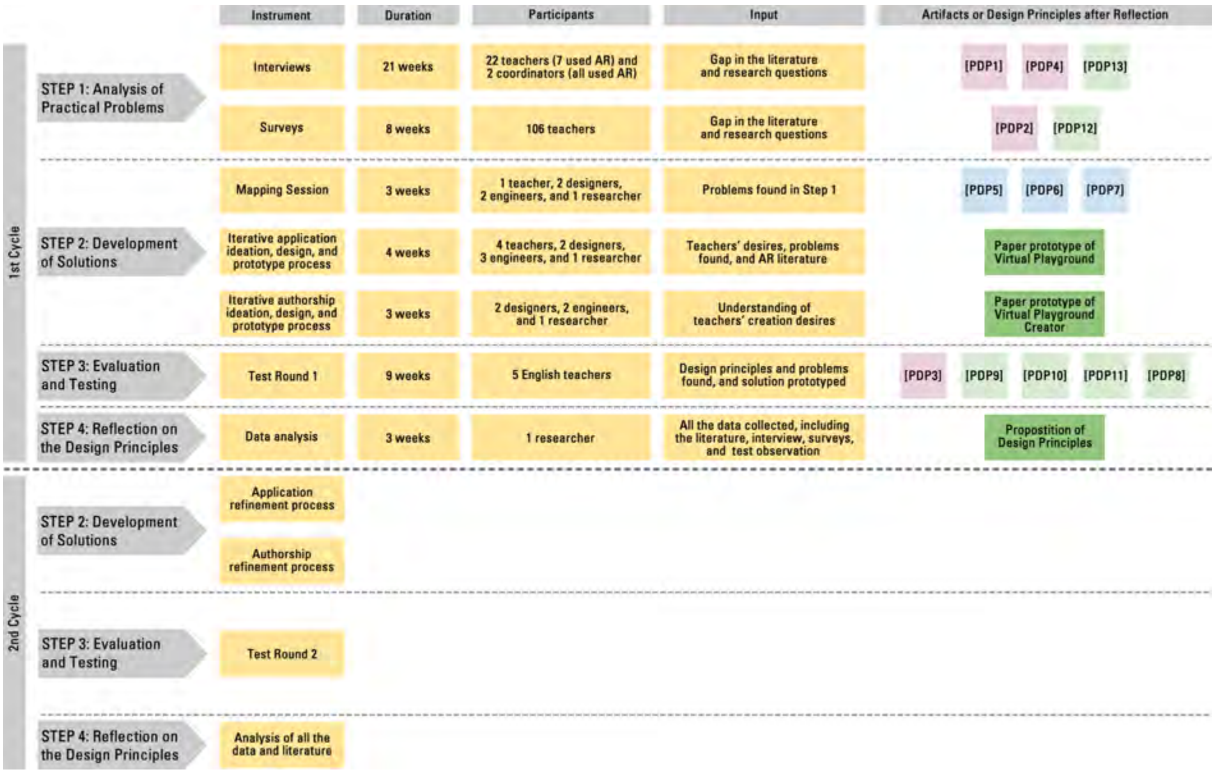
[PDP13] Enable assessment flexibility: enable flexible ways for teachers to decide and create appropriate evaluation.

- *Importance:* This is important so teachers can decide appropriate ways to evaluate their students. Studies have shown that teachers question the appropriateness of common evaluation techniques, such as multiple choice and conceptual questions to evaluate student's work with AR (SILVA et al., 2018; SILVA et al., 2019b). Alternative forms of evaluation can be provided as student's protagonism is encouraged, such as the use of rubrics and peer-assessment. Students will also be able to comment on other stories and teachers would be able to assess their participation. The stories collected can also be used as a portfolio of student's works.

Besides these design principles, it is important to consider the cost to use the AR application since some teachers may not have appropriate funding and may need to pay for it (SILVA et al., 2019b). Some of the design principles discussed in this work were mentioned in existing works (VERT; ANDONE, 2017), such as having mobile version, do not require internet connection, and provide statistics. Nevertheless, such studies lack pedagogical aspects like classroom management and content moderation.

Finally, in Figure 59, we detail the methods and the main results from the first cycle of development, testing and reflection to produce design principles and enhance solution implementation.

Figure 59 – Method overview and main results of the first cycle of development, testing and reflection to produce 'design principles' and enhance solution implementation. The colors of the DPs represent their types. Pink represents infrastructure aspects. Blue represents AR aspects, and green represents pedagogical aspects.



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8 SECOND CYCLE OF DEVELOPMENT, TESTING AND REFLECTION TO PRODUCE DESIGN PRINCIPLES AND ENHANCE SOLUTION IMPLEMENTATION

This chapter details the second cycle of development of solutions informed by existing design principles and technological innovations as described in Chapter 7, iterative cycles of testing and refinement of solutions in practice and reflection to produce design principles and enhance solution implementation.

8.1 DEVELOPMENT OF SOLUTIONS

In this section, we describe the process of enhancing our solution implementations based on all the information gathered from the first cycle and the produced design principles. We also describe the improved versions of the prototypes of both Virtual Playground and Virtual Playground Creator.

Based on the results from our first cycle of tests, we found out different issues that would ideally be fixed in order to promote a better experience for our users. We highlighted the most critical ones and classified them in three different categories, namely:

1. Bugs: for example, the instability reported with some of the 3D objects;
2. System adjustments: for example, the need to create a history of the use;
3. Pedagogic adjustments: such as flexibility in defining the rules for the activities proposed.

These issues were listed in order of priority so our team could work more focused. This process was done for both the application Virtual Playground and its authoring tool, Virtual Playground Creator.

8.1.1 Virtual Playground Refinements

This new version of the Virtual Playground prototype is much more stable than the previous one. The bugs reported, such as objects instability or objects that behaved in an unexpected way were fixed. The dynamics of the application have not changed much. As previously reported, Virtual Playground can be experienced by one single player or by a small group of two to four students. In a multiplayer case, the players have to enter a virtual room in the application to have a shared experience. Each room is identified with a unique number, therefore players have to join the same room using the same identifier to have a shared experience. These rooms are just abstractions to make the connection between players. After this stage, the AR experience can begin and the camera is turned on so the application can receive data. The tracking of the images using the camera are handled by Vuforia. The application uses now two kinds of markers. The first is the base to a 3D virtual scenario. The other is related to the 3D virtual character, which is significantly smaller than the scenario. The experience consists of one scenario's marker and several character's markers equal the number of players in the room interacting all together. Every interaction that happens can be recorded by a player for later editing and sharing. Although all the options are not fully functional some of them have been prototyped in order to understand user's reactions to it. One example of a feature that has not been implemented is the possibility to share student's video. Figure 60 shows one teacher using the second version of the Virtual Playground.

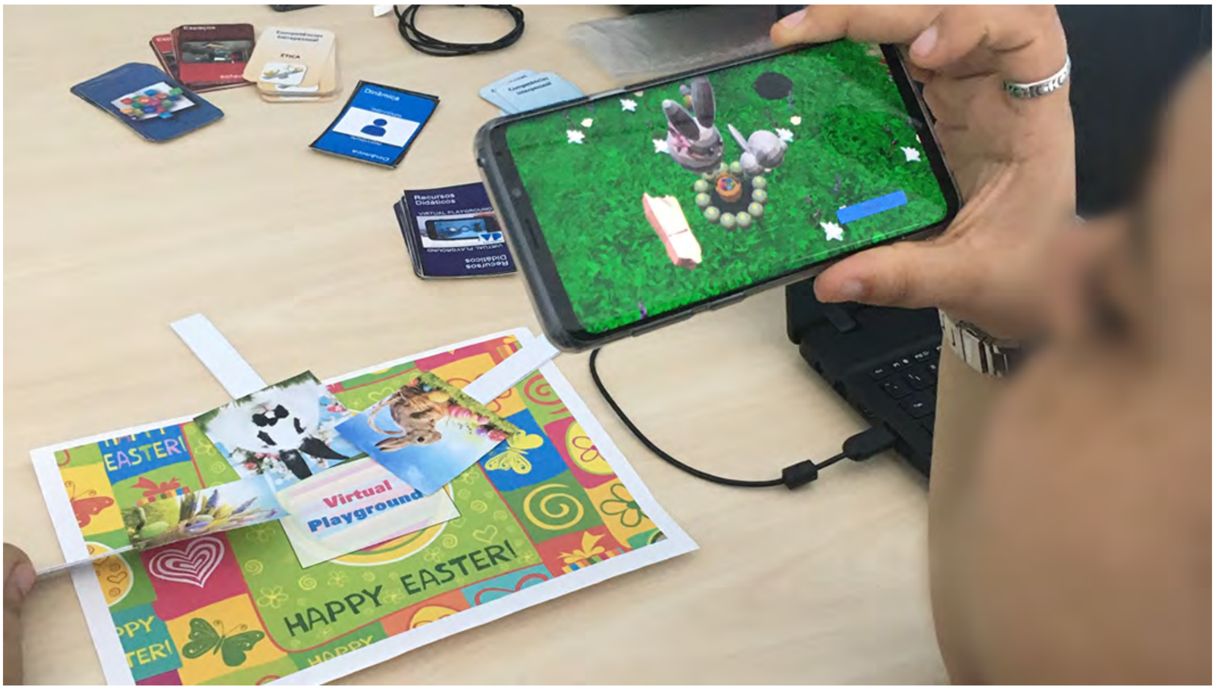
8.1.2 Virtual Playground Creator Refinements

After the first test round, we produced preliminary design principles for educational AR authoring tools. We used them to develop a functional prototype of Virtual Playground Creator considering features teachers missed along with the feedback we collected in the test, including content monitoring options, assessment flexibility and content moderation[1]. This new prototype was developed targeting low-end Android phones (starting from version 6.0). Initially, the app was designed focused on its purposes of use (such as sign in, Playground creation, AR customization and others), but not on design aspects of usability, aesthetic and techniques of engaging users for use. Like the previous version, it has two modules: one for the teacher and another for the student as shown in Figure 61.

On the left image of the teacher's module, we can see the menu with all the options

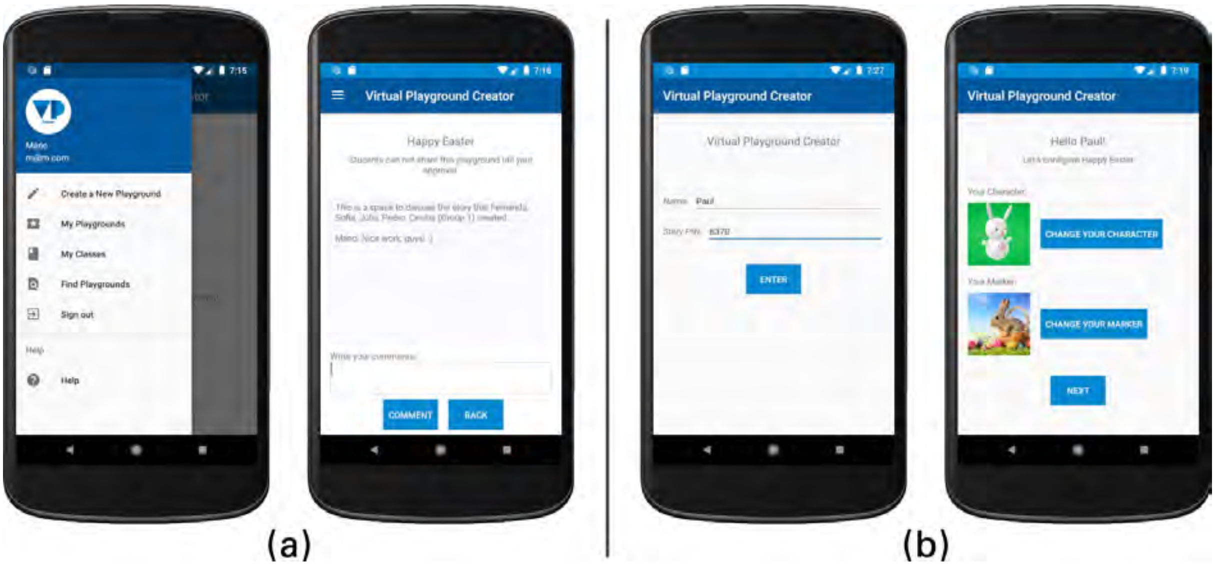
[1] A video showing the Virtual Playground Creator can be seen at <https://rb.gy/hvsueb>.

Figure 60 – One of the teachers using Virtual Playground prototype during the second round of testing. The larger paper enables the virtual scenario while each smaller markers with handlers represent a different character the user can move and see it in the mobile phone.



Font: Image elaborated by the author.

Figure 61 – Teacher (a) and student (b) modules of the Virtual Playground Creator second prototype.



Font: Image elaborated by the author.

they have, such as creating and accessing playgrounds; managing the schools and classes and finding playgrounds of fellow teachers. On the right, there is a comment section where teachers can discuss the student's production with them. Other features like adding guidance for students and editing the playgrounds are also available in the teachers' module of the authoring tool. In the students' module, there is an access mode on the left, in which they enter their names and the playground code the teacher provided for the lesson. As can be seen on the right image, once the student accessed the playground, he/she can personalize the AR content choosing the 3D character and the image that will work as a marker. Other features are also available in the students' module of the authoring tool, such as forming groups and collaborating with colleagues to write the script of the story.

8.2 EVALUATION AND TESTING

The goals of this second round of testing were to: (1) evaluate if Virtual Playground Creator allows teachers to create AR experiences for Virtual Playground they planned to use in their classroom; (2) investigate if there were missing or unnecessary features in Virtual Playground Creator; and (3) validate the design principles developed in this thesis. After the first round of tests, we evolved the Virtual Playground Creator to a functional mobile version aimed to address the feedback from previous evaluation and include the design principles discovered up to this point. This version included the modules of the teacher and the student. Due to the COVID-19 pandemic, these tests needed to be conducted online, which enabled to access teachers who were not necessarily located in our city, thus expanding recruiting possibilities. The tests occurred between April, 2021 and May, 2021.

In order to test these prototypes, we followed the steps below.

1. Invite teachers to read and sign a consent form using Google Forms[2]. Present the research goals, time required to participate, equipment needed and the steps involved in the test[3];

2. Invite teachers to fill out a form about their demographic information and another one about the design principles employed in the tool that will be tested (Form - Part 1)[4];

3. Explain and show, using visuals, what the Virtual Playground is and show parts of the prototype that are available and missing[5];

[2] Available at <https://rb.gy/lbofhw>.
[3] Available at <https://rb.gy/kzm0au>.
[4] Available at <https://rb.gy/u02cqz>.
[5] Available at <https://rb.gy/kzm0au>.

4. Teachers were invited to explore and get familiar with the Virtual Playground prototype through a live Twitch presentation done by the Ph.D. researcher. Teachers were able to chat, clarify questions and ask the researcher to move around to show the tool from different angles;

5. Ask teachers to prepare a complete didactic sequence using the tool Miro as exemplified in appendix C. In this tool, teachers had access to cards, illustrated in Figure 62, containing elements to help create a lesson plan (SILVA, 2018). These elements were the spaces available to teach, evaluation instruments, content, competences to be developed, people involved, and resources to use. The only requirement is that Virtual Playground should be one of the resources. Then, teachers organized these elements in a canvas available in the Miro, as displayed in Figure 63;

6. Ask teachers to create what they said they would like students to do with Virtual Playground using its authoring tool. Teachers were requested to download the Virtual Playground Creator APK[6] and used a screen recorder of their choice or one we suggested to record their screen while using the tool. They sent this recording later to the Ph.D. researcher. They applied the think-aloud protocol (MARTIN; HANINGTON; HANINGTON, 2012) during the use of Virtual Playground Creator.

7. Invite teachers to fill out a Google Form to evaluate the prototypes used in the test (Form - Part 2)[7].

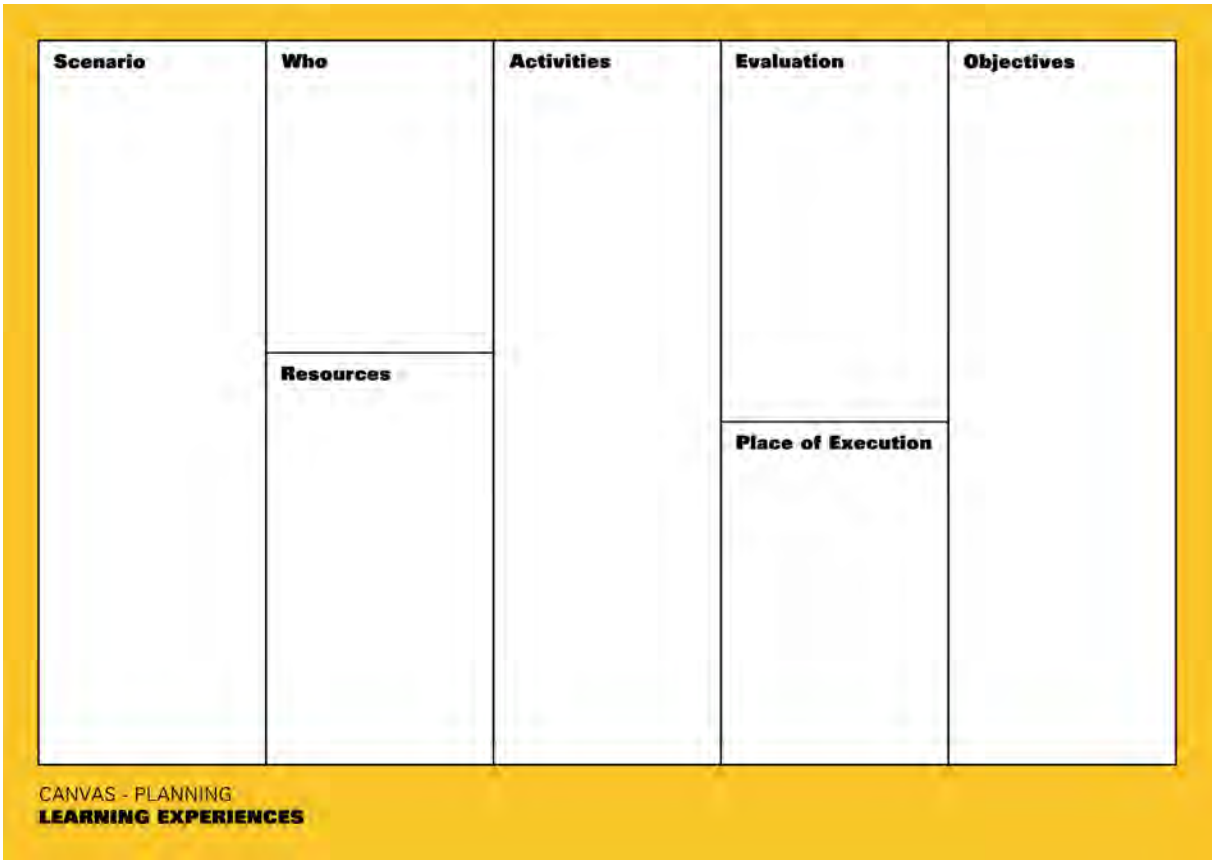
Before the test, teachers received a checklist with the equipment needed for the test as displayed in appendix D and a Google Slides presentation summarizing its steps and goals[8]. This protocol was validated through discussions with the advisors as well as with specialists (i.e: PhD researchers in the areas of technology in education, computer science and interaction). Furthermore, a pre-test with a designer and a pilot test with an English teacher were conducted. Both participants have previous knowledge of AR. Both pre-test and pilot test had the following goals: (1) to check that questions are understandable; (2) to evaluate the reliability and validity of the instruments; (3) to

6 Available at <https://rb.gy/j4thoy>.
7 Available at <https://rb.gy/28eobs>.
8 Available at <https://rb.gy/wwqtyx>.

Figure 62 – Planning cards used in the second round of testing.

Font: Adapted from (SILVA, 2018).

Figure 63 – Canvas Planning used in the second round of testing.



Font: Adapted from (SILVA, 2018).

ensure that our data analysis techniques match our expected responses; (4) the length of the protocol; (5) whether the instructions were clear or unambiguous; (6) the flow of the different sections. These goals were adapted from (KITCHENHAM; PFLEEGER, 2002; RUEL; WAGNER; GILLESPIE, 2016). During the pre-test and pilot test, the participants completed the test protocol and were later invited to discuss their opinions regarding the instruments themselves. As outputs of this stage, we identified aspects that needed to be updated in both forms used in the protocol as well as in the checklist sent to participants, such as the recommendation to do the test in a comfortable space. The flow of the sections were also refined as well as some of the instructions throughout the test. For instance, the Ph.D. researcher needed to check beforehand if the teacher met the requirements for the test and needed to remind teachers to end their recording after testing the Virtual Playground Creator. Furthermore, we validated the time needed for the test, which was defined as 2 hours. We also measured the length of each step. Adjustments were made to make them as concise as possible.

During the test, the data collected from each teacher interviewed consisted of the test transcript, 2 forms, 1 video of the teacher using the Virtual Playground Creator and 1 canva screenshot of the teacher didactic sequence planning. Due to the large amount of data, we decided to use the software ATLAS.ti[9], which belongs to the category of computer-assisted qualitative data analysis software, in order to support the analytical process. This process has been shown to appropriately support qualitative research, easing the coding process as well as the visualization, retrieving and analyzing processes (POCRIFKA; CARVALHO, 2019).

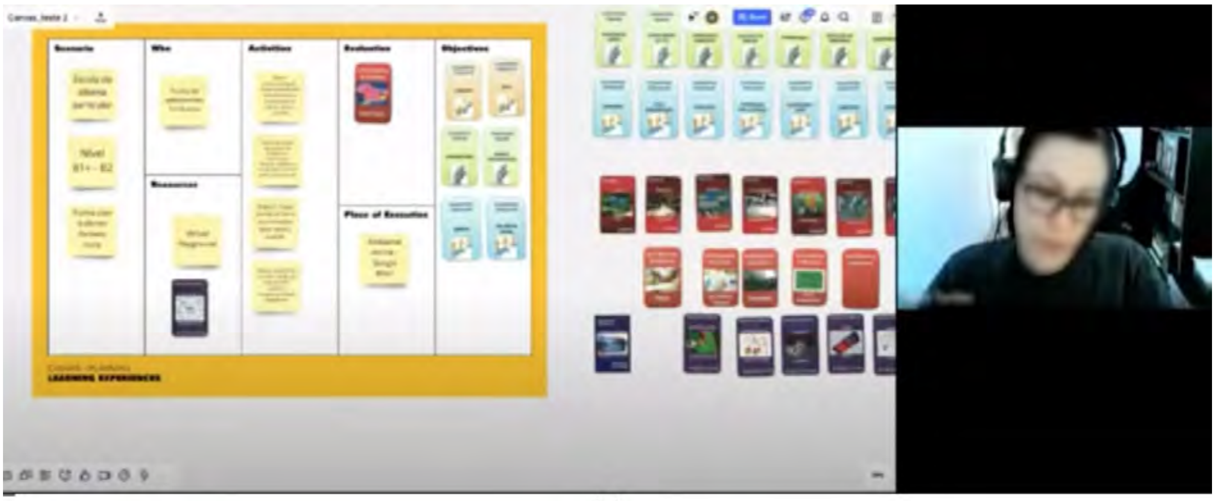
Figure 64 shows a teacher creating her didactic sequence and another one watching a demonstration of Virtual Playground use. Our unit of analysis was all the documents of each teacher considered together.

8.2.1 Data Analysis

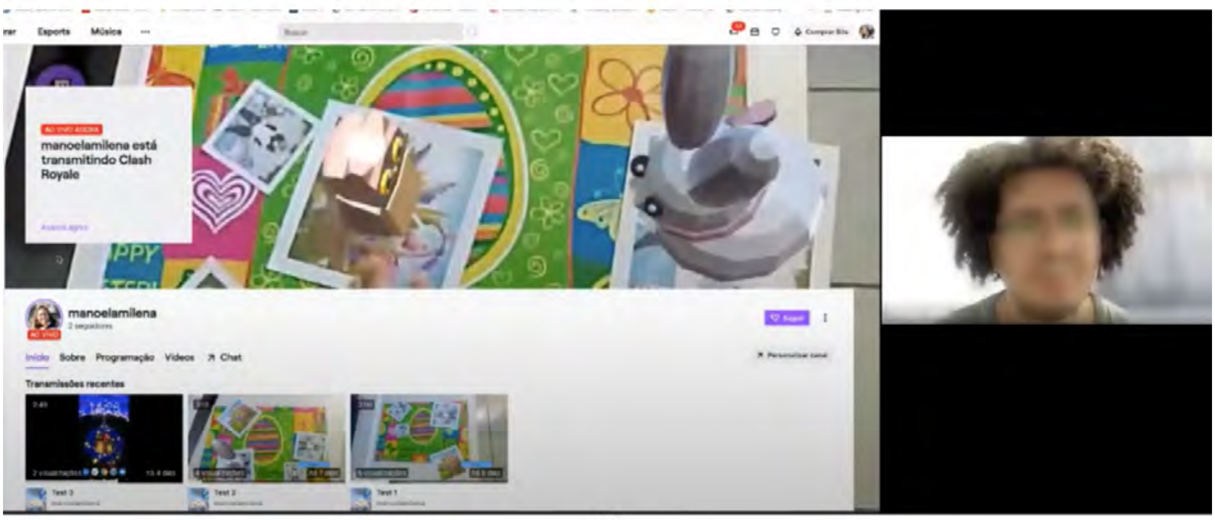
(SALDAñA, 2013) emphasizes that coding is just one way of analyzing qualitative data, not the only way. In his manual, he offers a repertoire of possible filters (coding techniques) to consider and apply to the researcher's approach to qualitative inquiry. He proposed two coding cycles, including 34 coding possibilities. He emphasizes that

9 Available at <https://rb.gy/lo6agb>.

Figure 64 – Teacher (a) is creating her didactic sequence and teacher (b) is watching a demonstration of Virtual Playground use.



(a)



(b)

Font: Images taken by the author.

coding is a cyclical process that requires recoding. The researcher's choices of coding will be directly associated to the study's goals. This process allows better systematization of the coding process, decreasing subjectivity since the steps and criteria are clearly defined (POCRIFKA; CARVALHO, 2019).

8.2.1.1 First Coding Cycle

Before the first coding cycle, we carried the pre-coding phase, which involved reading the data collected (i.e: interview transcripts, videos, canvas and forms). This stage involves circling, highlighting, bolding, underlining or coloring rich or significant participants quotes or passages that strike the researcher (SALDAñA, 2013). We used the software ATLAS.ti to highlight those passages, which facilitated later retrieval of those content. Memos were also written to register the first perceptions of the researcher related to the data at hand.

During the first cycle of coding, (SALDAñA, 2013) offers 24 possibilities of codes. We used the *grammatical methods*, which are techniques for enhancing the organization, nuances, and texture of qualitative data. As part of this method, we applied the attribute coding, which is characterized as a notation, usually at the beginning of a data set rather than embedded within it, of basic descriptive information. We collected demographic information of the participants (i.e: age, gender, academic degree, time teaching) as well as their profiles (e.g: experience with AR). We also applied subcoding, which is a second-order tag assigned after a primary code to detail or enrich the entry, depending on the volume of data or specificity needed for categorization and data analysis. The researcher first coded categories related to each research goal and later divided those codes into subcategories. Those initial categories were: interface, lesson planning, validation of the design principles, comments about the tool and teacher profile as shown in Table 5.

Table 5 – First Cycle Codes.

Code	**Number of Citations**	**Details About the Code Creation**
Interface	81	It refers to aspects related to the tool's interface.
Lesson planning	36	It refers to aspects related to the creation of the didactic sequence by the teacher.
Design principles validation	83	It refers to aspects related to the validation of the design principles proposed by the teacher.
Comments about the tool	21	Teacher's comments about the concept and/or use of the tool.
Teacher profile	28	It refers to aspects related to the profile of the teacher involved in the study.

Font: Table elaborated by the author.

Magnitude coding was also applied, which consists of adding a supplemental alphanumeric or symbolic code or subcode to an existing coded datum or category to indicate its intensity, frequency, direction, presence, or evaluative content. This type of code is supplemental shorthand to add texture to codes, subcodes, and categories. We used magnitude coding in order to classify the design principles according to teacher's rankings. For this classification, we subtracted the number of times the design principle was rated as less important from the number of times it was considered more important to define a "grade" as shown in Table 6. The tiebreaker criterion was the more positive voting (i.e. number of times a principle was considered more important).

Table 6 – Magnitude Coding.

	Most important	**Least important**	**Magnitude**
PDP1: Offer an offline version	4	2	*2*
PDP4: Provide support for teachers	2	0	*2*
PDP3: Provide an instructional interface	2	1	*1*
PDP7: Enable content curation	1	0	*1*
PDP9: Include pedagogic features	1	0	*1*
PDP8: Offer statistics	3	3	*0*
PDP2: Provide mobile version	2	2	*0*
PDP5: Offer content library	1	1	*0*
PDP12: Enable classroom management	1	1	*0*
PDP13: Enable assessment flexibility	1	1	*0*
PDP6: Enable sharing of AR experiences	0	1	*-1*
PDP10: Enable monitoring	0	2	*-2*
PDP11: Enable content moderation	0	4	*-4*

Font: Table elaborated by the author.

Elemental methods were also used as they are the foundation approaches to coding qualitative texts. We applied descriptive coding as part of this method, which summarizes in a word or short phrase, most often as a noun, a topic of a passage of qualitative data. The codes are identifications of the topic, not abbreviations of the content. These codes came up based on the subcoding created previously.

Exploratory methods, those that permit open-ended investigation, were also used. This method consists of exploratory and preliminary assignment of codes to the data before more refined coding systems are developed and applied. As part of this method, we used provisional coding, which establishes a predetermined "start list" set of codes prior to the fieldwork. These codes can be developed from anticipated categories of types of responses/actions that may arise in the data to be collected. They can be generated from literature reviews, study's conceptual framework and research questions, among others. In our case, we created a code based on an adaptation of the classification of the degree of maturity of the use of the tool in the didactic sequence; also, the validation of the design principles were classified by the teachers based on a 3 point likert scale. Finally, teacher's profiles were classified based on the adopter's categories developed by (ROGERS, 2003)[10] and their time teaching as proposed by (HUBERMAN, 2000). We also used as part of this method, the holistic coding, which is an attempt to grasp basic themes or issues in the data by absorbing them as a whole rather than by analyzing them line by line. These codes refer to some teacher's comments and some characteristics of their profiles, such as: their experience and perceptions of technology and content creation. Finally, *affective methods* were used as they investigate participants emotions, values and other subjective qualities of human experience. We coded compliments made to the tool, which reflect emotions towards it.

8.2.1.2 Transition Coding Cycle

(SALDAñA, 2013) explains that the goal of the transition cycle is not to "take the researcher to the next level", but rather to cycle back to the first coding efforts so the researcher can strategically cycle forward to additional coding and qualitative data analytic methods. For this cycle, the author offers four possibilities of codes. Among those options, we chose the *eclectic coding*, which the author admits is difficult to categorize since it meets selected criteria for grammatical, elemental, and exploratory methods; and can be considered both a first and second cycle approach to the data. Nevertheless, he argues that it best fits as an exploratory method. He explains that it employs a select and compatible combination of two or more first cycle coding methods. The author stresses, though, that the method choices should be purposeful and serve the needs of the study and its data analysis. In this stage, we refined the codes generated in the first cycle of coding. Also, *simultaneous coding* was applied at this stage. This type of coding is classified as part of the grammatical method and consists of the application of two or more different codes to a single qualitative datum, or the overlapped occurrence of two or more codes applied to sequential units of qualitative

[10] Classification details can be found at <https://rb.gy/r5szln>.

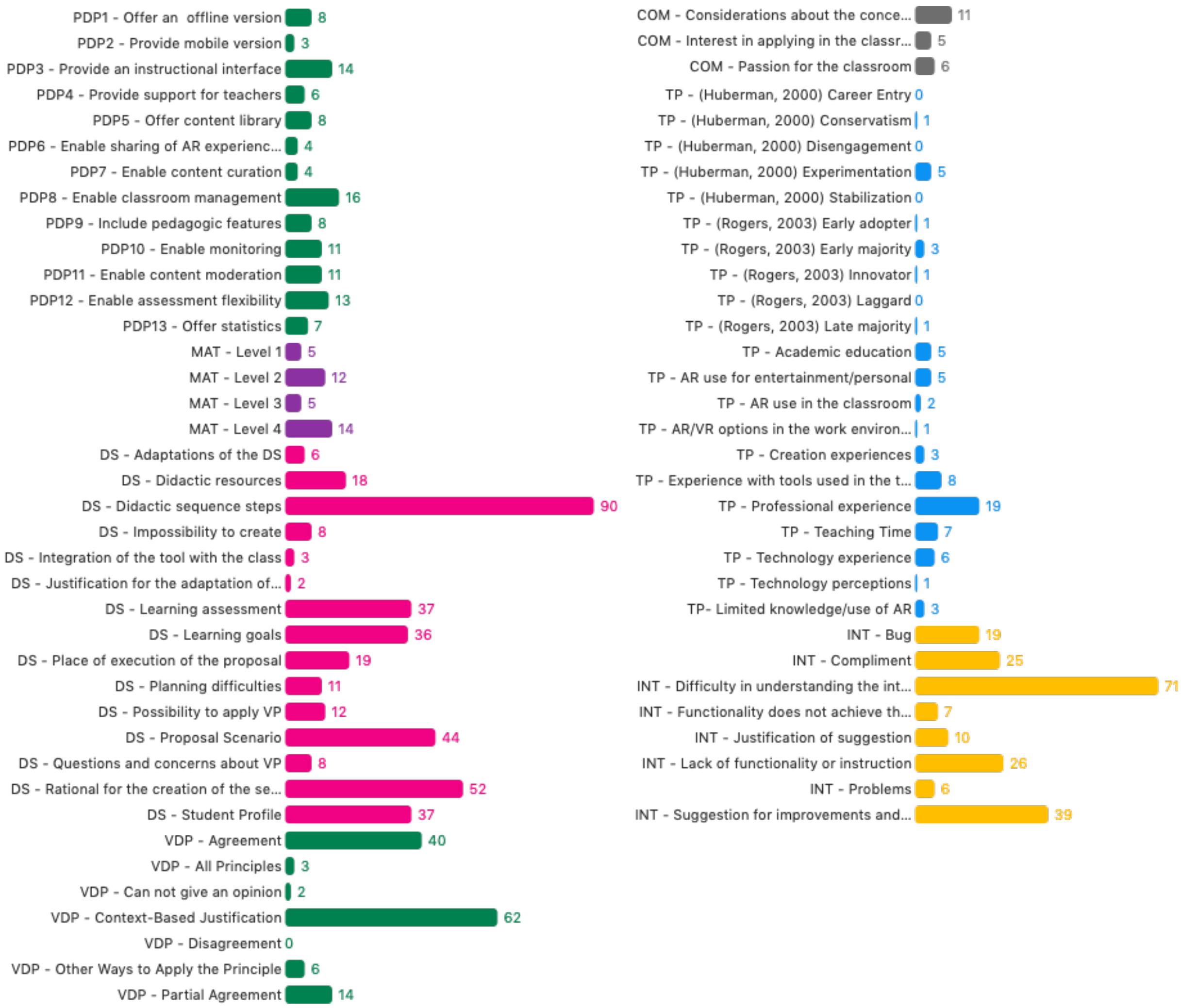
data.

Throughout the study we employed an additional transition method suggested by (SALDAñA, 2013) named *shop talking*, which consists of regular talks with a trusted peer, colleague, advisor, mentor, expert, or even a friend about the research and data analysis. Throughout this study, we discussed with advisors, and fellow researchers about the coding and analysis process.

8.2.1.3 Second Coding Cycle

Second cycle coding methods, according to (SALDAñA, 2013), are advanced ways of organizing and reanalyzing data coded through first cycle methods. The author explains that the primary purpose during this cycle is to develop a sense of categorical, thematic, conceptual, and/or theoretical organization from your array of first cycle codes. He proposes six types of coding for this cycle that can be used whenever the researcher deems necessary. Among the options offered, we chose *pattern coding* to help us achieve the first and second goals of this test, namely: (1) evaluate if Virtual Playground Creator allows teachers to create the AR experience for Virtual Playground they planned to use in their classroom, and (2) investigate if there are features missing or unnecessary in Virtual Playground Creator to adjust for the next iteration. (SALDAñA, 2013) explains that pattern codes are exploratory or inferential ones that identify an emergent theme, configuration or explanation. They are a type of meta-code, which means they pull together a lot of material into a more meaningful and economic unit of analysis. In other words, pattern coding is a way of grouping those summaries into a smaller number of sets, themes or constructs. To help us achieve our third goal for this test (validate the design principles developed in the thesis), we used *ellaborative coding*. Ellaborative coding is the process of analyzing data to develop theory further (SALDAñA, 2013). In this type of coding, the goal is to refine theoretical constructs from a previous study, the author explains that relevant text is selected with those constructs in mind. He adds that two different yet related studies are necessary for this type of coding. In our case, we are contrasting the results from these tests with results from the previous steps of this study. In ellaborative coding, the theoretical constructs emerge from the coded data's themes that are then grouped together into categories or meaningful units. The final version of codes are shown in Figure 65. This result will be properly discussed in the following sections. It is worth noticing that the code comments “COM” does not have a dedicated subsection for discussion, but rather will be detailed throughout the analysis of the codes whenever pertinent. The codes related to the validation of the design principles will be properly discussed in Chapter 9.

Figure 65 – Second Cycle Codes. (PDP#) stands for preliminary design principles number. (MAT) for maturity level. (VDP) for validation of design principles. (DS) for didactic sequence. (COM) for comments. (TP) for teacher’s profile. (INT) for interface.



Font: Image taken from ATLAS.ti.

8.2.2 Results of the Second Test Iteration: Validation of the Anticipation of Use of the Authoring Tool

This round of tests was conducted with 6 experienced language teachers who were recruited through online teaching communities. All of them were familiar with AR and have used it at least for personal use. Some of them participated in the previous steps of the research. The average length of the test was 2h36m34s. The longest test lasted 3h09m47s and the shortest one lasted 1h38m14s.

8.2.2.1 Teachers' Profile (TP)

The sample of teachers was balanced regarding gender. 50% of them are male and 50%, female. They were aged between 31 and 48 years old. Their average age was 37 years old. As regards to their academic background, the majority (4 or 66.67%) was graduated in language teaching (both English and Portuguese). Whereas 1 (16.67%) was graduated in communication and the other in foreign trade. Despite the fact that 2 (33.3%) were not graduated in the area they work, they are all experienced teachers. Their average teaching time was 14.8 years. The less experienced teacher has been teaching for 9 years, while the most experienced one has been teaching for 31 years. Thus, the majority of participants can be classified as in the experimentation stage of their careers, which according to (HUBERMAN, 2000) suggests that they are in a phase characterized by experimentation, motivation and search of new challenges and/or moments of questioning and reflection on their careers. Only one teacher was classified in the conservatism phase, which is described as phase of either conformism or activism (HUBERMAN, 2000). This particular teacher has demonstrated to be active. She is even currently doing a master degree in education and technology. It is worth noticing that in general these teachers seemed very engaged in their profession. One of the categories of the code comments "COM" as illustrated in Figure 65 captured lines that reflect teacher's enthusiasm for their careers. For instance, T2 was working as a consultant for the use of technologies and she mentioned that

> *"(...) you can take the teacher out of the classroom but you never take the classroom out of the teacher, right?"*.

As regards their adoption categories (ROGERS, 2003), half of them were classified as early majority adopters, each one of the other three teachers (16.67%) were classified as innovator, early adopter and late adopter. As regards their knowledge of AR, three (50%) used AR primarily as entertainment through games, such as Pokémon Go and Snap chat filters and two (33.3%) have used it with students. Two of them (33.3%) have limited knowledge of AR. They are identified in this study by $T\#$, where $\#$

are their corresponding numbers. Although we are aware that this sample might not represent the entire population of teachers, we believe they are suitable to assess the prototypes developed and explore new and interesting ways to use them in the classroom environment.

8.2.2.2 Considerations About Teacher's Didactic Sequence (DS)

One of the goals of this step of the study was to evaluate if Virtual Playground Creator allows the teachers to create the AR experience for Virtual Playground they planned to use in their classroom. In order to investigate this, we attempted to answer two questions:

1. Are there any relationships between the possibility of applying Virtual Playground in the didactic sequence and teacher's experience with AR?
2. Are there any relationships between the teachers profile and the level of maturity of technology use in their didactic sequence?

As regards to the first question, although we could not infer a strong relationship between the possibility of applying Virtual Playground in the didactic sequence and teacher's experience with AR from the sample collected some considerations can be made about this topic. The two teachers (T2 and T6) who have used AR in their lessons previously proposed activities that expanded the current possibilities offered by the tool proposed (i.e: insert dialogues and options in the narrative as well as change the 3D objects depending on the character's interaction throughout the story). Thus, they would need to modify their original planning to apply it in their classrooms. Also, the two teachers (T1 and T4) who reported limited knowledge of AR showed reservations regarding the use of the technology as they did not feel completely comfortable with it at first. For instance, T4 opted for a more traditional approach named PPP (Presentation, Practice, Production) as illustrated in his speech:

> *"(...) as I mentioned before, I'm thinking about a traditional class in a sense that it doesn't have a lot of things different from what we're used to seeing in classes so that it stays well within control and that it can be done well. It's within what the teacher is used to doing. Then we have a new element,*

which is generally the use of the tool, right? when the students will use the virtual playground to create their stories. If we were to think about an English class. This lesson would follow a very traditional approach: PPP. Presentation, practice, production. And then, at the time of production, then the students would use the virtual playground. And then they will build their little story. The teacher would use it beforehand to demonstrate, right? To insert them in a story there as an example. And then each student would be invited to use it. (...)".

T1, when asked if she has any questions or concerns regarding the use of Virtual Playground and/or Virtual Playground Creator replied the following:

"I don't know if I would be able to give the necessary instructions to the students today if they have many questions."

It is important to point out that these teachers although reporting limited AR experience, have plenty of experience using technology for education. T4 has been researching this topic throughout his academic career and T1 is currently doing a master degree on that topic. These results suggest that even though teachers are familiar with other types of technology, in the face of the introduction of AR they suggest the need for more caution and experimentation at first or even some concern regarding their own ability to provide support for students and keep their class under control. Among the teachers who used AR for entertainment, all of them evaluated that they could use Virtual Playground in their classrooms. T5 mentioned the need to present written information for students during their production time. T6 highlighted the need to adapt the themes chosen for her lessons. One of the categories of the code comments "COM" as illustrated in Figure 65 registered teacher's interest in applying the tool in their classrooms. Four teachers (T1, T2, T5 and T6) demonstrated spontaneously their interest in applying it in their classrooms. T2 mentioned that although she was working as a technology consultant in the school she could apply the lesson as an invited teacher.

Nevertheless, the limitations of the 3D library, as expected, were mentioned by all the teachers. T3 highlighted the need to create his own 3D objects. It is worth mentioning though that when asked if he has already created 3D content, he mentioned the following:

> *"Well, create from scratch with an application, with games, no because I don't have the tools neither the institutions I work with have these resources. But it has already been suggested to work with VR at the school I teach but in fact we were never able to produce anything. Nor use the games available there."*

This quote suggests that the teacher needs more input from the school to both use and create AR and VR content. This shows that although teachers usually demonstrate the desire to create content, this is a difficult task to do in real life, which might need extra support from stakeholders. Regardless of their previous use of AR, the teachers did not present difficulties to elaborate the didactic sequence. Their rational to create the experiences were their previous teaching experiences, i.e., lessons previously taught (T4 and T5); and lessons they would be teaching in the next few days (T1, T3 and T6) as well as their impressions and ideas after the observation of the tool (T2).

The second question refers to possible relationships between the teacher profile and the level of maturity of technology use in his/her didactic sequence. In order to define teacher's profile, we classified them according to the adopter categories proposed by (ROGERS, 2003) using the data available about them. Based on this classification, the distribution of our sample was the following:

- Innovators: T2
- Early Adopters: T4
- Early Majority: T1, T5 and T6
- Late Majority: T3
- Laggard: None

The lesson plans proposed by those teachers were codified (provisional coding) according to a previous classification developed in order to understand the maturity of technology use in the lessons. This classification was adapted from the (Future Lab, 2014) framework. We divided this classification in four stages as shown in Figure 65 labeled as "MAT" for maturity level. We have not considered the fifth stage as proposed in the framework due to the scope of this research, which is focusing on the teacher:

- Level 1: T3
- Level 2: T1, T4 and T5
- Level 3: None
- Level 4: T2, T6

One determinant characteristic that made these didactic sequences be classified as level 2 is the use of technology to enrich existing approaches to teaching. For example, T4's sequence presented many characteristics of a level 3 plan, such as include in his goals work with higher order thinking; he also planned to involve students in a more collaborative and independent activity using the application. Nevertheless, he used AR as an strategy to enrich more traditional approaches, which is a characteristic of level 2.

Based on the data collected, we have not found an evident relationship between the teacher profile and the level of maturity of technology use in his/her lesson plan. However, some considerations can be made about this topic. First, as expected we observed that the innovator teacher created a lesson plan that can be considered level 4. This teacher proposed more unexpected uses for the AR tool, which included interdisciplinary content among her objectives and a lesson centered more on students' independent development. T6 also planned a lesson considered level 4 in terms of maturity. Although this teacher was considered early majority, she has previous experience using AR in her lessons. In these two lesson plans, it is noticeable an expansion of the tool's potential, which can be seen from the suggestions of adding texts and interaction between 3D objects and its use to expand the students' linguistic skills and abilities. As previously mentioned, 3 lessons were considered level 2, two of those lessons were proposed by teachers classified as early majority adopters and the other by a teacher considered early adopter. It is important to point out that T4 who was considered an early adopter mentioned that based on his experience he usually introduces a new technology in a more familiar approach.

> *"My intention is a practice I have as a teacher. When I'm using something new I try to focus and not keep inventing too much because it gets a little out of control, right? If you're working on a new tool and want to get a very large set of features from it or if you're working on a new tool and want to*

use other tools in the lesson too, I think there's a lot for you to pay attention to and then you can lose a little bit of control of the pedagogical direction of the lesson... (...)"

As pointed out previously, the most determinant characteristic for this level (at least in the sample analyzed) is that teachers classified as level 2 tended to enrich their traditional teaching approaches. It is important to mention that in our sample the technology prototyped was new to most of these teachers because only two teachers participated in previous phases of the research. The teacher classified as late majority proposed a lesson classified as level 1. This teacher did not explore the full potential of the technology. His plan was to use it for students to create sentences using prepositions, the grammatical topic being studied and illustrate them using AR. Based on these results, we understand that the AR tool proposed has potential to be used in different contexts and levels of maturity depending on the teacher's - and why not add student's - creativity. This latter point might be explored in future works. The tool also allowed teacher's to work with diverse skills and competences as evidenced in the lesson plans proposed. Although no clear relationship could be established between teacher's profile and the maturity of didactic sequence proposed, results suggested that teacher's unfamiliarity with the technology might generate a tendency to more conservative approaches and need for control.

To summarize, as regards to our first goal, data has shown that in general the Virtual Playground Creator prototype allowed the teacher to create their AR experiences proposed, although, in some cases modifications were needed. The most visible issues were related to the limited 3D library in the prototype evaluated and lack of 3D modeling possibilities. We noticed that although teachers demonstrated interest in creating 3D content themselves, some of their lines revealed that this is not always easy due to a range of factors already discussed in this work, such as workload and knowledge. When asked about the possibility of content creation, T4 summarizes his ideas about this issue as follows:

"Creating it himself. I think it would be interesting although it would already be something that you would work to implement knowing beforehand that it will be little used. That there will be a minority that will use it, right? But if it's possible to have, I think it would be cool."

He mentioned that in his experience, some schools hire a special employee to support teacher's use of technology and the creation of simple digital artifacts, such as videos and games. Also, we noticed that the uses proposed seemed to vary according to teacher's previous use of AR and that this aspect, along with teacher profiles and experiences with technology also influenced the maturity of the uses proposed.

Finally, it is worth highlighting that one of the categories of the code comments "COM" as shown in Figure 65 captured teacher's considerations about the concept or use of the tool. Most of the teachers evaluated the concept positively describing the tool as "cute and beautiful"(T1), 'ìntuitive"(T2), "interesting" and a "very good and promising idea"(T3), and "cool" (T6). T2, though, mentioned that it also can have a high distracting potential, thus, she suggested to create conceptual maps for students' stories in her lesson in order to guide them throughout the process.

8.2.2.3 Considerations About Virtual Playground Creator Interface (INT)

We also observed if there were features missing or unnecessary in Virtual Playground Creator to adjust for a next iteration. When ranked by frequency, we observed that most of the issues raised were related to difficulties understanding the interface (71 citations) as can be seen in Figure 65. Most of these comments were related to nomenclature such as "institution", "private playground", and others. For instance, T6 needed to register again, because she got confused due to the need to add the institution twice. This type of result was expected since some of the functions were experimental and were not completely implemented, such as the details for the lists and filters to find playgrounds. Another issue raised was related to how the teacher selects and organizes student's groups. T2 presented difficulties to understand where to click to see the comments. Many adjustments regarding the interface were made to fix the issues raised, as detailed in Subsection 8.2.2.4.

The second most common code was suggestions for improvements and features (39 citations). The code justification of the suggestions (10 citations) were directly related with this code. Due to the exploratory nature of the test, teachers were encouraged to think about different possibilities with the application and in some cases expand and propose different uses for it that would suit their needs. For instance, T2 proposed to add individual instruction feedback to students through the comment feature. She justified that:

> *"(...) because when we put students in a group, it doesn't matter their age. You put a group to work, there's always a student who stands out, there's always the student who lags behind, there's always the student who doesn't do anything and joins the group just to put his/her name, right?"*

Another suggestion was given by T5 who manifested the desire to work with improvisation rather than a script. Although he recognized that in this idea students practice little reading (i.e. in his context they will read the adverbs suggested by the teacher) and no writing, he emphasized that this option brings humor to the class through the unexpected sequence of the story. Although we acknowledged the value of these particular suggestions, we did not implement them. The first one because we understand that one of the goals of the tool is to promote group-work and that it would be easier for the teacher to have a centralized communication process. As for the second one, we understand this is up to the teacher instruction than the tool itself.

Another frequent suggestion referred to the need to facilitate how teacher's see what students will see as they interact with the application, which was accomplished through the addition of the button "view as student". Other interesting suggestions by T6 were the addition of rubrics as well as the gamification of the experience so students would collect stars for example as they progress towards their goals. T1 suggested to have the application for iOS. These suggestions have been collected for future iterations of the prototype. Other suggestions involved the desire to highlight important points of the instruction to students as *"students have the habit of scanning texts"* according to T2. Both T2 and T5 suggested the use of avatars. As T2 put it:

> *"When the student creates the character, it has that gamified motivational aspect of avatar creation that gives the impression of belonging to the student. So it's very, very cool."*

Another important aspect was the integration of the AR tool to different steps of the lesson, both real and virtual. T2 suggested that students could take pictures of the mind map they create for the story and integrate it in the application. In her words:

> *"I think it gives depth to what will be created in the tool. It ends up going beyond just creating a moment for the class, right? You can put the entire*

class, the whole line of learning reasoning in the same tool so it adds value to the tool and learning."

T5 also suggested to use as markers laminated images he has in his school. These suggestions indicate the desire for integration between the AR application and the classroom environment, which is aligned with literature findings. (CUENDET et al., 2013) proposed the principle of integration when designing AR for the classroom. Our findings reinforce this aspect concerning authorship as well. We conclude that although the tool has been generally well accepted, teachers suggested interesting features that allow us to better understand their needs. Although not all of them were implemented in the final updated version, they are collected for future iterations.

The code lack of functionality or instruction had 26 citations. As regards to functionality, T5 and T1 wanted to the see their stories from a different angle, which was unstable due to marker issues. One way to solve that in future versions is to only provide markers that are more stable. Also, analyse the markers teachers and students will add and let the tool tell them if the marker is stable and give them the option to replace it if it is not. Other issues related to instructions were the lack of clarity regarding what to do with the PIN number and markers, give choice for the scenery marker, the lack of menu option in the student's module, and provide more details on how the tips will appear for the students. All of these issues were addressed in the final updated version as discussed further in Subsection 8.2.2.4.

The code compliment has 25 citations. The compliments were related to different aspects of the tool, such as the possibility to interact in the same room (T2) and the fact that the 3D objects are responsive (T3). T1 and T6 highlighted that they liked the comment option, which reinforces the importance of giving feedback to students. T5 pointed out that he liked the option to set the playground as private, whereas T4 highlighted the fact that the default option is to leave the playground private. These comments reinforce the importance of moderating student's content. Another compliment was related to the option topics to avoid, which was defined by T2 as a *"a positive limitation for the student"*. T3 mentioned that the adaptations made in the prototype comparing the first (test 1) and second version (test 2) were cool. Both T1 and T3 participated in both rounds of testing. T2 mentions the application is simple. It is interesting to note that most of these spontaneous compliments were related to pedagogic elements, such as promoting student's co-creation through instructions, monitoring their production (setting playground as private or public) and providing feedback (through comments). In general the application was positively evaluated by the teachers. In fact, T5 stated that the application itself is a spectacle explaining that his suggestion for improvement, i.e. add instruction throughout the story, could be done later and that it would be possible to use the application as proposed.

The code bug had 19 citations. Three teachers (half of our sample) had problems registering for the application and inserting the groups, which made them close the application and start it again. That happened when they left one specific and optional field empty. The tool wrongly treated this field as mandatory and, since it was empty, it considered all the information invalid and did not save anything. After found, this bug was fixed. T3 was not able to access the playground sometimes in the student's module. This issue occurred because he closed the application without logging out, which made the application do not save the PIN. Teacher's recording of the use was important to verify this issue later. After that report, the authoring tool keeps the PIN, along with all other important data saved after every change the user makes.

The code functionality does not achieve goal has 7 citations. This code refers to functionalities that do not achieve the intended goal or the expected result. The main observation was related to the question mark button, which was designed to offer help for the teachers, which in most cases did not catch their attention. They usually noticed it only after the researcher calls their attention. T4 mentioned the following about it:

> *"It's because I think I'm kind of digital native. Because digital natives wouldn't want to know about question mark, right? Ah, I've seen it. I know what it is. I'll put right here what I think it is."*

Another topic was the instruction for the topics suggested to students. At first, T1 did not think she needed to be concerned with it, in other words, she did not understand its goal.

Finally, the code problems had 6 citations. This code basically referred to difficulties of use. For instance, related to luminosity as occurred with T2 who used her cellphone in the dark mode and, thus, could not see some of the lines to fill out information while she was registering her group in the application. Another problem that happened with T1 and T2 was that the keyboard covered certain buttons leaving them confused about what to do next. After all, since we were doing the test online, teachers used their own devices, which allowed for a test in a less controlled scenario revealing problems that we would otherwise not be exposed to.

These results highlight the importance of the pedagogic aspects and instructions for teachers, helping them understand how the student will use the application to achieve the proposed learning objectives, as well as giving them some control over what will be produced and practiced. As T2 summarized:

> *"We don't want creative control. We want the student to create freely, but security control has to be as much as possible."*

8.2.2.4 Virtual Playground Creator Update

The UI changes at the second prototype were based in the participant's feedback and suggestions as well as in the principles proposed by (PETERS, 2014). The software used during the development of the prototype was Adobe XD[11]. At first, there was a focus on designing a new visual identity for the application having as parameters: the target audience; the psychology of colors and its influences on human behavior; typography; the different possibilities of application for the brand; and the commercial viability. The final brand as shown in Figure 66 has, on its composition, some explicit examples of the parameters, like typography and the influence of colors, for example. The chosen colors were variations of blue and orange colors.

Figure 66 – Virtual Playground Creator final brand.

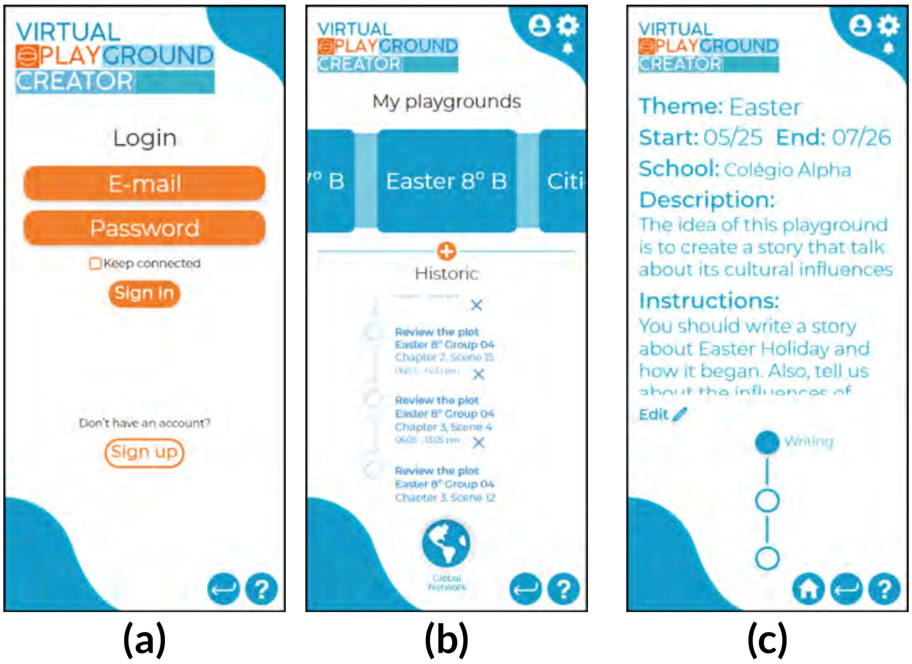
Font: Image elaborated by the author.

The UI of the final application was designed as a digital functional prototype. As the prototype was being developed, there were some reviews, during the process, aiming to avoid the majority of UI and UX issues, such as navigation problems, inappropriate

[11] Available at <https://rb.gy/g8lieh>.

icons and buttons sizes, and wrong animations. Those reviews were made by design and educational professionals that used the application and pointed out the majority of details. Focusing on a more intuitive experience, the navigation had, as a parameter, some default buttons, like return, home, settings and profile. Figure 67 shows a few examples of the finished UI.

Figure 67 – Virtual Playground Creator final interface: (a) login screenshot; (b) my playgrounds screenshot; and (c) instructions page.

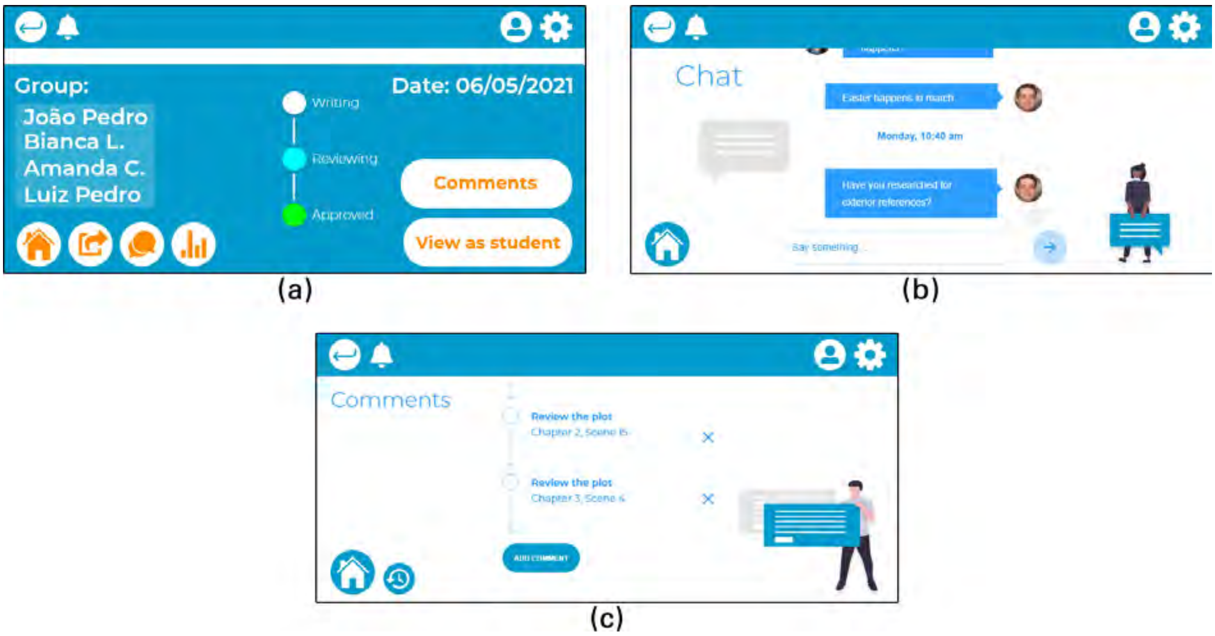


Font: Image elaborated by the author.

During the development of the UI, some important points were reviewed and corrections were made. Some of them due to new reads at the users test reports. Some of those corrections were about the interface vocabulary, as some terms were not very clear and created confusion on users' reasoning. Additionally, some terms were not understood by test participants. For instance, we replaced "Institution" by "School". Another term test users were confused was "targets". But instead of removing or changing it, we focused on developing a more intuitive experience and instructions so the users could understand this concept.

Due to the vocabulary review, some interface sectors were removed, changed or merged with others. As the private playground, for example; that was a way for the teacher to give some advice, comments and corrections to the students' story. However, there was a better way to structure that; using an interactive status screen as illustrated in Figure 68 (a), a chat screen as displayed in Figure 68 (b), in which both students and teacher can talk in real time and debate about any theme they need to, and also a comments section as shown in Figure 68 (c), in which teachers can point to some story scenes and give students tips and advice about it.

Figure 68 – Some changes on Virtual Playground Creator final interface: (a) interactive status; (b) chat screen; (c) comment section; and (d) Virtual Playground gameplay screenshot.



Font: Images elaborated by the author.

The Virtual Playground application shown in Figure 69 was designed focusing on an integrative experience. The user does not need to exit the AR scene to look for any information about the story. Also, we focused on designing a more minimalist and simple interface, using intuitive icons and a friendly navigation.

Figure 69 – Virtual Playground AR application.

Font: Image elaborated by the author.

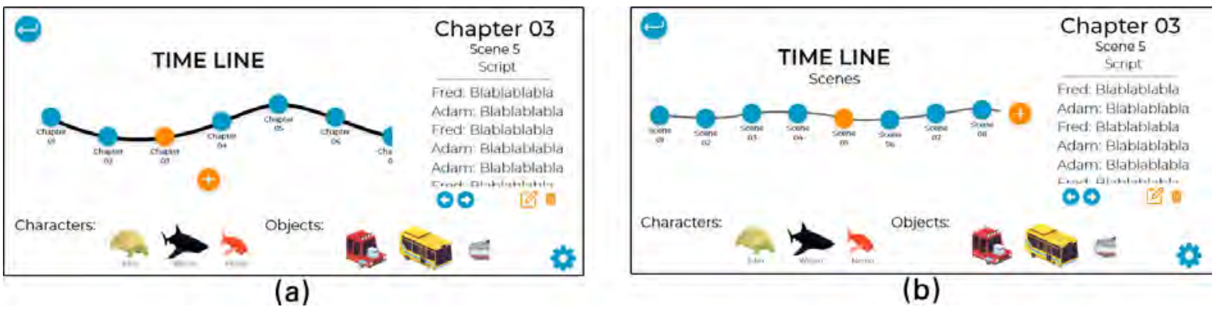
Students can create the story scenario as they want on their module. They just need to choose an object or character as shown in Figure 70 and link it to a target; after, they just need to take the printed target, place it on the chosen location and use it in the story.

Figure 70 – Virtual Playground Creator choice page on the student's module.

Font: Image elaborated by the author.

Additionally, the student has total control and a top view of the whole composition of the story. Just like objects and characters as mentioned above and, also, of the chapters and the scenes inside it as illustrated in Figure 71 (a) and (b), respectively.

Figure 71 – Story's timeline in the student's module of Virtual Playground Creator.



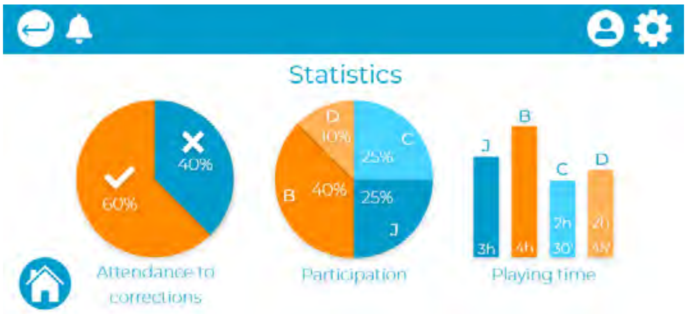
Font: Images elaborated by the author.

Teachers have a whole view of the student's story, as they can access the scenes and chapters. They can also access information about the group dynamics and statistics about the activity that allows them to monitor group participation, as shown in Figure 72. In this page, they might know how much time and effort each student is investing in the project.

As new tests and user reviews would be analysed by the developers, it would be possible to add new features and adapt some pages to solve issues as well as to improve the user experience.

Some examples of future features that were idealized by the developers are the following:

Figure 72 – Virtual Playground statistics screenshot.



Font: Image elaborated by the author.

1. Complete ready-made templates for teachers that do not have time for creating new plot or scenario ideas;

2. New refinement of the interface and a possible re-design of some buttons, icons, images and parts of the experience flow;

3. User's behavior monitoring; the institution could monitor how the student interacts with other colleagues and, also, the time they spent on the activities;

4. Give the teacher the possibility to offer to the students a previous summary with some advice that will be useful during the development of the story.

9 SECOND REFLECTION TO PRODUCE DESIGN PRINCIPLES AND ENHANCE SOLUTION IMPLEMENTATION

This chapter details the analysis of the data related to the preliminary design principles as well as the reflection to produce the updated version of design principles proposed and enhance solution implementation.

9.1 CONSIDERATIONS ABOUT THE VALIDATION OF DESIGN PRINCIPLES (VDP)

The third goal of the second round of tests was to validate the design principles developed in this thesis. A general overview of the data demonstrated that the principles suggested so far were validated by the teachers as shown in Table 7. Nevertheless, it is necessary to discuss in depth the aspects pointed out by the test. The preliminary design principles 2 (provide a mobile version), 3 (provide an instructional interface), 6 (enable sharing of AR experiences), 7 (enable content curation), 8 (offer statistics), 9 (include pedagogic features) and 13 (enable assessment flexibility) obtained full agreement from the teachers. Preliminary principles 1 (Offer an offline version) and 2 (provide a mobile version) were not included in the form because they are simply binary. The Virtual Playground Creator was available in a mobile format and after downloaded it worked offline, thus, we consider that it meets these two principles. The preliminary principles 4 (provide support for teachers), 6 (enable sharing of AR experiences), 7 (enable content curation) and 8 (offer statistics) were not fully implemented in Virtual Playground Creator and assessed by the teachers. We understand that PDP4, PDP6 and PDP7 are more related to the community building towards the use of the tool, thus, they were not prioritized in these initial rounds of testing. However, we acknowledge their importance in the final version of the product. Although we were not able to implement PDP4, we collected information on what kinds of support teachers would like to receive as detailed in our list of design principles. PDP6 was validated in the low-fidelity prototype. We understood that PDP8 were not prioritized as we are not evaluating with students at this point. Nevertheless, as happened with PDP4, we collected information on what kinds of information we could add in a future version of the prototype.

It is important to point out the difficulty in meeting all the criteria given the time available. Thus, we prioritized faster iterative and refinement cycles as the objective of this work is to propose a model based on the needs identified by users.

In this subsection, we discuss aspects related to the validation of the principles proposed and its implementation that can help to refine them.

Table 7 – Teacher's agreement with the principles proposed (Form - Part 1) and with its implementation in Virtual Playground Creator (Form - Part 2). (Y) stands for full agreement, (P) for partial agreement and (N) for disagreement. (-) stands for not applicable. PDP7 was broken into two statements (ST). Gray principles are related to infrastructure aspects. Pink principles are related to AR aspects. Orange principles are related to pedagogical aspects.

	Form - Part 1						Form - Part 2					
	T1	T2	T3	T4	T5	T6	T1	T2	T3	T4	T5	T6
PDP1	Y	Y	Y	N	P	Y	-	-	-	-	-	-
PDP2	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-
PDP3	Y	Y	Y	Y	Y	Y	Y	P	P	Y	Y	P
PDP4	Y	Y	Y	Y	P	Y	-	-	-	-	-	-
PDP5	Y	Y	Y	Y	Y	P	P	P	N	P	N	P
PDP6	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-
PDP7 (ST1)	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-
PDP7 (ST2)	Y	Y	Y	Y	P	Y	-	-	-	-	-	-
PDP8	Y	Y	Y	Y	Y	Y	-	-	-	-	-	-
PDP9	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	P	Y
PDP10	Y	P	P	Y	Y	Y	Y	P	P	Y	Y	Y
PDP11	Y	Y	Y	P	Y	Y	Y	Y	P	Y	Y	Y
PDP12	Y	Y	Y	Y	Y	P	P	P	P	Y	P	P
PDP13	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	P

Font: Table elaborated by the author.

[PDP1] Offer an offline version: as regards PDP1, which refers to the need for an offline version. It is noteworthy that the context of the COVID-19 pandemic imposed changes in all contexts of life and consequently in education, bringing the experience of what some authors call emergency remote education (SILVEIRA, 2021). In this sense, teachers experienced very different realities in the context of this test, involving fully remote or online teaching (T1, T2 and T4), hybrid teaching (T3, T6) and face-to-face teaching (T5 which was based on a previous experience). Nevertheless, the majority of teachers agreed with this need, given that the teaching contexts are very varied and in many cases it is not possible to guarantee access to a stable connection. This aspect was even associated with accessibility by T6, as observed in her speech:

> *"I totally agree. I think that the fact that it's offline is very important because it expands its use. Not everyone has access to the internet, unfortunately. So this is very good because it gives accessibility to people who don't have internet, right? So it's affordable and that's good."*

It is also important to note that, although at the time of the test, she was working completely online, T1 fully agreed with the need for the offline version and justified her answer by stating that she considered the normal life context as can be seen in her speech:

> *"From my current context, always online. (...) When I told you, it was a possibility of a normal life where we can go out and do things outside, right?"*

Her speech thus suggests that the context of internet availability was considered temporary (or circumstantial) by this teacher. This was the principle with the greatest magnitude in the teacher ranking scale as shown in Table 6. However, there were contexts in which this is not necessary, such as the case of T4 who works in distance learning. T5 stated that he partially agrees with it, given that he has already taught in contexts with and without internet access;

[PDP2] **Provide mobile version:** all teachers completely agreed to the importance of having a mobile version of the authoring tool. T1 highlighted that although she has never used AR in her classroom at that point, she believes she would ask students to leave their physical space, which reinforces the need for a mobile version;

[PDP3] **Provide an instructional interface:** all teachers completely agreed to the importance of an instructional interface. This was considered the third principle in magnitude, which demonstrates its importance as displayed in Table 6. As regards to its implementation in the Virtual Playground Creator, it was observed that half of the participants totally agreed that the instructions provided by the tool were clear for the execution of the activities. While the others (T2, T3 and T6) partially agreed with this statement. These teachers highlighted that some instructions and nomenclatures were not clear. These points were further discussed in Subsection 8.2.2.3. It is noteworthy that even those who totally agreed with the statement had questions throughout the test that were clarified by the Ph.D. researcher;

[PDP4] Provide support for teachers: five teachers completely agreed to PDP4, which refers to support for teachers. Only T5 partially agreed with the statement. He commented:

> *"There are some teachers who do not have much knowledge of digital and augmented reality."*

His speech suggests that support would be more or less necessary according to the teacher's digital and AR knowledge. Through the analysis of the didactic sequences, we observed a certain correlation between a more mature use of the tool and the degree of teaching experience with AR technology. This might suggest that the application of this principle could encompass different levels of support depending on the teacher profile, for example, low, medium and high support depending on the teacher's profile. Future research might be needed to determine how to properly assess teacher's profile to determine support;

[PDP5] Offer content library: five teachers fully agreed to PDP5, which refers to offering a wide variety of content library. Only T6 partially agreed, arguing:

> *"I would like to be able to also create characters, environments, objects and everything else that could help me carry out the activities in an authorial way."*

In the interview, however, there are points of contradiction, demonstrating the difficulty of teachers to create objects and 3D elements from scratch, as is evident in her speech:

> *"I as a teacher. I will not necessarily be able to create from scratch a 3D character, isn't that?"*

There is the same kind of contradiction in T3's speech in which the teacher at one point says

> *"I think both (have 3D objects available and create them) are equally important to have a collection as it is. You create yours yourself and make it available too, right? Sharing is the important thing. The more the better."*

But when asked if he has experience in creating, he points out the difficulties found in this regard:

> *"Well, create, create from scratch with an application, with games, no because I don't have the tools or the institutions that I work have these (...) resources. These tools but it was suggested to create. Not to create, it was suggested to work with VR there at the school but in fact we were never able to produce anything. Nor use the games that are there."*

T4 explained that some schools he has knowledge of hire professionals specialized in the management of technologies, being responsible for selecting technologies, training teachers in this regard and creating digital artifacts such as videos. Thus, he suggested that although the possibility of creating their own 3D objects sound interesting, it could be underused by teachers. These observations corroborate what has been observed during this research: although teachers are interested in and recognize the importance of creating 3D objects, their working conditions (high workload combined with lack of knowledge and access to tools) make it difficult for them to create content. This suggests that it would be more feasible to provide a wide range of 3D object options, preferably with the possibility of small customizations as highlighted in T1's speech:

> *"(...) because I'm the type of person who's very resistant to everything that's ready, I'll always want that character that has a head the color of this thing here (teacher shows an orange object) then I'll want it..."*

Furthermore, one could think of a joint creation process involving the student or even qualified professionals. From a commercial point of view, one could even think of a model in which creators could make models available at low cost, customized according to user's demands and offer them on a platform. As regards the implementation of this principle, most teachers partially agreed with it (T1, T2, T4 e T6) whereas T3 and T5 disagreed. As expected, the library provided did not meet the proposed teaching needs, which requires an increase in the library provided, as well as options for customizing elements as previously discussed;

[PDP6] **Enable sharing of AR experiences:** all teachers completely agreed with the need to share the AR experiences created. T6 highlighted that this is an important aspect because *"they can learn together."* T1 explained that this is the coolest part. She believes this is the part that students like the most as she puts it:

> *"I think the students. It's the part they like the most when they do it. They want to show it, they want to share it."*

These comments suggest that this principle is aligned with more active methodologies, in which students become responsible for their learning processes and in certain occasions can also become responsible for their peer's learning processes as well (SILVEIRA, 2021). Learning together and sharing their knowledge and productions are important parts of this process;

[PDP7] Enable content curation: it is important to point out that PDP7 was broken down into two statements: the first related to the importance of accessing and using activities created by other teachers and the second related to how to assess the quality of this produced content. All teachers agreed with the need to access and use activities created by other teachers. This principle also acknowledges that teachers can learn from one another as illustrated by T1's speech:

> *"It is important for me to be able to look for and use activities created by other teachers. I agree. (...) I was born a researcher and a student. I will die as a student. I think. To go after, to know how other people are doing."*

Regarding the evaluation of the quality of the content produced, we have T5 partially agreeing on the quality of the content. This teacher emphasized the importance of being able to edit the content previously produced according to his needs and specific contexts. He cited as an example the Kahoot platform that brings this possibility to the teacher;

[PDP8] Offer statistics: all the teachers completely agreed to PDP8. For T1, statistics are essential in the context of technology as a novelty for the student so that the teacher can make the appropriate interventions and help the student to achieve their goals, such as it is observed in her speech:

> *"Yes. I think it's important to monitor student performance in many ways. Thinking about technology as a novelty for the student, this monitoring is*

> *essential for the teacher to be able to make the appropriate interventions and help the student to achieve their goals."*

She also added that, due to her personal experience, she thinks monitoring is important to understand the student's emotional side. This is an interesting point that could be coupled with what has been labeled in the literature as multimodal learning analytics, i.e., a set of techniques that can be used to collect multiple sources of data in high frequency (video, logs, audio, gestures, biosensors), synchronize and code the data, and examine learning in realistic, ecologically valid, social, mixed-media learning environments (BLIKSTEIN, 2013). As an example of the use of multimodal techniques in an AR context, (RADU; TU; SCHNEIDER, 2020) found out that different posture clusters are associated with collaboration and learning in their AR study. These metrics were correlated to dyad posture variables such as spine similarity, distance between peers, and synchronized orientation of participants;

[PDP9] Include pedagogic features: all teachers completely agreed with this option, which represents the ability to co-create content with students. T1 summarizes its importance in her statement:

> *"I really believe in co-authorship. Co-creation, you know? I think the student needs to create. He is already very exposed. Things are there, right? Depending on your predisposition to learn, as Ausubel says. (...) You go there and drink from that fountain or not. Now the possibility of you doing this producing. I think that's where I see the biggest leaps of my students, you know? Ah, you have the responsibility to create something. It's yours too, right? So the possibility of you also being the author of something. It makes you the owner of that and then you treat it with more affection. Including the cognitive. Your cognitive. Oops! We're going to show what is ours, right? So we'll show you our house in the best way, not just slap things together."*

As regards its implementation in the Virtual Playground Creator, 4 teachers (T1, T3, T4 and T6) fully agreed, while T2 and T5 partially agreed. T2 stated that:

"It would be interesting if the teacher could join the game to create with the students in case any student does not know what to do or even to have some more mediating function."

T5, on the other hand, claimed that he would like to put specific instructions during production, e.g. adding adverbs that should be used in specific times during the storytelling. This point was also emphasized by him as regards to PDP8. Through these comments, it is noticeable the desire of these teachers to intervene at the time of creation itself, not just in the preparation and subsequent evaluation phases;

[PDP10] **Enable monitoring:** four teachers completely agreed to PDP10, while 2 of them, T2 and T3, partially agreed with it. This result was repeated when asked to evaluate the implementation of this principle. These teachers mentioned important points, namely: T2 indicated that she agrees with the need to mediate the student's work, giving greater support so that they can achieve their goals. T3, in turn, emphasizes that this can become a problem in larger classes, but that monitoring should be calibrated in order to maintain the student's autonomy. To summarize, we found out two main aspects related to monitoring: mediation and autonomy. The latter can become more challenging depending on specific contexts (e.g: bigger classes that could be divided into groups);

[PDP11] **Enable content moderation:** this principle is related to PDP10. Regarding this aspect, only T4 partially agreed due to his teaching context, which involves mostly adults. We found out that the aspects related to this principle are: the need to check the adequacy of the content being produced as well as the need to provide a follow-up for that content. It is also related to specific educational contexts, for instance, younger students might need more moderation as T4 points out:

"I acknowledge that I understand that this functionality is especially more relevant in specific contexts: basic education, language courses, children and adolescents".

As regards its implementation, 5 teachers completely agreed with it while one partially agreed with it. This teacher mentioned that he would like to enter the room to check what students were doing;

[PDP12] Enable classroom management: this principle brings three main aspects, namely: the creation, customization and management of AR experiences. Regarding the creation and personalization of experiences, 5 teachers agreed with its importance and only T1 partially agreed with it, stating that:

> *"Nowadays I feel little need to use this technology, as I have so far little knowledge about the topic and its potential. However, I believe that with greater familiarity with AR, this need should arise."*

Additionally, concerning this aspect, T2 suggested that students could take pictures of the mind map they create for the story and integrate it in the application. In her words:

> *"This would be more effective both in the pedagogical construction of the learning experience and in the evaluation of the process."*

This suggests the need to integrate the technology with the overall didactic sequence. T5, on the other hand, suggested the need to guide students during the storytelling, for instance, by showing them specific adverbs that should appear in specific parts of the story, which reinforces the need for a certain degree of control by the teacher. Regarding the management of groups, we have T4 that considered it more important in an online setting, since, according to him, it would be easier to do it in person without the help of the application as illustrated in his speech:

> *"I think if the students can go from one group to the other, for example. If there is a risk of them getting confused and ending up working in a way that is outside the teacher's planning. Then, I think it is important to put the maximum number of students because when I'm in a physical classroom, I say it's going to be the three of you and it's the three of you. There's no way to change that because the three students are in front of me, right? But when (...) it's an activity that I'm not in person with people, then whatever I can do to make it clear that there is that maximum number stipulated there, I think it's interesting to make it clear."*

This point suggests the importance of considering the peculiar context that we are living during the pandemic, which encompasses the transition between the real and virtual and the possible adoption of hybrid models. The virtual space can pose challenges for teachers as T2 pointed out:

> *"Especially in these times of virtual learning because it's such a thing to come here to mess with. Then my friend comes in there to tease. So when you have the control, no one will enter and especially for the teacher, it is very important to have this control."*

She highlighted though that the control she desires is associated with security not creativity.

[PDP13] Enable assessment flexibility: all the teachers completely agreed to PDP13. T1 and T6 highlighted that they liked the comment option as a way to provide feedback for the students. When testing the Virtual Playground Creator, the teachers were able to provide additional suggestions regarding that aspect. This test revealed that 4 teachers agreed with the implementation of that particular principle while 2 teachers (T2, T6) partially agreed with it. T2 suggested to add comments to particular students rather than just for the entire group. T6, on the other hand, suggested the inclusion of rubrics so students could check their progress in real time as she puts it:

> *"As a suggestion, add rubrics so that students can track performance in real time. Symbols would appear that represent good, partial or non-development of performance towards the goal (rubrics)."*

Interestingly, the two teachers who partially agreed to the implementation of this principle were the only ones who have previously used AR in their classes.

9.2 REFLECTION TO PRODUCE DESIGN PRINCIPLES AND ENHANCE SOLUTION IMPLEMENTATION

With all the data collected and analyzed, we consolidated the design principles for the development of an AR authoring tool aimed at education. In the following sections, we present them to guide developers and designers when creating new AR authoring tools for education in the future.

9.2.1 What are the Updated List of the Design Principles Developed Throughout this Research?

This study suggests as previously demonstrated and confirmed through the second round of tests that AR authoring tools for education should consider three aspects: the infrastructure to use AR in classrooms, the augmented reality content itself, and how it will be related to the educational content. In this subsection, we present the updated list of the design principles that new AR authoring tools should follow as well as ways to incorporate them as features in future iterations of the authoring tool whenever updates were necessary. As previously done, we present them as design principles accompanied by a one-sentence description (AMERSHI et al., 2019). Additionally, we include three paragraphs to each design principle: one to state the impact of the second round of tests regarding the principle, another to reinforce its importance, and one to exemplify how we used or intend to use this design principle in the Virtual Playground Creator.

9.2.1.1 Infrastructure Aspects

[DP1] Offer an offline version: Enable AR experience offline.

- *Impact of second round:* The final round of tests reinforced this principle as important as suggested by its high magnitude classification (Table 6).
- *Importance:* Schools often lack internet infrastructure, which is a major barrier for teachers in adopting technologies like AR (SILVA et al., 2019b). It is important to take into account though the different contexts of our target audience. For instance, in the context of remote education this principle may not be applied.
- *Example:* Teachers can create Virtual Playgrounds without the internet using built-in targets and 3D characters and share the experience with students using Bluetooth.

[DP2] Provide mobile version: Enable users to use the experience in a mobile version.

- *Impact of second round:* This principle was also reinforced due to the flexibility and accessibility it promotes.
- *Importance:* Students often carry mobile phones with them so it is useful to design for these devices. It is important to notice that as technology evolves and becomes widespread, other types of technology might be used. The concept behind this principle relates to massive used devices, which are currently represented by smartphones and tablets.
- *Example:* The current prototype of the authoring tool is intended to run on low-end Android phones (version 6.0). Nevertheless, the tests raised awareness to the need of expanding it to iOS platform.

[DP3] Provide an instructional interface: Provide instructions for teachers and students to easily understand how they could use the tool.

- *Impact of second round:* This principle was reinforced as evidenced in its third rank in the magnitude coding in Table 6.
- *Importance:* This is important because teachers usually have a limited amount of planning time, which can be a limiting effect when incorporating new technology (SILVA et al., 2019b).
- *Example:* The adjustments in the instructions enabled us to better understand teacher's needs and work context. Both colors and typography were considered aiming to provide a more user-friendly experience for the user. The prototype was also reviewed to avoid the majority of UI and UX issues. The navigability flow was designed focused on a fluid navigation for users.

[DP4] Provide support for teachers: Help the teacher understand what the AR system can do and how it could be used in their lessons.

- *Impact of second round:* This principle was ranked in second place in the magnitude coding which demonstrates its importance (Table 6).
- *Importance:* Teachers feel the lack of support as a barrier preventing them from adopting new technologies, such as AR (SILVA et al., 2019b).
- *Example:* Our data suggest that the need for support might vary according to the teacher's digital and AR knowledge. We observed a certain correlation between

a more mature use of the tool and the degree of teaching experience with AR technology. This might suggest that the application of this principle could encompass different levels of support depending on the teacher profile. Introductory videos of the tool as well as examples of its use might be beneficial for teachers in this regard.

9.2.1.2 Augmented Reality Aspects

[DP5] Offer content library: Enable teachers and students to access an ample variety of content.

- *Impact of second round:* The data suggested that it would be more feasible to provide a wide range of 3D object options, preferably with the possibility of small customizations. Although teachers demonstrated interest in and recognized the importance of creating 3D objects, their working conditions (high workload combined with lack of knowledge and/or access to tools) make it difficult and can hamper their ability to create content.
- *Importance:* This is important to allow teachers to use the tools purposefully in their lessons and also to empower students in their learning process.
- *Example:* In this version, there are few 3D characters and markers available in Virtual Playground Creator. In future versions, we intend to provide access to a free online repository of 3D contents, such as Sketchfab[1], and also allow the students to capture their own drawings and use them as markers. Furthermore, one could think of a joint creation process involving the student or even qualified professionals. From a commercial point of view, one could even think of a model in which creators could make models available at low cost, customized according to user's demands and offer them on a platform.

[DP6] Enable sharing of AR experiences: Enable sharing AR content among fellow educators.

- *Impact of second round:* Although this principle was not ranked high in the magnitude coding (Table 6), our result suggested that this principle is aligned

[1] Available at <https://rb.gy/zswc9v>.

with more active methodologies, in which students become responsible for their learning processes and in certain occasions can also become responsible for their peer's learning processes as well (SILVEIRA, 2021). Learning together and sharing their knowledge and productions are important parts of this process.

- *Importance:* Our research with teachers has shown that sharing content is important to provide students with an authentic audience for their learning. As for teachers, sharing content can be a tool to foster collaboration among their peers and decrease the planning workload as evidenced in the results from the interviews. These results have shown that some teachers proactively share content with colleagues as a way to promote learning and collaboration.
- *Example:* Teachers can share their creations and search for other teachers' playgrounds.

[DP7] Enable content curation: Enable teachers to find and use good quality content previously created by third parties.

- *Impact of second round:* Data suggest that this principle can be divided into two parts: the first related to the importance of accessing and using activities created by other teachers and the second related to how to assess the quality of this produced content. This principle was ranked fourth in the magnitude coding (Table 6), which demonstrates the importance of teachers collaborating and learning from one another.
- *Importance:* Our research with teachers has shown that they are interested in content curation as it can help them find and use content faster and more easily.
- *Example:* In future versions, we intend to allow teachers to evaluate each other's Playgrounds, which will give them a sense of their Playground quality. It is also interesting to allow them to modify and reuse playgrounds produced by other users.

9.2.1.3 Pedagogical Aspects

[DP8] Offer statistics: Provide an overview of the usage of the AR experience which would inform educators concerning students patterns.

- *Impact of second round:* The second round of tests reinforced the importance of this principle to aid teachers in the assessment process and improve student's learning, which was especially important for teachers starting to use this type of technology. Different types of data could be collected including multimodal learning analytics (BLIKSTEIN, 2013).
- *Importance:* This is important to aid teachers in the assessment process by enabling them to provide customized feedback for learners.
- *Example:* As previously exposed, in future versions, we intend to provide different data to teachers to help in their evaluation, such as the time students take to create their Playground, how many interactions they had with other students, how was his/her participation in the comment session.

[DP9] Enable co-creation of experiences: Enable teachers to co-create AR experiences with students according to their pedagogical goals.

- *Impact of second round:* Data from the second round of tests reinforced the significance of this principle as a way to give more responsibility for the learners by sharing responsibility for learning and content creation with them. Teachers also demonstrated the desire to intervene at the time of creation itself, not just in the preparation and subsequent evaluation phases.
- *Importance:* This is a significant issue to give more responsibility for the learners by sharing responsibility for learning and content creation with them.
- *Example:* Virtual Playground Creator allows teachers to set the tasks with instructions to aid learners in their creation process and topics to practice that will appear as a reminder to students during the application use. The tool also has one module for teachers and another for students where they can co-create the AR experience. In future versions, teachers could be able to insert specific instructions for students during production time.

[DP10] Enable classroom management: Enable teachers to create, personalize and manage the AR experience according to their own classrooms.

- *Impact of second round:* Data suggested that this principle brings three main aspects, namely: the creation, personalization and management of AR experiences.

The management of these experiences includes monitoring students work without compromising their autonomy, thus, we combined PDP12 (related to classroom management), to PDP10 (related to monitoring). This principle also involves the integration of the AR experience to the classroom as a whole.

- *Importance:* This is significant because classrooms differ fundamentally from other workplace environments. As examples we mention the focus on learning goals and classroom management.
- *Example:* Teachers can add their institutions and classes as well as manage the playgrounds in the context of their classes. They are also able to monitor in the playground dashboard the groups students are forming and every step students are taking during their creation. In future versions, students would also be able to register the steps taken throughout the storytelling even if it is not in AR as a way to record their whole creation process.

[DP11] Enable assessment flexibility: Enable flexible ways for teachers to decide and create appropriate evaluation.

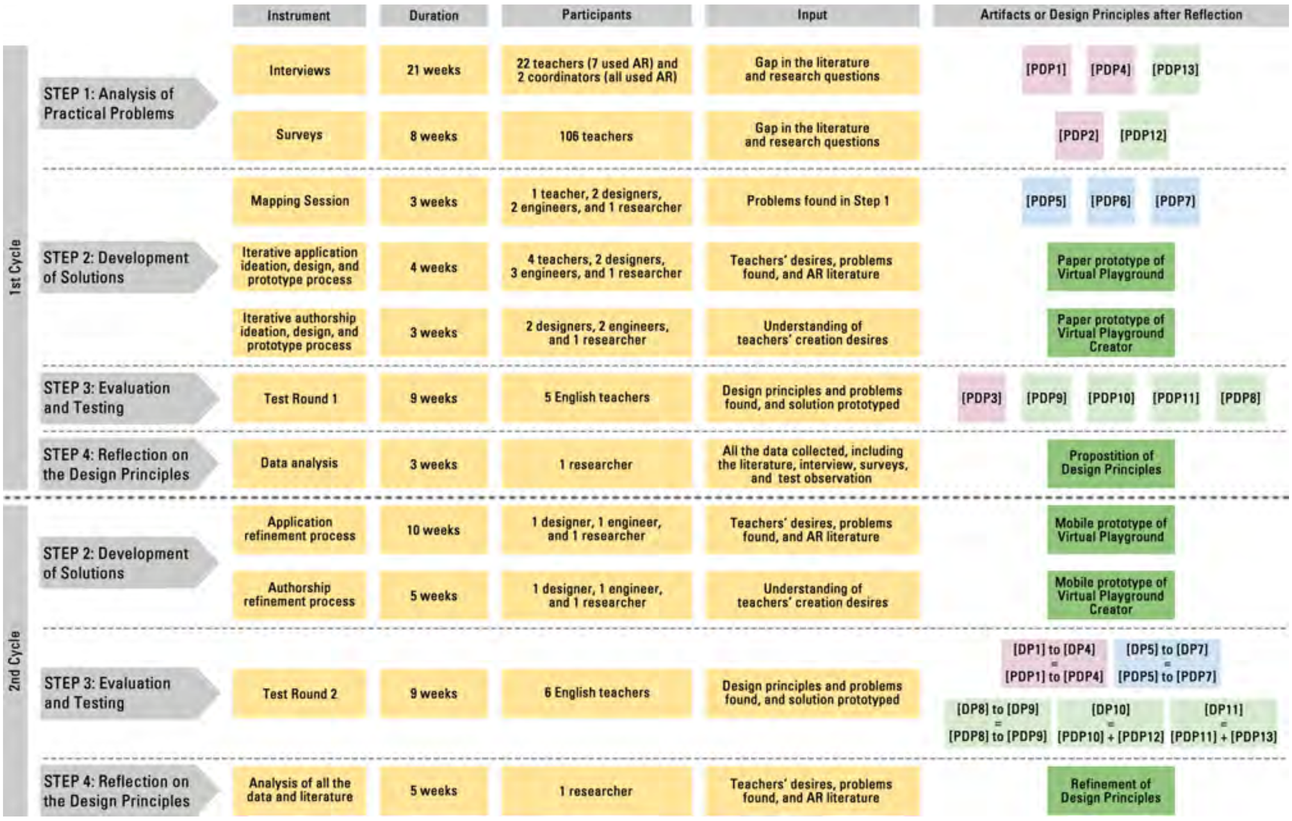
- *Impact of second round:* Data have reinforced the need for flexible assessment of students, including the use of rubrics and peer assessment. PDP11 (related to content moderation) as a form of the teacher assess appropriateness of the content was also combined with assessment flexibility (PDP13) depending on the teaching context needs.
- *Importance:* This is important so teachers can decide appropriate ways to evaluate their students. Studies have shown that teachers question the appropriateness of common evaluation techniques, such as multiple choice and conceptual questions to evaluate student's work with AR (SILVA et al., 2018; SILVA et al., 2019b). Alternative forms of evaluation can be provided as student's protagonism is encouraged, such as the use of rubrics and peer-assessment.
- *Example:* Virtual Playground Creator allows teachers to moderate when student's productions are ready to be published and watch every story created by the students as well as discuss it with them in an open chat. In a future version, we intend to improve this principle by allowing students to also be able to comment on other stories as well as enabling teachers to assess their participation. The stories

collected can also be used as a portfolio of student's works. Teachers might also be able to insert rubrics to help students understand how they will be assessed.

As previously discussed, it is important to consider the cost to use the AR application since some teachers may not have appropriate funding and may need to pay for it (SILVA et al., 2019a).

Figure 73 details the methods and the main results from the second cycle of development, testing and reflection to produce design principles and enhance solution implementation.

Figure 73 – Method overview and main results of the second cycle of development, testing and reflection to produce design principles and enhance solution implementation.



Font: Image elaborated by the author.

9.2.2 Do Existing AR Authoring Tools for non-programmers Meet the Proposed Design Principles?

There are some AR authoring tools for non-programmers available, both in the industry and in academia. We analyzed 10 of them to see which of the proposed principles they used. This was important to understand how existing tools currently meet teacher's demands.

To select the tools, we initially searched for academic papers that introduced AR authoring tools for education. We used the string *("Augmented Reality" OR "AR") AND ("Authoring Tools")* in the ACM Digital Library, IEEE Xplore Digital Library and ScienceDirect. We excluded tools published before 2015 to try to explore the most recent AR SDK. This screening resulted in only two papers: one introduced UNED ARLE (CUBILLO et al., 2015) and the other developed WebAR (BARONE et al., 2017). We contacted the authors and asked for a version of the authoring tool we could test.

After that, we looked for AR authoring tools commercially available that are designed specifically for education. The only one we could find was CoSpaces EDU[2].

We completed the list with general-purpose AR authoring tools that are commercially available because our initial results as detailed in Chapter 6 indicated that it is more common for teachers to use these tools for education than look for the academic ones. To select them, we chose the seven most popular AR platforms in Google Play Store and Apple App Store that have authoring tools. They are: Augment[3], Blippbuilder[4], CraftAR Creator[5], Lens Studio[6], Vuforia Studio[7], WiARframe[8], and ZapWorks Studio. We also added Virtual Playground Creator (as VP Creator) in the table to see what design principles the prototype satisfies in its current form.

Table 8 summarizes what design principles each tool meets (in green) or not (in red). Those in yellow mean that they are partially satisfied. For instance, tools that partially meet DP6 only allow teachers and students to share the marker and the 3D asset, but not the AR experience as a whole. Thus, the other person has to combine them in a new AR experience. As previously explained, we contacted the manufacturer and authors to request access to the tools, but, unfortunately we did not have access to two of them, Vuforia Studio and UNED ARLE, which were excluded from our evaluation.

As expected, most authoring tools meet technical features in the AR dimension. On the other hand, they lack almost all of the pedagogical design principles. Only CoSpaces

[2] Available at <https://rb.gy/qeyxen>.
[3] Available at <https://rb.gy/yexnzd>.
[4] Available at <https://rb.gy/li7zpq>.
[5] No longer available.
[6] Available at <https://rb.gy/3trmyc>.
[7] Available at <https://rb.gy/htk0cc>.
[8] Available at <https://rb.gy/ghzrfs>.

Table 8 – The design principles the most popular AR authoring tools meet are in green (Y). Those in yellow indicate that they partially meet the design principle (P) and in red are the ones they do not provide (N). The last column shows the score of each tool in the proposed design principles. The tools are Augment (A1), Blippbuilder (A2), CoSpaces EDU (A3), CraftAR Creator (A4), Lens Studio (A5), WiARframe (A6), ZapWorks Studio (A7), WebAR (A8), and VP Creator (VP).

	Infrastructure				**AR**			**Pedagogical**				
	DP1	**DP2**	**DP3**	**DP4**	**DP5**	**DP6**	**DP7**	**DP8**	**DP9**	**DP10**	**DP11**	**Score**
A1	N	N	P	N	P	P	N	P	N	N	N	1.82
A2	N	N	N	N	N	P	N	N	N	N	N	0.45
A3	N	Y	N	Y	Y	Y	Y	N	P	P	N	5.45
A4	N	N	N	N	N	P	N	N	N	N	N	0.45
A5	Y	N	P	N	N	Y	N	N	N	N	N	2.27
A6	N	N	Y	N	Y	Y	Y	N	N	N	N	3.64
A7	Y	N	P	N	N	P	N	N	N	N	N	1.82
A8	N	N	N	N	N	P	N	N	N	N	N	0.45
VP	Y	Y	Y	N	P	Y	N	N	Y	Y	Y	6.82

Font: Table elaborated by the author.

EDU meets more than one in this category. In fact, since it is designed for education, CoSpaces EDU satisfies more than half of the features we found that teachers want when authoring for education. One simple way to see that is by giving the tool one point for each design principle they meet, 0.5 for partial satisfaction and no points for features they do not have. After normalizing to have a score between 0 and 10, we can see that CoSpaces EDU has the highest score among the analysed tools. Virtual Playground Creator is placed as reference. This data, thus, indicate that we have a shortage of AR authoring that take pedagogical aspects into account.

10 CONCLUSION

Literature review has shown numerous advantages for the use of AR technology, such as increased motivation and cognitive performance (SERIO; IBáñEZ; KLOOS, 2013; RADU, 2014; THEODOROU et al., 2018). However, although this technology seems promising, its use is still not widespread in education. Studies have shown that one recurrent limitation of AR in educational settings is that teachers cannot create new learning content easily since the bar of entry to content creation is high for non-programmers (SCHMALSTIEG; HÖLLERER, 2015; ROBERTO et al., 2016a; BACCA et al., 2014). This study has shown that one of the reasons for this might be the lack of suitable authoring tools, as further explored in this research.

Through Design Based Research (DBR) with the participation of an interdisciplinary team to investigate and propose design principles for AR educational authoring, we contributed to the field by identifying how teachers would like to create AR experiences based on their pedagogic needs. This result was used as input for the design principles proposed.

Based on the interviews with 15 teachers that used technology in education, as well as 7 teachers and 2 coordinators who used AR in education to understand, we concluded that although AR technology is evolving, its use is still limited. Nevertheless, there are teachers willing to learn and use AR technology in their classrooms due to its potential, especially for contents that are difficult to visualize or contextualize in other ways. These teachers usually had ample access to technology in the workplace and were provided with support. Although their access to support did not vary significantly when compared with teachers who have not used AR, we noticed that some of the teachers who used AR were pioneers and in some ways taking a leadership role as regards to the use of technology in their schools. In our AR sample we had two coordinators that were responsible for technology integration. Although their participation brought interesting insights to our research especially in terms of the institutional support offered, this might have influenced our results. Data have also evidenced that the introduction of AR changes considerably teacher's work regarding both planning and execution of the lesson. We observed that teachers changed their teaching strategies in different ways, such as using rotation among working stations or taking students out of the classroom. Additionally, assessment strategies must be different as pointed out by one of the teachers:

> "*In the presentation I held was that lots of teachers are afraid of using multimodality and AR because they feel it is hard to do a fair assessment. So, to know what did the student do, how did he do it and, you know, like compare if they worked together they can see which student did what. And is it a good way of evaluating? Do lots of things that we like augmented reality and in my case using it as tool for multimodality but then they say we still want to have our written test in the end.*"

As concerns content creation, data suggested that similar to other media, it is important to enable content curation and ease customization of AR experiences. This is important since teachers may not always have the time to create content from scratch, but would like to make sure they are using high quality content in their lessons as well as the need to customize, reuse and co-create with their students. The data revealed that content creation was limited. Among the reasons for this were: lack of the teachers' experience and suitable authoring tools. Teachers only experienced content authoring with HP Reveal (formerly known as Aurasma) and 3 out of the 4 participants mentioned that it was not so user-friendly. Their experiences also revealed that teachers are willing to have students create or co-create AR content. Data, thus, suggest that teachers are interested in a co-creation process, in which, they have some control of what students produce whereas students can learn and create autonomously.

The survey conducted with 106 teachers revealed that although teachers seem interested and eager to learn about AR, its use has not reached higher levels of maturity in schools yet. Different aspects were related to that, such as lack of infrastructure, authoring tools and time, which supported the findings from the interviews. The infrastructure issue, for example, brought the need for an offline version of the authoring tool. Results have also shown that teachers need more guidance and support in order to better connect AR use with their pedagogic goals. Price of the tools were also a concern for them. Additionally, we observed the need for AR tools to support collaboration, creativity through content creation (authoring tools) and ability to assess students in more flexible ways are also related to more mature uses of technology. Thus, these would be interesting features to be provided by AR tools. The data helped to raise awareness of teacher's needs when it comes to this technology and point out their needs regarding authoring tools. Based on the initial results, the Ph.D. research personal background and availability of participants, we defined a "case study" focused on language learning for children and teenagers.

The mapping session and the workshops presented some problems that developers and researchers must take into account if they want to build an effective tool. The solution chosen in the decision session and detailed in the sketch iteration evidenced the great yearning for an application with which students can collaborate and the teacher can easily create and reuse virtual content to explore different topics. Thus, we proposed an AR storytelling application, named Virtual Playground and its AR authoring tool, named Virtual Playground Creator as our "case study". This tool was proposed in the context of language learning. However, we recognize that storytelling is an important ability across different fields to help students express their knowledge as illustrated in Dan Meyer's 3 Act Math[1], in which he shows that one can make math a series of stories to solve. This belief is also recognized in a chemistry teacher, speech:

> "*We exchanged our legislation (...) From the school board and it is actual now for all the schools in the whole Sweden. It says that you should use digital technology to express creativity and explain or illustrate your knowledge with this digital storytelling.*"

The answer to our research question concerning *"what features are important when authoring for education"* was translated into the design principles proposed in this research that can guide new AR authoring tools for education. We consider this set of principles the main contribution of this thesis. To achieve that, we had the participation of an interdisciplinary team of teachers, designers and engineers. From this study, we highlighted 11 design principles that are important for AR educational authoring. They were divided in three categories: infrastructure, augmented reality and pedagogy. Some of these design principles include: offering mobile version, the possibility of sharing the AR experience with other teachers, and enabling classroom management. Moreover, teachers are interested in co-creating AR experiences with their students. This is important to give students more autonomy and independence, which is also correlated to more mature uses of technology. This research has also shown that authoring tools

[1] Available at <https://rb.gy/twbnea>.

are still a major issue when we think about AR use in education. Although there are some options of AR authoring tools that do not require any programming level, only a few of them were designed specifically for educational activities. Moreover, these tools lack features that teachers would like to see when creating educational AR experiences, specifically pedagogical ones. These features are critical to provide flexibility so teachers can adapt the AR experience in different educational contexts. Finally, this work shows that AR authoring tools are important to support widespread use of AR in classrooms.

To validate the proposed design principles, we implemented and tested a functional prototype of an AR authoring tool that satisfies seven of them. The first evaluation cycles validated the concept and indicated that the tool is flexible and enabled teachers to author different didactic sequences. Results suggested that the tool could enable authentic work proposals. The second round of tests validated the design principles proposed and were the base for their refinement. It is noteworthy that the context of the COVID-19 pandemic imposed changes in all contexts of life and consequently in education, including the second round of tests carried out during this research. The participant teachers experienced very different realities in the context of the second test, involving fully remote or online teaching, hybrid teaching as well as face-to-face teaching. These different realities brought us some insights into the applicability of some of the principles proposed in a myriad of contexts. Results have shown that the tool allowed teachers to work with diverse skills and competences as evidenced in the didactic sequences proposed. In general, the Virtual Playground Creator prototype allowed the teacher to create their AR experiences proposed, although, in some cases modifications were needed. The main issues were related to the limited 3D library in the prototype evaluated and lack of creation possibilities. The input received was used to improve the UI and UX of both Virtual Playground and Virtual Playground Creator as detailed in Subsection 8.2.2.3. Although no clear relationship could be established between teacher's profile and the maturity of didactic sequences proposed, results suggested that teacher's unfamiliarity with the technology might generate a tendency to more conservative approaches and need for control. The maturity of the lessons proposed were still not very high. Results have also reinforced the importance of the use of statistics to aid teachers in the assessment process and improve student's learning, which could also encompass different types of data including multimodal learning analytics (BLIKSTEIN, 2013); as well as the importance of flexible assessment including the use of rubrics and peer assessment.

The design principles proposed are generic enough to cover different types of applications. Thus, we believe they might be transferred to other disciplines beyond language in which AR might be of use. However, it is necessary to validate the application to understand at what extent they might apply in different contexts. Another important point to mention is the creation of different processes and products that resulted from this work. We have used the Design Based Research and many adaptations were needed throughout the process as described in this document. Ultimately, it is important to address as much of the issues found in this research as possible so teachers can become more confident in AR use and feel confident enough to explore this technology in the classrooms and promote effective learning. It is important to mention that the goal is not just to use more of AR, but use it effectively, connected to the learning objectives and integrated to other technologies available in schools as advocated in the maturity model. In this sense, our results evidenced the need for interdisciplinary work that combines AR technology features with teacher training and school support so this ultimate goal can be properly achieved. Although we opted for the maturity framework and did not specify a methodology to be worked with, specific methodologies, such as problem-based learning could also be explored in the context of AR use. This would be especially interesting in STEM related fields. This aspect was mentioned by a Biology teacher in our study, who claimed that he would like to work with AR for problem solving.

10.1 FUTURE WORKS

We are aware that we need to continue these tests with more teachers in order to strengthen our prototype as well as refine the design principles proposed. Moreover, we need to understand what are the minimum set of affordances that are critical for the tool's use in the real environment. Additionally, it would be interesting to apply the tool in the schools in order to understand its impact on the students and in the school environment. We understand that future research needs to be done with the students and school management in order to better understand the impact of this technology in education as well as to further validate our second research hypothesis.

We intend to evolve Virtual Playground Creator to meet all the proposed design principles before a new cycle of tests. As this research pointed out, teachers usually do not use academic systems. Therefore, we intend to use these design principles to create a commercial version of Virtual Playground and its authoring tool, Virtual Playground Creator. To do that, we will follow the Voxar Labs' Entrepreneurial Journey, which is a process designed to transform research into sustainable businesses and it is currently being applied to other research projects from the lab. This will provide the infrastructure necessary for the tool to be known and used outside the university helm.

Another interesting line of research that is intertwined with teacher training is to investigate how the tool itself could help teachers define if AR is the best solution for their context. This would involve many interesting questions, such as what parameters could be used and what context information would be needed to provide the right recommendation.

10.2 THREATS TO VALIDITY

As limitations of this work, we point out the number of subjects interviewed (9 who used AR) and the number of answers (106) received in the form during Step 1 as detailed in Chapter 6. Also, we understand that the small sample size for some of the tests might have skewed the results. Authors are aware that the teachers who used AR are in a way pioneers in the use of technology and may not represent the general population.

Finally, it is important to point out that solving the problems discussed in this work might not directly cause teachers to use AR in more advanced levels. Results evidence that the effective use of AR, similarly to other technologies, depends on different aspects and stakeholders. Each of them play an important part in the process. As evidenced in Subsection 3.3.2, many behavioral elements regarding the teacher play an important part in this process. These traits take time to be developed. Moreover, circumstances at workplace also play a significant role in adoption. Aspects such as these are not in direct control of developers.

10.3 CONTRIBUTIONS

Our main contributions are:

- Literature review regarding AR authoring tools for education, which may help researchers to have a quick overview of the area;
- Characterization of teacher's use of AR and its specificity, which has been published and can help other researchers to better understand these users;
- Characterization of what is preventing teachers from using AR, which has been published and can aid other researchers to better understand the context in which users are inserted;
- A prototype of an AR application for education named Virtual Playground, which has been published and can help language learners as well as inspire researchers who want to prototype ideas involving multidisciplinary teams;
- An AR authoring tool prototype named Virtual Playground Creator, which helps to validate the design principles proposed as well as might enable more exploration of AR in educational contexts;
- An evaluation of existing AR authoring tools on the perspective of education, which may help researchers to have an overview on how current AR authoring tools are positioned concerning the educational perspective;
- List of design principles that can guide new AR authoring tools development for education.

10.4 PUBLICATIONS

As regards to publications, the results concerning the characterization of teachers who used AR have been published (SILVA et al., 2018) as well as the online survey with teachers, which demonstrates what is preventing teachers from using AR (SILVA et al., 2019b). The concept and development of Virtual Playground as well as its first round of testing have also been published (PEREIRA et al., 2020). Additionally, this Ph.D. study was selected to be presented and discussed in the SBIE Postgraduate Students Experience (STUDX) 2019 (SILVA; TEICHRIEB; CAVALCANTE, 2019). There were also four publications not directly related to this study (SILVA et al., 2019a), (SILVA; TEICHRIEB; CAVALCANTE, 2017), (SILVA et al., 2016) and (ROBERTO et al., 2016b). Nevertheless, they were important to gain experience in the Ph.D. topics. For instance, in (ROBERTO et al., 2016b), authors explored creative design techniques in order to create an AR application aimed at education.

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GLOSSARY

AR Interaction This feature takes the user interface to a whole new level as a virtual control panel can be overlaid directly on the product and operated using an AR headset, hand gestures and voice commands. This AR capability is still in its infancy in commercial products, but it could be revolutionary (PORTER; HEPPELMANN, 2017).

AR Visualization The coexistence of virtual and real information allows students to visualize complex spatial relationships and abstract concepts.

Augmented Reality (AR) concept for technological systems involving the combination of real and virtual worlds, real-time interaction, accurate 3D registration of virtual and real objects (AZUMA, 1997) and simulation, online effects and 2D perspective elements (SALMI; KAASINEN; KALLUNKI, 2012). Desktop computers, handheld devices, head-mounted monitors, among others, can be used to implement AR systems (BROLL et al., 2008; JOHNSON et al., 2010; LIU, 2009).

Authoring Tools AR authoring has two possibilities for programmers and non-programmers (HAMPSHIRE et al., 2006). The first category usually refers to code libraries such as ARToolKit. However, they require user programming knowledge. The latter refers to tools in which abstraction is added and low-level programmability is removed or hidden. In this work, we will explore AR authoring tools for non-programmers. Tools for non-programmers are content-driven and often include graphical user interfaces to build applications without writing a single line of code. Thus, these tools can also be called content design tools.

Field of View (F.O.V.) The field of view corresponds to the volume a user can see similar to what naturally happens in the human eye, however, from a technology standpoint it depends on the capacity of different devices. It usually depends on the ratio between the sensor width and the focal length. Cameras with two lenses can create wide field-of-view stereoscopic content (SZELISKI, 2021).

Instruction and Guidance AR's ability to transform instruction and guidance practices, to improve the way users receive and follow instructions, to transform the way users interact and control the product (PORTER; HEPPELMANN, 2017). AR can provide real-time, step-by-step visual guidance on different tasks, transforming complicated 2D schematic representations of procedures into interactive 3D holograms that guide users through the required processes (PORTER; HEPPELMANN, 2017).

APPENDIX A – INTERVIEW PROTOCOL OF TEACHERS THAT USED AR

Interview Protocol of Teachers that Used AR

1. Teacher's background:
    a. What is your age?;
    b. How long have you been teaching?;
    c. What is your educational background?;
    d. What school subjects do you teach?;

1. Teacher's planning:
    a. What is the age bracket of your students?;
    b. How do you usually plan your lessons?;
    c. How do you usually choose the contents to be worked with in the lessons?;
    d. What kinds of resources (digital or not) do you use to plan your lessons?;
    e. What kind(s) of multimedia content(s) do you usually use?;
    f. How long do you spend weekly to plan your lessons?;
    g. What kinds of activities (e.g: theoretical, practical) do you usually use/do in your lessons?;
    h. How do you plan the time of your classroom activities with students?;
    i. Besides the aforementioned resources, who helps you in your lesson planning?;
    j. What kinds of resources are desirable at the moment of your lesson planning?;
    k. What are the five most difficult contents to teach throughout the year? Please, justify your answer.;
    l. What are the five easiest contents to teach throughout the year? Please, justify your answer.;
    m. Do you take into account the demands of the students?;

1. Role of Technology:
    a. Is there a technology department in your school?
    b. How is technology management in your school?
    c. Is there any official demand for technological content/resources?

1. Role of AR:
    a. What kinds of AR tools did you use in your class?
    b. What did you use the AR tools for?
    c. Why did you choose to use these tools?
    d. What were the positive aspects of using AR in your lessons?
    e. What were the negative aspects of using AR in your lessons?
    f. What would you change in this/these particular lessons?
    g. Were you able to create content to the AR tool?
    h. If yes, how was it?
    i. Did you have any difficulties to create the content? Please give some examples.
    j. How would you improve this process?
    k. Would you like to create contents for the AR tool?
    l. If yes, for what concepts?/to teach what?

APPENDIX B – SURVEY

Use of Augmented Reality (AR) in Education

Dear teacher, this form is part of my Ph.D research. It intends to investigate what is your knowledge of Augmented Reality and what are your experiences using it in education. We invite you to read the free and informed consent letter below and check the box if you agree to participate. We appreciate your collaboration!
*Obrigatório

1. Endereço de e-mail *

____

Free and Informed Consent Letter for Participants in the Research Project

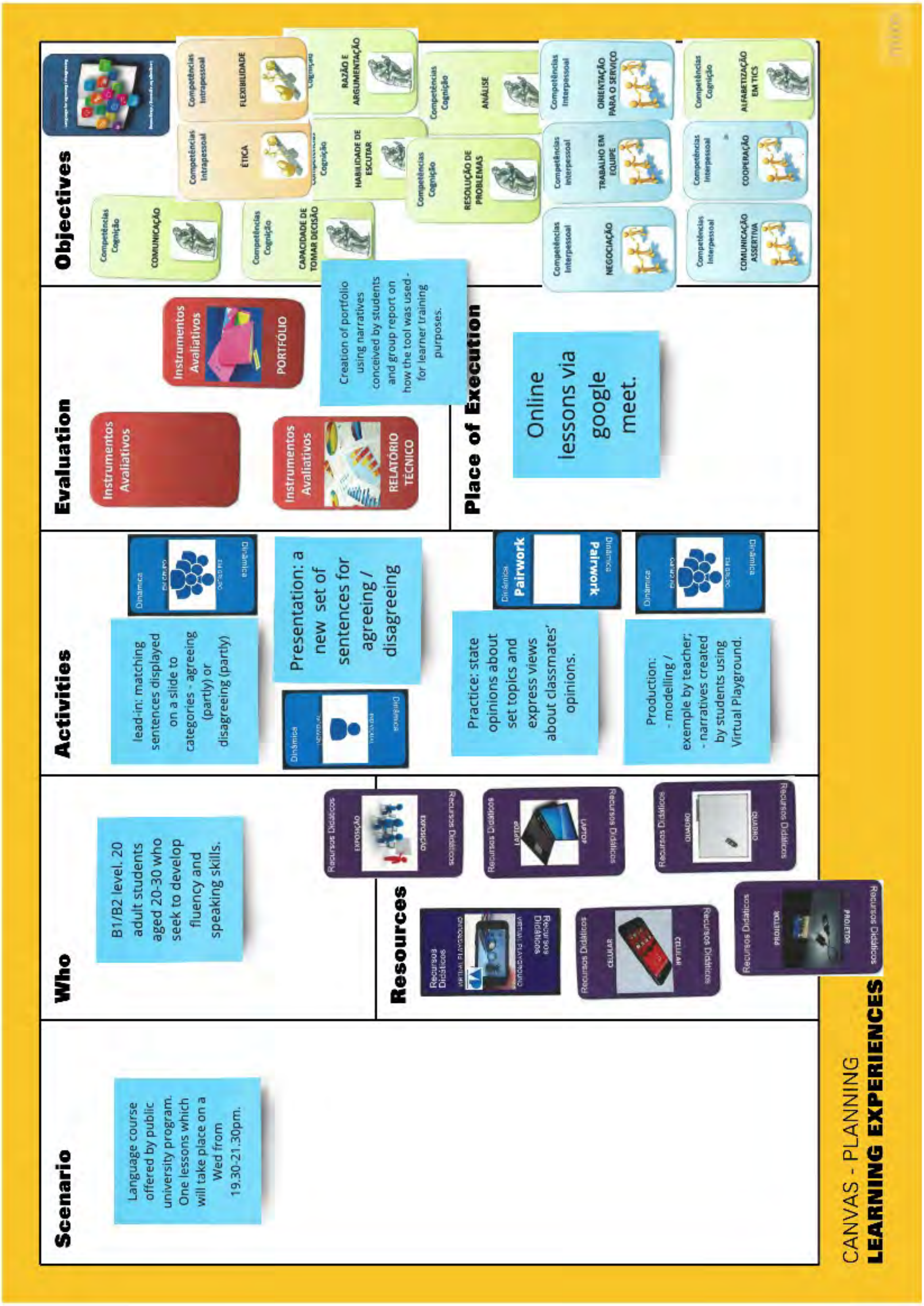
2. We invite you to participate in the PhD level development research carried out within the scope of the Graduate Program in Computer Science of the Federal University of Pernambuco. The purpose of the research is to investigate the use of technology by the teacher emphasizing, in particular, augmented reality to identify authorship needs. Your participation is voluntary and will be given through this form. We ensure absolute confidentiality regarding the information provided and your identity, preserved in the publication of abstracts, articles and works resulting from this research and even after the final report of this study has been written. Responsibility for research: Manoela Milena Oliveira da Silva, PhD candidate at the Informatics Center - UFPE, under the guidance of Profs. Dr. Veronica Teichrieb and Dr. Patricia Smith Cavalcante. *

   Marcar apenas uma oval.

   ◯ I agree to participate voluntarily and place my information related to the study available to the above mentioned research.

Personal and Background Information	Dear teacher, this section intends to provide some information about your background.

APPENDIX C – CANVA EXAMPLE



APPENDIX D – TEST CHECKLIST

TEST CHECKLIST

- ☐ I filled in the consent form (instructions available on the slide sent by the researcher)
- ☐ I have a computer available for the test
- ☐ I have a smartphone (minimal requirement Android 5.1)
- ☐ I have a screenrecorder app (e.g: AZ Recorder)
- ☐ My devices are properly charged
- ☐ I've dowloaded the Virtual Playground Creator (instructions available on the slide sent by the researcher)
- ☐ I have a comfortable space to participate in the test

THANK YOU FOR YOUR PARTICIPATION!

Researcher: Manoela M. O. da Silva
Questions?
+ 55 81 99650-1534
mmos@cin.ufpe.br

ANNEX A – CONSENT FORM BR

Universidade Federal de Pernambuco - UFPE

Programa de Pós-Graduação em Ciência da Computação – Centro de Informática

Linha de Pesquisa: Visão Computacional, Realidade Virtual e Aumentada

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO PARA PARTICIPANTES DO PROJETO DE PESQUISA

Convidamos o(a) Sr (a) a participar da pesquisa em desenvolvimento, nível doutorado, realizada no âmbito do Programa de Pós-Graduação em Ciência da Computação da Universidade Federal de Pernambuco.

O propósito da pesquisa é investigar o uso da tecnologia pelo professor enfatizando, particularmente, a realidade aumentada para identificar suas necessidades de autoria.

Sua participação é voluntária e se dará por meio de entrevista oral e testes dos protótipos apresentados. Como participante, você será convidado a testar os protótipos apresentados e responderá algumas perguntas sobre sua experiência durante o estudo e sobre seu perfil demográfico. A sessão poderá ser gravada em áudio e/ou vídeo. Por fim, a pesquisadora irá explicar e responder quaisquer perguntas que você tenha relacionadas à pesquisa.

Asseguramos o sigilo absoluto referente às informações prestadas e à sua identidade, preservadas na publicação de resumos, artigos e trabalhos resultantes desta pesquisa e mesmo após a elaboração do relatório final deste estudo.

Responsabilidade da pesquisa: Manoela Milena Oliveira da Silva, doutoranda do Centro de Informática- UFPE, sob a orientação das Profas. Dra. Veronica Teichrieb e Dra. Patrícia Smith Cavalcante.

Assim, eu, ____,

Portador (a) da identidade n° ________________________, após ter sido esclarecido sobre a pesquisa, aceito participar de forma voluntária e coloco minhas informações, áudios e vídeos relativos ao estudo à disposição da pesquisa acima mencionada. Este documento é emitido em duas vias que serão ambas assinadas por mim e pelo pesquisador, ficando uma via com cada um de nós.

____

Assinatura do/a entrevistado (a)

____

Assinatura da pesquisadora

Recife, _____ de _____________de _______.

ANNEX B – CONSENT FORM USA

Study Title: Augmented Reality Authoring Tools in Education
Researcher: Manoela Milena Oliveira da Silva
Version Date: 04/2019

Participation is voluntary

It is your choice whether or not to participate in this research. If you choose to participate, you may change your mind and leave the study at any time. Refusal to participate or stopping your participation will involve no penalty or loss of benefits to which you are otherwise entitled.

What is the purpose of this research?

The purpose of this research is to investigate teacher's needs for AR authoring tools aimed at education.

How long will I take part in this research?

Your participation will take approximately 120 minutes to complete.

What can I expect if I take part in this research?

As a participant, you will be presented to the concept of Augmented Reality and the concepts followed in the iterative design process you are participating. You will be requested to present, share and select ideas collaboratively for the use of Augmented Reality with small groups of students. You might also be asked to complete additional questionnaires about your experience during the study and about your demographics, and the session may be audio and/or video recorded. Finally, the experimenter will debrief you and answer any question you might have.

What are the risks and possible discomforts?

If you choose to participate, your experience will be similar from interacting with peers in a regular environment.

Are there any benefits from being in this research study?

At the end of the study, we will provide a thorough explanation of the study and of our hypotheses. We will describe the potential implications of the results of the study both if our hypotheses are supported and if they are disconfirmed. If you wish, you can send an email message to Bertrand Schneider (bertrand_schneider@gse.harvard.edu) and we will send you a copy of any manuscripts based on the research (or summaries of our results).

Will I be compensated for participating in this research?

There will be no financial compensation for this study.

If I take part in this research, how will my privacy be protected? What happens to the information you collect?

The data we collect will be kept confidential. Your data will be stored in a locked office in a locked file cabinet or on a password-protected computer. We will not use your name or information that would identify you in any publications or presentations.

The information with your name on it will be analyzed by the researcher(s) and may be reviewed by people checking to see that the research is done properly. The information may also be seen by transcribers.

If I have any questions, concerns or complaints about this research study, who can I talk to?

The researcher for this study is Bertrand Schneider who can be reached at 617-496-2094 or bertrand_schneider@gse.harvard.edu.

- If you have questions, concerns, or complaints,
- If you would like to talk to the research team,
- If you think the research has harmed you, or
- If you wish to withdraw from the study.

This research has been reviewed by the Committee on the Use of Human Subjects, Richard A. and Susan F. Smith Campus Center, 1350 Massachusetts Avenue, Suite 935, Cambridge, MA 02138; email: cuhs@harvard.edu for any of the following:

- If your questions, concerns, or complaints are not being answered by the research team,
- If you cannot reach the research team,
- If you want to talk to someone besides the research team, or
- If you have questions about your rights as a research participant.

Statement of Consent

Please state verbally that you have read the information in this consent form and that all your questions about the research have been answered to your satisfaction.

SIGNATURE

Your signature below indicates your permission to take part in this research. You will be provided with a copy of this consent form.

____
Printed name of participant

____ __________________
Signature of participant Date

ANNEX C – CONSENT FORM INTERVIEWS

Federal University of Pernambuco - UFPE

Postgraduate Program in Computer Science – Informatics Center

Research Line: Computer Vision, Virtual and Augmented Reality

FREE AND INFORMED CONSENT LETTER FOR PARTICIPANTS IN THE RESEARCH PROJECT

We invite you to participate in the PhD level development research carried out within the scope of the Graduate Program in Computer Science of the Federal University of Pernambuco.

The purpose of the research is to investigate the use of technology by the teacher emphasizing, in particular, augmented reality to identify authorship needs.

Your participation is voluntary and will be given by recorded oral interview.

We ensure absolute confidentiality regarding the information provided and your identity, preserved in the publication of abstracts, articles and works resulting from this research and even after the final report of this study has been written.

Responsibility for research: Manoela Milena Oliveira da Silva, PhD student at the Informatics Center - UFPE, under the guidance of Profs. Dr. Veronica Teichrieb and Dr. Patricia Smith Cavalcante.

Hence, I, ____,

Identity holder nº ________________________, after having been informed about the research, I agree to participate voluntarily and place my information and audios related to the study available to the above mentioned research. This document is issued in two copies, both of which will be signed by me and the researcher, leaving a copy with each of us.

____

Signature of the interviewee

____

Researcher's signature

Recife, _____ of ____________, ________.

ANNEX D – CONSENT FORM TESTS

Federal University of Pernambuco - UFPE

Postgraduate Program in Computer Science – Informatics Center

Research Line: Computer Vision, Virtual and Augmented Reality

FREE AND INFORMED CONSENT LETTER FOR PARTICIPANTS IN THE RESEARCH PROJECT

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Hence, I, ____,

Identity holder nº ________________________, after having been informed about the research, I agree to participate voluntarily and place my information and audios related to the study available to the above mentioned research. This document is issued in two copies, both of which will be signed by me and the researcher, leaving a copy with each of us.

____
Signature of the interviewee

____
Researcher's signature

Recife, _____ of ____________, ________.