StorytellAR: Supporting Creative Thinking in Storytelling with Augmented Reality

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Declaration
I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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[1] OUT-Once Upon a Time, https://doi.org/10.54499/PTDC/CED-EDG/0736/2021

Abstract

Storytelling plays a significant role in a child's development, fostering creative and cognitive skills. However, children are often reluctant to create their own stories, either due to a lack of inspiration or interest. While previous research has examined technology's role in addressing these challenges, many approaches fall short by restricting creativity, being overly complex, or requiring specialized equipment. Augmented Reality (AR), though widely studied for its educational and interactive potential, remains an underexplored medium in the context of digital storytelling. To address these gaps, we developed a mobile AR application to support story creation, as well as to explore how this technology impacts the collaborative creation process and the resulting artifacts. A user study was conducted to observe participant behavior, preferences, and the generated artifacts. Our findings reveal that the system encouraged creativity, collaboration, and embodied interaction. Participants found the AR environment more engaging and preferred it over other digital mediums. Additionally, the study highlighted the importance of agency, artistic expression, and multiculturalism in the storytelling process.

Keywords

Storytelling; Child–Computer Interaction; Augmented Reality; Creative Thinking.

Resumo

A narração de histórias desempenha um papel significativo no desenvolvimento infantil, promovendo competências criativas e cognitivas. No entanto, as crianças muitas vezes mostram-se relutantes em criar as suas próprias histórias, seja por falta de inspiração ou de interesse. Embora estudos anteriores tenham explorado o papel da tecnologia na tentativa de resposta a estes desafios, muitas abordagens falham ao restringir a criatividade, serem excessivamente complexas ou exigirem equipamento especializado. A Realidade Aumentada (RA), apesar de amplamente estudada pelo seu potencial educativo e interativo, continua a ser um meio pouco explorado no contexto da narrativa digital. Para colmatar estas lacunas, desenvolvemos uma aplicação móvel de RA para apoiar a criação de histórias, bem como para explorar o impacto desta tecnologia no processo de criação colaborativa e nos artefactos resultantes. Realizou-se um estudo com utilizadores para observar o comportamento dos participantes, as suas preferências e as histórias criadas. Os nossos resultados revelam que o sistema incentivou a criatividade, a colaboração e a interação *embodied*. Os participantes consideraram o ambiente de RA mais envolvente e demonstraram uma preferência por este em relação a outros meios digitais. Além disso, o estudo destacou a importância da agência, da expressão artística e do multiculturalismo no processo de criação narrativa.

Palavras Chave

Criação de Histórias, Interação Criança-Máquina; Realidade Aumentada; Pensamento Criativo.

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Acronyms

2D Two-Dimensional

3D Three-Dimensional

AR Augmented Reality

FOV Field of View

GPS Global Positioning System

HMD Head-Mounted Display

PCB Printed Circuit Board

UI User Interface

UUID Universally Unique Identifier

1

Introduction

Contents

Storytelling is a fundamental component to the development of a child, most notably in the areas of creativity, communication, collaboration, language and cognitive skills [8–11]. As such, it is important to encourage children to engage in storytelling activities, both in educational and ludic contexts. However, children are often reluctant to create their own stories, which can result from a lack of inspiration, as well as due to the task not seeming appealing enough [12, 13].

Technology has the potential to not only mitigate these issues, but also to enhance storytelling activities, as its adoption in education has been observed to increase entertainment and engagement while promoting the development of the aforementioned competencies [14, 15]. For children, the ability to observe or interact with virtual objects and characters, particularly in three-dimensional (3D) spaces, is a significant motivator for their ongoing usage of the system [16]. This is further reinforced when applied to storytelling since a digital medium enables visualizing ideas with ease, which not only facilitates the story creation process, but also fosters collaboration among children by allowing them to more clearly express and discuss their ideas.

Augmented Reality (AR) is a technology that allows interacting in real time with virtual 3D content overlapped onto the physical environment [17]. Therefore, when using an AR application, the real world greatly influences the experience, making it a suitable medium for encouraging the creation of narratives that incorporate physical elements, which might be the child's surroundings and their toys [3, 4], or even their own scenarios and props created through analog means such as paper or playdough [18]. Not only does this inspire children to use existing objects in novel ways, but it can also motivate them to engage in artistic endeavors that stimulate their creativity, while not limiting their imagination to the choices available in the system. Moreover, research has shown that interacting with physical objects plays a significant role in the development of children's cognitive abilities [19]. Hence, it is important to provide adequate support for this type of interaction. AR also facilitates direct collaboration by not confining activities to the virtual realm, and allowing users to be more aware of the presence of others and see them at all times [20].

1.1 Problem

The Creative Learning Spiral [21] is an approach devised by Resnick that aligns with a constructionist model of learning [22] and encourages creative thinking. It is a cyclical process of "Imagine, Create, Play, Share, Reflect, and back to Imagine" [[23], p. 2]. In light of this concept, the author delineates some principles that tools designed for children should follow, such as being adaptable in order to not restrict imagination, providing opportunities to create and experiment, focusing on sharing with peers as a source of inspiration, and encouraging the evaluation of their own work in order to improve it.

Many of the existing applications of technology to support storytelling activities do not follow these principles, as they are constraining in different aspects. Most enable experiencing only existing stories with limited or no possibility to influence the narrative in meaningful ways, forgoing the ability to create [1, 24, 25]. Others allow fabricating stories, but have a number of drawbacks, such as being too complex for inexperienced users [26, 27] and discouraging playful exploration or experimentation [26, 28–30], or requiring separate equipment [31–38].

Taking into account the attributes of AR and its recognized benefits when used in educational contexts [39], it has the ability to improve on the existing systems and address their issues. In spite of this, AR still hasn't been sufficiently explored in the context of storytelling, especially with respect to the creation of narratives by children.

1.2 Approach

This project centers on the usage of augmented reality to create animated stories. With its persistent connection between the real and virtual worlds, AR overcomes system limitations by allowing to incorporate physical elements into the narratives. Moreover, it allows the environment to serve as a source of inspiration, and enhances engagement in the activity, encouraging children to participate in storytelling.

The application developed for this project enables children to create stories on a mobile device, either individually or in collaboration with peers. These stories are built through the interactions of virtual elements, which children can move through space or assign animations to. Stories can be set in the physical world or within virtual 3D landscapes, offering flexibility for creativity even when the physical environment is not as inspiring, and allowing to explore different locations. Additionally, the stories can be further enriched and personalized with audio recorded by the users.

1.3 Research Questions and Hypotheses

To guide the development of the system, as well as to have a basis for evaluating its success in meeting the defined objectives, the following research questions and associated hypotheses were formulated:

- **RQ1:** Does the solution promote creative thinking?
  - **H1:** The solution leads to the generation of creative artifacts.
  - **H2:** The materials do not constrain the story.
  - **H3:** The design facilitates experimentation.
  - **H4:** The solution encourages reflecting and building up on past work, as well as sharing it with peers to exchange ideas.
- **RQ2:** Does the solution promote real-time collaboration?
  - **H5:** The solution facilitates discussion during story creation, and enables equal participation in this process.
- **RQ3:** How often and in what ways do children make use of their surroundings in the stories?
  - **H6:** The physical environment is incorporated in the stories.
- **RQ4:** Does the solution increase willingness to engage in storytelling activities?
  - **H7:** The users enjoy creating their own stories and feel more motivated to do so.

The validity of these hypotheses was evaluated through a user study conducted in a school setting with fourth-grade children, where pairs of students were tasked with collaboratively creating and recording a story using the system.

1.4 Organization of the Document

In Chapter 1, we introduce the problem addressed in this study, outline the research questions guiding the investigation, and present the hypotheses we anticipate will be verified. In Chapter 2, we provide a background on the theories that informed our approach, and present previous works on the field, analysing their strengths and limitations. In Chapter 3, we describe the prototype that was developed, focusing on both its design and technical aspects. In Chapter 4, we describe the methods employed to evaluate our solution. The results obtained from the evaluation are displayed in Chapter 5. In Chapter 6 we discuss the aforementioned results, identify the limitations of the study and propose future research directions to verify and expand upon our findings. Finally, in Chapter 7, we summarize the main takeaways from the project and our contributions to the field.

2

Related Work

Contents

2.1 Background

2.1.1 Sociocultural Theory of Cognitive Development

Lev Vygotsky's sociocultural theory [40] emphasizes the importance of interpersonal communication and cultural context in the development of cognitive processes. Speech, which often accompanies activities, helps children perform tasks and guides their behavior. It is through speaking that children organize their thoughts, plan solutions to a problem, and seek assistance when facing challenges. Vygotsky introduced the concept of the zone of proximal development, defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" [40, p. 86]. This underscores the value of collaboration as, through engaging in activities alongside peers with a higher proficiency in different capabilities, children can perform tasks that they aren't yet capable of doing independently, thus developing emerging cognitive functions.

2.1.2 Constructionism

Constructionism, a theory proposed by Seymour Papert, suggests that "learning is particularly effective when it is embedded in an activity the learner experiences as constructing a meaningful product" [22, p. 1]. Unlike the traditional model of learning, where concepts are often presented in isolation from practical application and learned through rote memorization, the constructionist model proposes that knowledge should be acquired in the context of other activities that personally motivate the learner. Papert praised the use of computers as limitless tools for building various artifacts, such as games, simulations and artistic creations. In line with this, he co-developed LOGO, a flexible and intuitive programming language. While having a project in mind, children explored the capabilities of the language while applying concepts of mathematics, physics, music and others [41].

Following these ideals, Mitchel Resnick introduced a set of principles that aimed to help children grow as creative thinkers. These are the Four P's of Creative Learning: Projects, Passion, Peers and Play [21]. He asserts that children learn better when working on the creation of projects they deeply care about, in a playful and experimental way, and when they collaborate with peers and receive feedback. Moreover, Resnick describes the Creative Learning Spiral, a cycle of "Imagine, Create, Play, Share, Reflect, and back to Imagine" that occurs when learners work on a project [23]. Following the educational success of the programming language Scratch[1], which he co-founded, the author delineates a set of principles for designing technologies that support creative learning: tools should be versatile to avoid constraining childrens' imaginations; the technology should be oriented towards creation, rather than mere interaction; the process should be fun and engaging, and allow children to experiment with new ideas; it should enable sharing creations with others to inspire and motivate; and finally, the technology should allow children to review their work and reflect on their successes and shortcomings, thus consolidating learning and sparking new ideas.

2.1.3 Embodied Cognition

The Embodied Cognition theory argues that body and mind are intrinsically linked, and that the development of cognitive processes does not occur in isolation, being instead shaped by an individual's sensory and motor interaction with the environment [42, 43]. As a result, physical action and perception are paramount for potentiating the acquisition of fundamental competencies, not only for the task at hand, but also extending to other activities involving the same processes [44]. Research has demonstrated that

[1] Scratch homepage, https://scratch.mit.edu/

embodiment has an influence on areas such as memory [45], socialization [46], language [47], music cognition [48] and knowledge acquisition for education [49]. The principles of embodied cognition have been increasingly applied within digital contexts, often for educational purposes. These approaches enable interaction with systems through sensorimotor input or output, leveraging perception and movement to facilitate learning and understanding.

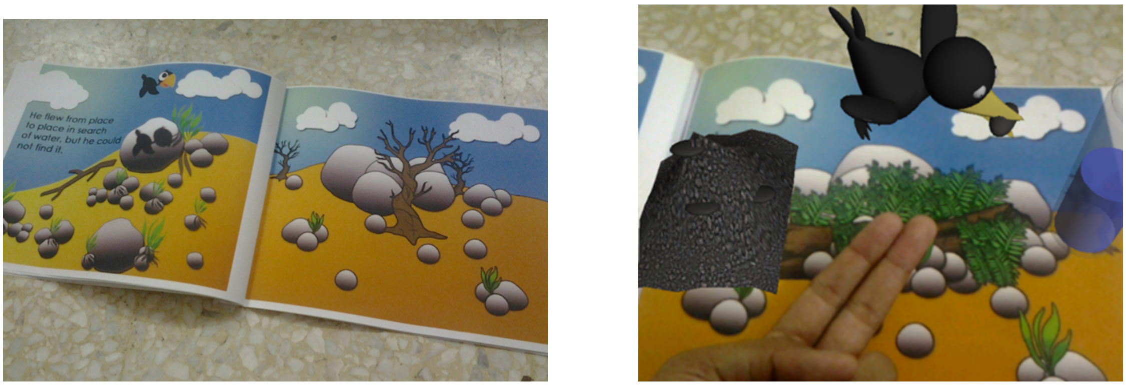
2.2 Literature Review

Existing systems that support storytelling differ in how much the user can interact with the story. Some systems present only a complete story where the user is a passive watcher, and while they might be able to make some decisions, they ultimately do not affect the course of the story. Contrarily, more interactive storytelling systems allow the user to influence certain details in an existing story to change its plot. Taking a step further, there are systems that enable users to create an entire story from scratch. In this literature review, we will focus on the last two types of systems.

2.2.1 Interactive Storytelling

Interactive storytelling systems allow the user to perform certain actions in order to affect the story. This technique is best known through electronic games, where the user is often placed in the role of the main character. In interactive fiction [50], text-only stories are shown on the screen, prompting the user to type the action they wish their character to take in order to progress through the story. With posterior advances in computing power, these were expanded into graphic adventures, which still allowed choice but with the inclusion of visuals to accompany the story. However, one can argue that mainstream video games aren't to be considered interactive storytelling, as the story that is formed tends to be heavily influenced by mandatory gameplay elements, such as puzzles designed to entertain the player [51].

On the opposite end of the spectrum, there are systems that attempt to establish a clearer correspondence with the classic story book format. One approach is to use physical books as basis for a digital augmentation, commonly through augmented reality [1, 24, 52]. In these systems, the content on the pages of the book is used as markers that get recognized by the application and trigger the appearance of virtual characters that can be interacted with. This approach integrated with a real book has the advantage of the access to the story continuing beyond the digital application. Other strategies to present interactive stories employ the simple presentation of text and graphics on a display as they would appear in a book, possibly with the addition of accompanying audio or other novel features [53]. Similarly to the aforementioned interactive games, the narrative can be influenced by the user, usually by pressing buttons symbolizing multiple choices. Besides this, some systems allow changing the presentation of the story itself. This is the case of TinkRBooks [25, 54], storybooks that can be viewed on a tablet that



(a) Physical book. **(b)** Gesture-based interaction with virtual elements.

Figure 2.1: Interactive storytelling system in ”An Interactive Mobile Augmented Reality Magical Playbook: Learning Number With The Thirsty Crow” [1].

allow children to point at textual and graphical elements in order to change them. This produces simple changes in the story, such as changing the weather from ”sunny” to ”rainy”, which promote literacy by connecting written and visual concepts.

While interactive storytelling systems allow some freedom in determining plot elements and sometimes the story’s resolution, they are always tied to the same base narrative and setting created by the authors. Moreover, as it is impossible to represent every single possible outcome, the choices are limited to what was programmed in the system. When the user only controls the actions of a single character, the outcome of these choices might not even be clear, as they sometimes only change events further in the future. For these reasons, this type of system highly constrains the creativity of the users by not allowing them to alter the stories in the ways they desire. While they play an important role on the promotion of storytelling behaviors related to reading and listening, systems that only support interaction, but not design or creation, pose a challenge to the development of creative thinking [21].

2.2.2 Story Creation

Current story creation systems provide the ability to author rich stories with an expressive graphical representation. However, to grant the user the freedom to create exactly the type of story they envision, these systems are naturally more complex. By integrating the storytelling component with preexisting software frameworks, such as game engines, the system can take advantage of their established methods to develop visual applications. This approach is adopted by Kapadia et al. in the creation of a tool that automatically generates interactive narratives [26]. To create a story, the user needs to use an engine to program the different plot arcs, the state and relationships of the characters and objects, and the desired animations. One issue with this approach is that, similarly to other systems, it requires programming knowledge, thus posing a significant skill barrier to story creation. Moreover, the ensuing workflow is more suited for materializing stories that are already formed, forgoing the process of exploration that gives rise to new ideas [21]. A subsequent study [27] aimed to make this type of tool more accessible by developing a graphical platform to define the story characteristics, but it still required understanding specific concepts such as behavior trees and logical expressions, making the tool difficult to use by users who do not possess this knowledge.

The expected level of computer literacy required for these systems makes them unsuitable to be used by children, though it is undeniable that programming-based methods offer a lot of freedom in creating a completely personalized story. The popularization of drag-and-drop and block-based programming environments such as Alice [55] or Scratch [56] has made this skill more accessible to children by replacing code with visual blocks that can be arranged together into a sequence of actions. These environments help children express their creativity in the form of games, music, animations, and, more relevant to the present work, stories [57–59]. Nevertheless, most block coding systems aren't suited for younger children who haven't yet acquired reading skills. To address this, Dietz et al. developed Visual StoryCoder (Figure 2.2), a mobile application for story creation [2] that relied solely on programming blocks that had symbols in place of text, as well as an animated voice agent that provided help and suggestions. The narrative was formed by sequencing together blocks representing chapters, and augmenting them with drawings, music and sound effects. While the simplicity of this system is a plus, both due to it being easy to use and facilitating swift story creation, the limitation of the types of media that can be used and how they can be arranged restricts the variety of stories that can be authored. It is difficult to find a balance with systems involving programming as, if they allow too much freedom, they pose an added layer of complexity that might detract some children from using them to create stories, particularly as they encounter problems in the code [60], but when simplifying them too much, their limitations are apparent.

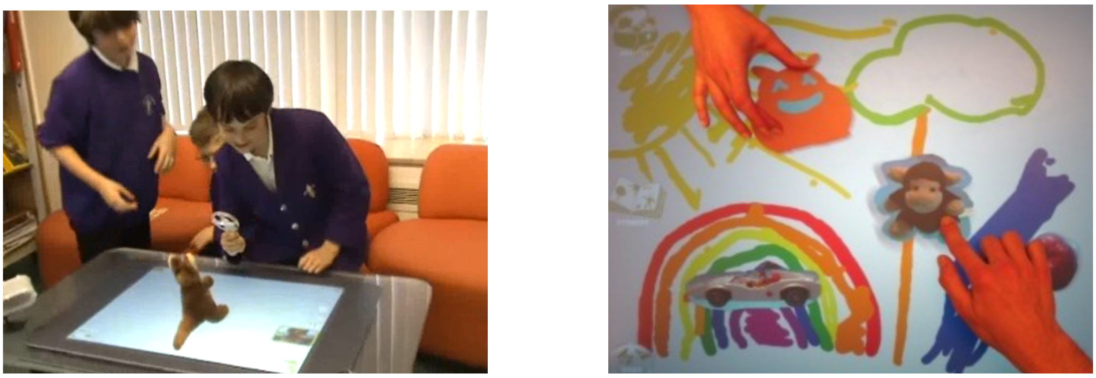
Figure 2.2: Story creation with block programming in Visual StoryCoder [2].

Visual interfaces tend to be less complicated and more accessible, as their reliance on images means that they can more easily be used by children whose literacy skills are still in development [61]. As the usage of text is limited, there tends to be an emphasis on the addition of media chosen or created by the children to complement the story, an activity that mirrors the process of creating illustrations to accompany traditional written stories. Technology further reinforces self-expression with multiple mediums by enabling the addition of elements such as video and audio recordings, digital drawings, photographs and even animations. Other approaches employ the use of premade media to direct children's efforts towards the plot and explore different possibilities. However, Rubegni and Landoni [29] noted that, in these circumstances, the level of detail given to the characters tended to diminish. This was particularly evident when the images depicted characters from popular entertainment media, and the resulting stories would conform to the established ones. Therefore, the authors caution that providing a complete set of characters and scenarios might direct the narratives in a specific direction.

These graphic-based systems can be separated into those that require creating a story with a specific structure, and those that allow for more free-form narratives. The first category of systems aligns with concepts from the school curriculum regarding storytelling, such as learning the general structure and constituents of a narrative belonging to a specific literary genre. For instance, these applications can prompt the definition of typical plot points such as setup, conflict, climax and resolution and provide guidance on what to include in each of them [4, 30, 62], or ask to detail features of story elements such as a protagonist or an antagonist [28, 29]. Moreover, these systems often provide inspiration by presenting text or images that may be included in the stories as a starting point. Both of these factors are important in overcoming the initial hurdles of starting a story, as well as in creating a compelling and thought-out narrative that fills the authors with a sense of pride. Nonetheless, one can argue that by only anticipating the creation of structured narratives, children's creativity is restricted by not letting them experiment with different or unconventional formats [21].

Unstructured narratives generally consist in sequences of scenes that make extensive use of the various types of media previously mentioned. With the possibility to animate images and easily create special effects through simple drawings, the objects and characters are manipulated towards a creation akin to a theatre play, often enhanced with the inclusion of dialogue [63, 64]. To allow children to fully represent what they envision, physical elements are transported into their stories through audio, image and video capture [3, 18]. Through this continuous interaction with the physical world, they draw inspiration from their environment, either by creating stories set in their current location, by bringing their toys to life through animations, or by using colors and patterns as a basis for other creations (Figure 2.3). Their creativity is stimulated by encouraging them to look at their surroundings with a different lens and giving them a new purpose.

Indeed, as Decortis and Rizzo emphasize, the story creation process is naturally ingrained in the



(a) Photographing a toy to use in the story.

(b) Animating story elements.

Figure 2.3: Children creating a story with photographs and drawings in TellTable [3].

local environment [18]. Such integration is amplified in location-aware narratives, which are meant to be experienced in the locations they take place in, and commonly track Global Positioning System (GPS) coordinates to determine the viewer's progress in the story [65]. The inclusion of various types of media to capture ambient sounds or to illustrate imagined creatures living in the area provides a highly immersive experience. When creating a story, the author's imagination is sparked by their physical presence within the setting, being encouraged to delve deeper into the details about the narrative and how they wish to convey their ideas [66]. The lack of inspiration is mitigated through a careful observation of the environment to find items and structures that can be incorporated in the story [4]. Yet, the strengths of this type of storytelling are what makes them cumbersome to use. Authoring and viewing stories requires traveling to a specific location, which poses a significant obstacle to children in particular. As such, even the sharing aspect [21] of the process is compromised due to the effort it requires.

Even if the aforementioned systems promote the manipulation of objects, once the content has been imported into the program the interaction is done solely on the digital displays. Tangible interfaces [67] associate physical objects with digital functionalities, allowing users to interact with the system through the objects themselves. Their applications range from the usage of puppets whose movements animate characters on a display [32] or play back recorded dialogue when shaken [33], puzzle pieces that construct a story based on the sequence of their connection [35], blocks that determine the appearance of story elements on a screen and their interactions [36–38], among many others. The usage of physical objects to interact with the system provides for a more intuitive and embodied experience, which contributes to an increased engagement and immersion in the storytelling activity. Instead of a task, it becomes more similar to play. Still, the reliance on single purpose objects presents a significant obstacle to the accessibility of these systems, as there is an added cost and burden of acquiring the tangible objects. In this sense, systems involving more readily-available devices should be considered.

An alternative method to engage with the physical and virtual worlds simultaneously is through augmented reality, a technology that has consistently demonstrated positive outcomes when applied to

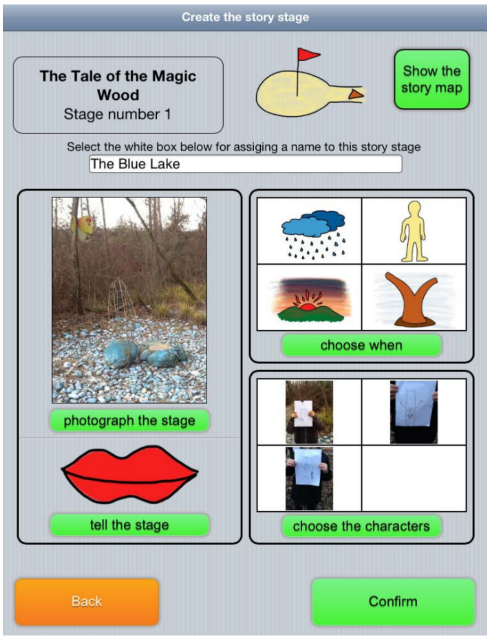


Figure 2.4: Setting a stage in a physical location in CASTOR [4].

educational settings. Through numerous studies and practical applications, AR has proven to be an effective tool for enhancing the learning experience [39, 68, 69]. Children perceive the appearance of virtual objects as magical and engage more in learning activities [20, 70], making it a good device to absorb concepts and acquire competences. Regarding storytelling, children who create stories with the support of AR perform better in terms of narrative skill, story length, and creativity [16].

The characteristics of AR make it non-limiting by nature. Any object can appear on screen to be manipulated, and existing objects with generic representations can be transformed in multiple ways by using them as markers [31]. Similar to the aforementioned digital systems, the real environment can serve as a backdrop, but with the added advantage of real-time interaction to dynamically switch contexts. Unexpected elements can appear in the environment, sparking new ideas for stories. Regardless, this connection to the real world should not be perceived as a constraint, as stories can be set in different locations through the creation of sceneries with toys and painted cardboard. Additionally, the camera view enables the dynamic movement of physical characters, allowing them to interact directly with the virtual world and vice versa.

Despite the possibilities it offers, AR still hasn't been sufficiently explored in application to storytelling, particularly regarding story creation. An example worth highlighting is StoryMakAR [5], a toolkit rooted in the maker culture [21] that encourages students to customize physical characters and props with reusable materials, connect them to a plug-and-play printed circuit board (PCB), and program their behaviors during the sequence of events of the story via a block-programming web application. Story events can then be triggered via an app on a mobile phone, and through AR they can include virtual-physical interactions, where virtual characters influence the behavior of the physical devices, such as opening the door of a physical house (Figure 2.5). Students enjoyed using their creativity to customize the components of the story in their entirety, from appearance to behavior [21], and using the capabilities of AR to incorporate both physical and virtual elements in their creations. But despite the fact that the majority of the students in the study found it easy to program the devices and control the sequence of events, this suffers from the same accessibility problem as programming-based systems described above, which is why it is more oriented towards teens. Additionally, basing the entire system on the construction of physical objects can pose a problem of lack of engagement if a student is having difficulties, particularly if they are alone and can't request help from peers. Indeed, one of the two students in the study who were working alone gave up on including physical interactions into his work when he saw that the bird he had built did not function as he wanted.

Another relevant application is SceneAR [6], a mobile application that allows creating short stories in a comic strip style. The stories are authored by placing 3D characters and speech balloons in the physical environment through touch controls. The models are retrieved by searching in a remote object library, another way to avoid constraining users' stories to objects available in the app. The story sharing feature was welcomed by users who were struggling with lack of creativity, as not only did they feel inspired by others' content, they also used the remix feature to directly expand on existing stories, which resulted in the collaborative creation of narratives. Such observation reinforces the importance of sharing as a promoter of creativity [21]. However, as the shared stories are played back in AR format to provide a more engaging experience, it is also possible that some of the story context is lost if it is viewed in an environment that does not correspond to what was envisioned by the author. Even though this is mitigated to an extent through a description listing physical requirements, it is impossible to use real objects as story props, which was attempted by some study participants, as seen in Figure 2.6.

2.2.3 Final Remarks

The explored systems address children's lack of inspiration by motivating them to observe their surroundings [4] and the interactions between digital story elements [36, 37], and by sharing their creations [3, 6, 18]. Through sharing, it is possible to directly build up on the stories of others, get new ideas for their own stories, or even share items and characters across stories. Many systems expand the limits of creativity by allowing the inclusion of media created or captured by the children [2–4, 18, 28, 30, 56, 62], or even encouraging the customization of physical objects [5]. Regarding engagement, all students reported enjoying experimenting the systems, likely due to their graphical nature and attractive visuals. The collaborative aspect was also observed in all systems, with those relying on interaction with a single device functioning mainly by turn taking. Though this sometimes led to children taking a leading role in the development of the story, groups made sure everyone was able to contribute in some way. Other

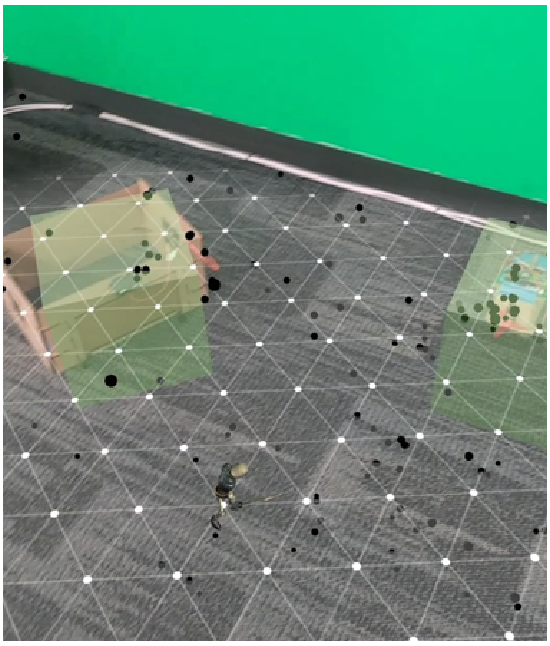


Figure 2.5: Virtual skeleton interacting with programmed house in StoryMakAR [5].

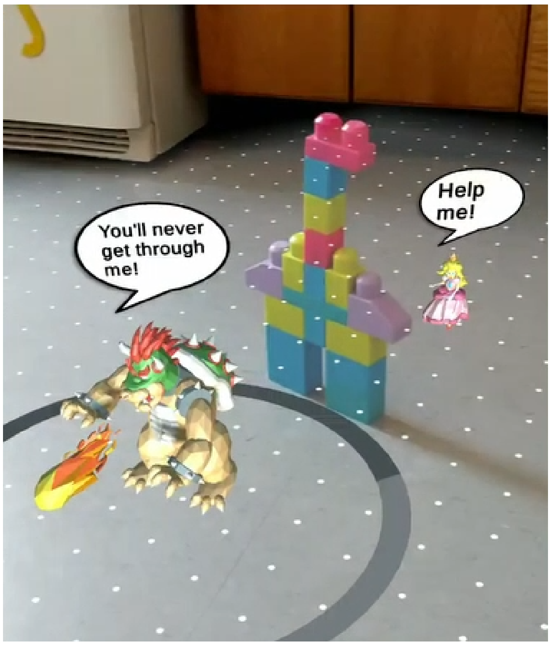


Figure 2.6: Using building blocks as part of a story in SceneAR [6].

systems more focused on working with physical objects could have children working at the same time and distributing tasks [5]. While this level of coordination can be beneficial, they also miss out on the aspect of building up on each other's ideas.

3

The StorytellAR System

Contents

To evaluate whether the designed system met our objectives, we developed a prototype consisting of a mobile application that allows users to record stories in AR and play them back at any location. In this chapter, we describe the structure and components of the stories, the technologies employed in developing StorytellAR, as well as the design decisions and functionality of each part of the application.

3.1 System Overview

Stories are structured as a collection of scenes, which resemble a short film when played back. Each scene consists of a video recording of the virtual story elements interacting in augmented reality, performing actions directed by the users. Scenes are also accompanied by sound effects from the application, as well as audio captured from the microphone, which allows the addition of narration, dialogue and ambient sounds. AR helps overcome the system's limitations, that is, the diversity of elements that

Figure 3.1: Virtual story elements coexisting with physical objects.

children have at their disposal, and avoids constraining their imagination. Any additional backgrounds, characters or objects can be included in the story by capturing physical elements with the camera, making it possible for children to integrate their toys or themselves into the stories, as seen in Figure 3.1. Having the real world as a backdrop for the story encourages continuous interaction with the physical surroundings, facilitating an embodied interaction with the system and promoting communication with peers. Moreover, it increases engagement and interest in the activity, and helps inspire new themes and events for the story from both static background elements and unexpected occurrences.

3.1.1 Story Elements

The main elements used in the stories, as well as the user interface illustrations, were developed within the project Mobeybou [71]. The story elements were selected for their appealing design, diverse animations, and connections to existing narratives and real-world cultures. They consist in human characters, mythical creatures, animals, music instruments and magical objects. A variety of atmospheric conditions is also available, which may incorporate particle effects, overlays and sound effects. The landscapes, encompassing beach, volcano, forest, desert, and city settings, provide versatile environments suitable for various stories. They feature assets sourced from the Unity Asset Store[1], including stylized textures and low poly objects, the art style of the latter having been selected for its ability to complement the hand-drawn look of the two-dimensional (2D) elements.

[1] Unity Asset Store, https://assetstore.unity.com/

3.1.2 Platform

Our solution is developed with mobile devices in mind for two reasons. Firstly, because current head-mounted displays (HMDs), while offering more immersion and freedom of movement, aren't designed to be worn by children, due to their significant size and weight. Popular devices such as Magic Leap specifically recommend against being used by younger children because of these concerns [72]. The second reason pertains to the expense and inconvenience of purchasing separate devices. By creating a mobile application that doesn't require special equipment or environmental conditions, our solution can more easily be used at home or in the classroom through widely owned devices. To this end, we intend to make the application available for download through the most common app distribution platforms.

3.1.3 Architecture

The application was developed in the Unity Engine [73], one of the leading tools for AR development. This engine was chosen due to its support for rendering both 2D and 3D graphics in a 3D space, as well as for its powerful AR Foundation [74] framework, which not only simplifies the incorporation of features such as plane detection, but also allows building an application for both Android and iOS with minimal or no modifications required.

The ARCore Extensions package [75] provides additional functionality to AR Foundation, and was used for its Recording and Playback API, which allows recording the camera's video stream along with AR objects' data, storing that in the device, and playing it back later. Since using the playback feature requires the AR session to be working, it can't be used when the device doesn't detect sufficient features of the environment, such as in low light conditions or when the camera is covered. As such, the Recording and Playback API is only used for recording the camera's video stream, and not for playback.

3.2 Creating a Story

3.2.1 Story Creator

The story creator initially displays the camera view, accompanied by two rows of buttons, allowing users to immediately experiment and test ideas before beginning the story creation process. The buttons in the top row reveal the story element menus, illustrated in Figure 3.2, enabling users to select elements to add to the scene. To maintain a simple user interface (UI), only one instance of an identical object can be present in the scene at the same time, and for landscapes, only one can be active. To remove an element from the scene, it must be selected again in the same menu, where it will be marked with a cross over its thumbnail if it is currently in the scene. This graphical representation of the UI elements ensures even younger children with limited literacy skills can easily use the application.

Figure 3.2: Menu for adding or removing animals and mythical creatures.

Story elements spawn directly in front of the camera, close to its position, as this is where children are most likely to interact with the objects and set the story. To increase the connection between the real and virtual worlds, they appear to occupy a specific physical location, and maintain it even when the device moves. These elements are billboards—2D sprites in a 3D world—so they always turn to the same direction the camera is facing to remain visible and easy to manipulate. Elements representing living beings and objects can be moved by dragging them to the desired position. They can be placed in any location, enabling a broader visual representation of events. This movement is performed on the two axes defined by the screen plane. Therefore, to move an element on the axis perpendicular to the screen, the user must physically rotate the device and place it on that axis. Additionally, these elements can be resized through a pinch gesture. Even though it is a more complex gesture, it is expected that it will be used more sparingly, as the size of the elements is not likely to change much throughout a story.

To make a character perform an animation, the user must first select the corresponding button from the bottom row of buttons (visible in Figure 3.1), and then tap on the character. As some animations are only available for a certain set of characters (for instance, the attack animation cannot be applied to human characters due to the original assets not supporting it), the characters capable of performing the selected animation are highlighted with a blue outline. Human characters can also be given objects, which makes them perform different animations with them and, in the case of music instruments, play sound as well. To do so, the object must be dragged until it is on top of the character. These interactions provide a swift way to assign actions to characters, while allowing the freedom to leave objects scattered throughout the environment without requiring them to be used.

Atmospheric effects, which enrich the stories with further visual details, accompany the position of the camera to always remain visible. Some consist in images overlaid on the screen. For instance, the night effect enables a semi-transparent dark blue image on screen space. Others involve particle effects in world space that are parented to the camera, so that their origin point moves along with the camera.

Landscapes provide interesting settings for the stories, allowing characters to be transported to various environments, especially when the physical space is not conducive to inspiration. They are placed on top of real-life surfaces, to increase immersion and connection with the physical space. When a landscape is enabled, the system activates plane detection, and a blue plane previews the surface that will be occupied by the scenery. Once it covers the desired area, users can tap on the plane to spawn the landscape. Each landscape consists of two components: a ground texture applied to a plane identical to the one selected, and various three-dimensional objects. The size of the plane determines the number of objects added, which are randomly chosen from a pool of thematic objects specific to each landscape. This pool also indicates the probability of each object being added and the maximum number of instances present. As a result, each instance of the landscape is unique, with variations in both the objects present and their positions. Additionally, the ground texture can feature some motion, as is the case of the beach landscape's water texture, which has a scrolling effect to simulate wave movement. An example of a landscape is visible in Figure 3.3.

After planning the narrative of the scene, children can then press the record button and begin enacting their vision. During recording, everything displayed on the screen is captured, along with the accompanying audio. The recording stops after pressing the same button a second time.

Figure 3.3: Possible configuration of a desert landscape featuring interactions among three characters.

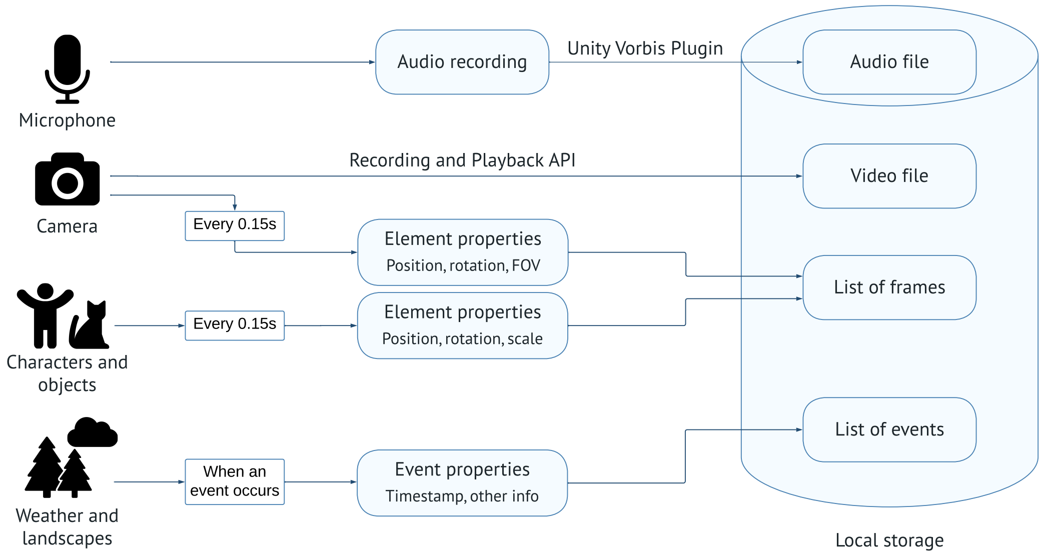


Figure 3.4: Data captured during the recording.

3.2.2 Recording

When a scene starts being recorded, the system saves the video from the camera, the audio from the microphone, the properties of the objects currently in the scene, and any events that happen. The data captured during the recording is represented in Figure 3.4. As previously mentioned, the video feed from the AR camera is captured using ARCore's Recording and Playback API. The audio from the microphone is captured into an audio clip. It is then trimmed to the match the length of the video recording and converted to Ogg using Unity Vorbis Plugin [76].

The properties of the objects in the scene are captured periodically in a sequence of frames. Each frame contains a list of recording data, which holds several properties of the objects in the scene at the time of the recording, namely, their position, rotation and scale. Additionally, the position, rotation and field of view (FOV) of the AR camera are also recorded in the frame, as this represents the user's perspective within the environment. Approximately seven frames are captured per second, in order to save storage space and reduce the impact on performance.

Sporadic changes to the scene are stored in a list of events. These events include changing a character's animation, enabling or disabling weather effects, and enabling or disabling a landscape. Each event is stored alongside a timestamp that indicates the time elapsed from the start of the recording to the moment the event occurred.

Once the system stops recording, the resulting data is saved in the device's persistent storage. This includes the story's metadata—Universally Unique Identifier (UUID), title, authors and description—and its cover image, along with data for each scene that composes the story—camera recording, audio

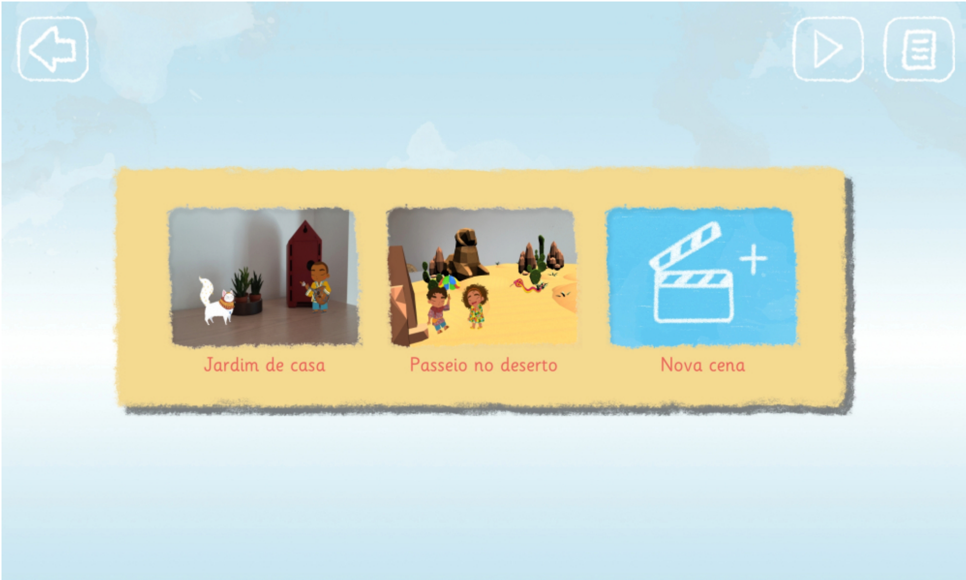


Figure 3.5: Scene browser with two recorded scenes.

recording, a binary file with the recorded objects' frames and another binary file with the recorded events.

3.2.3 Scene Browser

Upon finishing the recording, users are directed to the scene browser, shown in Figure 3.5. This screen displays all the scenes of the story, with each of them identifiable by a screenshot captured at the end of the recording. By clicking on a scene, users they can change its title, play it back, or delete it. It is also on this screen that they can create new scenes to continue the story. From the scene browser, one can also access the story options page, which allows users to edit the title, authors, description and cover of the story, the latter by capturing a photo with the device's camera. This additional customization reinforces the sense of ownership over the completed artifact.

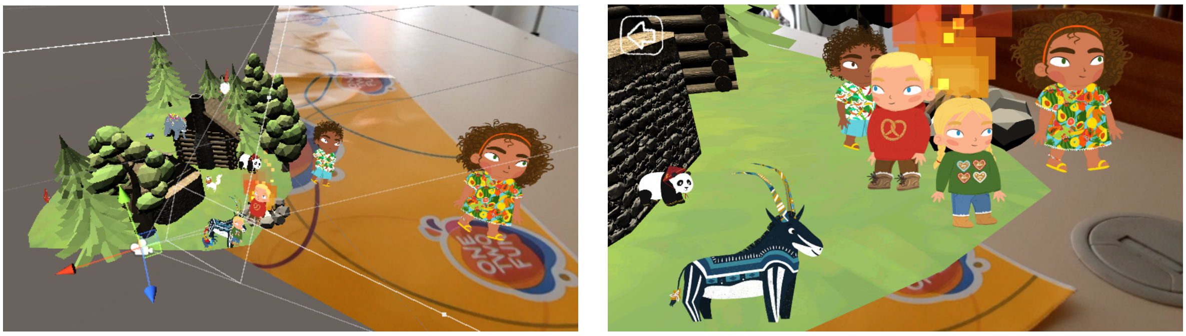
3.3 Viewing a Story

The process of viewing a story has been documented in a video[2], using a story created during the study as an example. This video showcases the features described in this section and a possible story format.

3.3.1 Story Browser

The story browser is accessible from the main menu and displays a gallery of all the stories created on the device. By clicking on a story, the user can either continue editing it, which takes them to the

[2]Story created by user study participants, https://youtu.be/rgWbd6cVkWo



(a) In-editor view of a story scene. **(b)** View of the same scene when played back.

Figure 3.6: In-editor view of a scene and corresponding result when played back.

aforementioned scene browser, or view it in its current state. This enables users to review their past work, make improvements, or expand upon it if desired, as well as to show their creations to others. Viewing a story plays back all of its scenes sequentially, similar to watching a film.

3.3.2 Playback

The playback screen has a video player as its background, displaying the recorded camera stream from the creation stage. This ensures that the context of the recording is preserved even when viewed in a different location, especially if the story's events are influenced by the original recording conditions. When playback begins, both this video and the recorded audio start playing simultaneously, and the processing of frames and events commences. This approach maintains the appearance of a seamless video, despite managing multiple components separately. Figure 3.6 shows the in-editor view of the elements and the background relative to the camera, and the resulting image as it appears in the story.

Frames are played back at the same interval at which they were recorded. During frame processing, the elements present in it are analysed, and are added or removed from the scene accordingly. The properties of each element are then applied to the objects in the scene, with their current positions, rotations, and scales being linearly interpolated to the new ones, to obtain a smooth movement despite the low number of frames. As the elements' appearance on the screen depends on the user's location and orientation in the world, the camera's position, rotation and FOV are also updated in the same way with the data captured from the AR camera. Given that story events occur more sparingly, they are simply set to trigger at the recorded timestamp. Any events that are associated with a sound effect, such as certain animations, will also reproduce the audio.

Because virtual elements are not part of the video, and instead are overlaid in real-time onto the video background, the recorded stories cannot be viewed outside of the application. However, this limitation can be addressed by utilizing an external screen recorder to capture the stories as they are playing.

4

Evaluation

Contents

In the following sections, we outline the methods employed to evaluate the developed prototype, the participants and format of the user study, the data collected during the testing sessions, and how these efforts address the research questions presented in Section 1.2.

4.1 Experiment Design

The system was evaluated with fourth-grade children, who were paired into groups of two (and one group of three) and tasked with collaboratively creating a story using the application. Each session was recorded, to analyze participant behavior. This data was used to assess general attitudes toward the system, identifying features that caused frustration or engagement, and evaluating the system's usability. Additionally, it provided insights into the story creation process and how the pairs worked together.

At the end of each session, a semi-structured interview was conducted with the children to supplement the behavioral data, offering a more complete understanding of their preferences and desires for the system. The interviews also helped evaluate whether the system had succeeded in providing inspiration for story creation and promoting collaborative work. Finally, the children were asked to rate our system in comparison to two other story creation methods and explain their reasoning. This feedback was gathered to identify the strengths and weaknesses of each medium and to understand which aspects the children valued most.

The recorded stories themselves were also analyzed. From these, information was gathered regarding the themes chosen, the presence and type of recorded audio, the use of camera movements, the number and types of virtual elements included, and the actions performed by the characters. These measures aimed to explore the most common ways the system was used, identify creative or unusual approaches, and evaluate the overall creativity of the stories. The presence of the physical environment in the narratives was also observed.

4.2 Participants

To evaluate the system, fifteen children were selected from a class of fourth-grade students. Ten of the participants were female and five were male, with ages ranging from 9 to 11 years old (mean = 9.7, SD = 0.6). All of them owned mobile devices (tablet or smartphone) and used them mainly for gaming purposes, but reported not doing so very often, with only four participants using such a device on a daily basis. As the class had previously been involved in studies related to the Mobeybou project, every participant had experience using digital story creation tools and marker-based augmented reality. Only two participants had used an application featuring markerless augmented reality prior to the session.

Regarding story creation habits, the participants often wrote stories as part of their school work. Only two of the participants weren't very fond of creating stories and only did so when asked, whereas the remaining participants created stories during their free time by writing on paper (10 participants) or on digital devices (3 participants), recording videos or animations (2 participants), and enacting them with toys or games (2 participants). They also mentioned producing other types of media to accompany their stories, such as illustrations (4 participants) and music (1 participant).

4.3 Apparatus

The system was installed in a Samsung Galaxy Tab S6 Lite running Android 13. The device was placed in a stand in landscape mode, so that participants could keep their hands free during the study, if they wished. Crafting materials were available, including cardboard, a small stand, paper, crayons and pens.

A camcorder was used to capture video and audio during the session.

4.4 Procedure

The parents provided informed consent for their children's participation in the activities of the Mobeybou project [71], including this study, as well as for filming and photographing the sessions. These activities were also submitted to the ethics committee of Universidade do Minho. Prior to the start of the study, the class's teacher defined six groups of two elements and one group of three elements, the latter having more elements to accommodate for a member with a developmental delay (P3). This division, detailed in Table 4.1, ensured that all of the group members got along well.

Table 4.1: Study participants divided by group.

Group	Participant	Gender	Age	Likes to Create Stories
G1	P1	F	9	Yes
	P2	F	9	Yes
	P3	F	11	Yes
G2	P4	M	9	Yes
	P5	M	10	No
G3	P6	M	9	Yes
	P7	F	10	Yes
G4	P8	F	10	Yes
	P9	F	10	Yes
G5	P10	F	10	No
	P11	F	10	Yes
G6	P12	F	10	Yes
	P13	F	10	Yes
G7	P14	M	9	Yes
	P15	M	10	Yes

The system was first presented to the entire class, by projecting a short video that demonstrated how to use each feature. The participants were also informed of the purpose of the experiment and of the tasks they would be doing. During the following days, each group was called separately to the school's library to perform these tasks. The guide followed during the sessions is presented in Appendix A.

Each session began by ensuring that the participants were comfortable with having the experiment recorded and analyzed for the purpose of the study. Following this, the demographic information described in Section 4.2 was gathered from each group member. Questions about how to use the system were clarified before the next stages, but they were allowed to ask for assistance during the study.

Participants were then prompted to begin the exploration stage, in which they could interact with the story creator screen to familiarize themselves with the interface and the AR functionality, and think about the story they wanted to make. When the group felt they were ready, they could press the button to start recording the story, thus beginning the recording stage. The participants were allowed to pick up the tablet and its stand and move around the room freely, as well as to use the crafting materials and other objects available in the library. When the story was completed, the group was asked to give it a title and take a picture to use as a cover. Neither of these stages had a fixed time limit, but if fifteen minutes had elapsed from the start of each stage and the participants did not seem to be making significant progress, they were advised to finish the task shortly.

Due to challenges with plane detection caused by the room's conditions and the device's low-quality camera, colorful patterned papers were placed on the two tables in the room for the final three groups. This was done to make the surfaces more distinguishable from the rest of the objects, thereby facilitating easier plane detection. This setup is visible in Figure 4.1.

Figure 4.1: Patterned paper placed on top of a surface to facilitate plane detection.

The session concluded with a semi-structured interview, where both participants were encouraged to discuss their experience interacting with the system and crafting the story together. The following questions were used as a guide:

- Q1: How did you come up with the idea for the story?
- Q2: Are you satisfied with how the story turned out, or is there anything you wish you could have done differently?
- Q3: What part of the application did you like the least?
- Q4: Was there anything that you found difficult to do?

- Q5: What part of the application did you like the best?
- Q6: Is there anything you wish the application had?
- Q7: Would you prefer to use the application alone or with friends?

The group was also asked to, collaboratively, order three story creation methods according to their preference and to verbalize their reasoning. They performed this task with the aid of a Paper Ladder [7] with five rungs, depicted in Figure 4.2, where higher rungs were regarded as preferable. The tokens corresponded to each of the three methods being compared: writing on paper, using StorytellAR, or using Mobeybou StoryMaker[1], a desktop program that they had used the previous year.

Figure 4.2: Scores assigned by a group to the three story creation mediums, arranged in a Paper Ladder as outlined by Sylla et al. [7]

[1] Mobeybou StoryMaker, https://mobeybou.com/apps/

5

Results

Contents

The results from the user testing phase are presented in this chapter. The data was gathered through observations from the recorded sessions, videos of the created stories, responses to the interview questions and preference scores assigned by the participants.

5.1 Overview of the Stories

Each group was tasked with creating a single story, resulting in a total of seven stories. The duration of these stories ranged from 01'14" to 11'48" (mean = 05'50", SD = 03'00"). Most were well-structured, having a defined exposition, confrontation and resolution, per a three-act structure model [77].

The themes of the stories were diverse, including characters facing peril from enemies or adverse weather conditions, embarking on journeys to explore new lands and hunt for treasures, or finding themselves in unusual situations. The narratives were presented in various formats: one group used both narration and dialogue, two groups opted for narration only, and one group used solely dialogue. Additionally, three groups chose to create silent stories, conveying the narrative solely through character movements and ambient effects.

Consequently, two of the silent stories featured the highest number of animations performed by characters—48 and 32 actions, respectively. The most frequent actions included ”sleep” (21 times), ”laugh” (15 times) and ”scared” (15 times). Actions often occurred in response to other actions; for example, characters would start dancing when another character played an instrument, or a character would faint after being attacked by an animal. In one group, a sequence of actions was observed where a character became angry before attacking.

The stories featured at least as many human characters as the number of participants in the group. Silent stories had a higher average number of human characters (mean = 4.33, SD = 1.25) compared to those with narration and/or dialogue (mean = 2.50, SD = 0.50). Participants generally selected characters matching their own gender, particularly in groups where each participant controlled a specific character. However, four of the same-gender groups included at least one character of the opposite gender. All stories included characters from different cultures, with Brazilian characters being the most frequently used (7 times), followed by German characters (4 times). The nationalities of the human characters featured in each story are represented in Figure 5.1.

Animals and creatures were present in every story, typically acting as companions to the human characters or as enemies. While most characters retained their originally defined role, with friendly characters consisting in animals and unfriendly characters in mythical creatures (antagonists, as defined by Sylla et al. [36]), some deviations occurred, such as antagonists being reinterpreted as merely ”a strange and mysterious animal,” or a friendly animal attacking the protagonists. Animals never took the role of protagonists, and remained silent in all but one story.

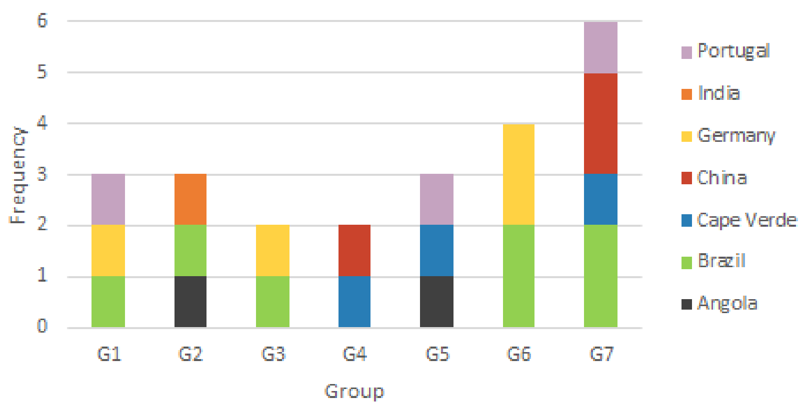


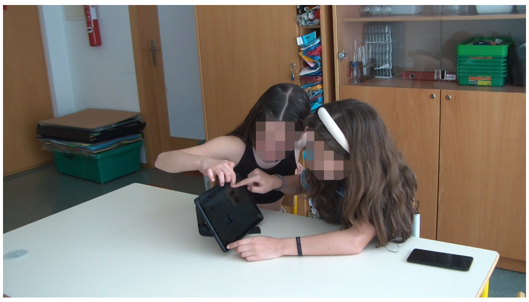
Figure 5.1: Frequency of human characters by nationality appearing in each group’s story.

An average of 2.7 objects (SD = 1.5) were used per story. This mainly consisted in musical instruments which, with the exception of one group, were used in each story at least twice. In contrast, non-musical objects only appeared in two stories. Weather effects were included in all but one story. While two groups used only one type of weather effect, the others experimented with multiple effects. Every group used between one and three landscapes in their stories (mean = 1.71, SD = 0.70). The most commonly used landscapes were ”city” (4 times) and ”volcano” (3 times).

Some participants manually moved the characters and camera during recording. Through Spearman’s rank correlation coefficient [78], a moderate correlation was found between audio dynamics and character movement (ρ = 0.55), as well as between character and camera movement (ρ = 0.66). Stories with more dynamic audio (dialogue over narration) and deliberate camera movement also featured more character movement. Characters were manually moved not only to traverse different areas of the scenery but also to simulate flying, sliding down landscape objects, or wiggling to indicate which character was speaking at the time.

While most groups moved characters to some extent, only two groups utilized camera movement for storytelling purposes. One group walked around the room to show the characters interacting in different sections of the landscape. The other group used camera rotation to reveal and conceal characters during key moments, such as following a character as she leaves the scene, then rotating back to focus on the remaining character who laments her departure. This sequence can be seen on Figure 5.2.

(a) Characters on the right leave the scene.



(b) Participants moving the camera along with the characters.

(c) The other character moves to the left to enter her house.

(d) Participants pointing the camera to the inside of the house.

Figure 5.2: Participants rotating the camera to focus on characters in different locations. The figures on the left show the in-app view, while the corresponding real-world actions are displayed on the right.

5.2 Narrative Development Process

The participants spent between 06’21” and 31’36” (mean = 16’05”, SD = 07’29”) interacting with the system during the exploration stage. Though part of this time was dedicated to planning the story, much of it was also due to difficulties in using the system, particularly with placing landscapes.

The groups began by selecting either the characters or the landscape they wanted to use. However, they continued to experiment with different elements both while planning and recording. Subsequently, six of the groups proceeded to plan the beginning of the story or an outline of the main events. Among these, two groups planned out the entire narrative beforehand, with one writing it down on paper (Figure 5.3), and the other going as far as to rehearse it, including dialogue and movement. A third group did their planning in stages, recording an idea and reviewing the outcome before recording the next scene.

Figure 5.3: Participants planning the story by writing it on paper, and taking turns narrating it.

5.2.1 Engagement

All participants demonstrated signs of engagement throughout the activity, with behaviors indicative of concentration observed for the majority of both stages of the experiment. These behaviors included leaning forward, consistently facing the device, and touching their face or mouth while thinking. Only one instance of disengagement was noted, involving participant P7, when an issue with landscape detection persisted for over four minutes. During this period, P7 began to gaze around the room and fidget slightly. However, once the issue was resolved, she quickly re-engaged with the activity.

Participants appeared eager to use the system, with members of four groups smiling as soon as they were handed the device, and some playing with the elements even before starting to create the story: “Hello! [Wiggles character] It hasn’t started yet [Laughs]” (P8). Notably, one group had planned aspects of their story in advance, having heard about the application from a member of a previous group.

Laughter was common across all but one group, occurring not only in response to the elements and animations, but also to interpersonal interactions, as members made playful remarks. Other signs of enthusiasm included physical expressions such as jumping (1 instance), throwing arms in the air (4 instances), and clapping (2 instances). These actions typically occurred when starting or finishing the story, making a character perform an action, or after taking a picture to use as the story's cover. Additionally, there were six instances of participants dancing, five of which occurred after a character began playing an instrument. Participants also verbalized their surprise and excitement through exclamations, especially when a landscape appeared (9 instances).

> [Volcano landscape is activated]
> P4: Oh my God...
> P5: What is this?!

5.2.2 Collaboration

Group G1 exhibited the most unequal participation, as this was the only three-element group which included a special-needs student, participant P3. As such, P3 did not always want to interact with the application. However, she remained engaged in the activity, and responded when her partners encouraged her to contribute ideas and details to the story.

Regarding interaction with the system, the number of times each participant held the tablet and interacted with the application was roughly equal among the members of five groups. Two minor discrepancies were observed, when the participants were unable to use the stand to support the device, and when one member took the initiative to place the landscapes. However, besides group G1, group G6 had displayed the most inequalities, as participant P12 occasionally walked away with the device while viewing the landscapes, which led to her partner P13 showing some signs of frustration.

In terms of story creation, only group G6 explicitly assigned roles and tasks, as each member controlled their respective character. In other groups, members spontaneously chose what to work on, switching tasks throughout the activity. In four of the groups, participants contributed to the story when they felt inclined to, rather than taking turns.

Ideas were introduced either through explicit discussion about what to include and how to execute it (observed in 5 groups), or through glancing and gesturing at each other for agreement while recording (4 groups). When disagreements over a partner's idea or character selection arose, one participant typically conceded without showing signs of resentment.

When asked whether they would prefer to use the system alone or with friends, all participants except P4 expressed a preference for working together. P4 found both options acceptable. Reasons for preferring collaboration included generating more ideas (4 participants), having more fun together (2 participants), incorporating different voices for the characters (2 participants), and finding it more challenging to use the application alone (2 participants). However, P13 noted that using the system with more than two people might be difficult, as it could complicate reaching a consensus on ideas and selecting elements without overlap.

5.3 Thematic Analysis

A thematic analysis [79] was conducted on the gathered data. The resulting codes and their corresponding themes are presented in Table 5.1, which also includes the frequency of each code and the number of groups in which it appeared. Codes marked with asterisks are associated with more than one theme.

5.3.1 Culture and Knowledge

This theme encompasses codes that address the mention of various countries and cultures, as well as knowledge of geographical features and the wildlife characteristics specific to certain locations, along with natural phenomena associated with those regions. The codes ”Choose elements according to country” and ”Choose elements to match landscape” reflect the participants' selection of elements based on their country of origin, either to diversify the cultural representation or to align with the active landscape. The codes ”Mention real-world locations or phenomena” and ”Want real-world landscapes” pertain to the association of certain landscapes with real-world phenomena or locations (e.g., equating the pyramids in the desert landscape with the pyramids of Giza) and the desire for these to be explicitly identified in the application. Finally, the code ”Want landscapes to include appropriate animals”, reflects participants' desire for each landscape to feature fauna native to the corresponding region.

5.3.2 Artistic Expression

This theme highlights a preoccupation with the creative and artistic aspects of the stories. The codes “Explicitly mention weather events” and “Incorporate sound and music” pertain to the enrichment of the stories through the addition of audiovisual effects relevant to the plot. The participants' wishes for greater visual variety and detailing are expressed in the codes “Want a greater variety of elements” and “Want to change characters' appearances”. The latter emphasizes adapting the characters' appearances to reflect some story events, such as changing color or wearing different clothes.

> P8: There is a wind coming. (...) It's so cold! I'm going to put a coat on. Actually, is there a coat here? [Searches in objects panel]

The codes “Dislike elements (dis)appearing abruptly” and “Dislike unrealistic graphics” display concerns for maintaining immersion and realism. The former pertains to characters appearing or disappearing “out of nowhere” (P8), as well as there not being a smoother transition when switching landscapes, as it makes travel appear instantaneous and reveals the camera background underneath. The latter refers to dissatisfaction with the low-poly art style of landscapes and the two-dimensional nature of story elements, which were perceived by one participant as unrealistic and disconnected from the real world.

Table 5.1: Results from the thematic analysis, with the number of occurrences of each code per group, total number occurrences of each code, and the number of groups in which that code emerged.

Theme	Code	Occurrences Per Group G1	G2	G3	G4	G5	G6	G7	Occurrences	Num. Of Groups
Culture and Knowledge	Mention real-world locations or phenomena	1	2		4			4	11	4
	Choose elements according to country		2			1		2	5	3
	Choose elements to match landscape	1						3	4	2
	Want landscapes to include appropriate animals							3	3	1
	Want real-world landscapes		1						1	1
Artistic Expression	Explicitly mention weather events	5	2		4	2	1	2	16	6
	Dislike elements (dis)appearing abruptly				4			3	7	2
	Incorporate sound and music *	1		1	2		1	1	6	5
	Want a greater variety of elements	1			2	1	1	1	6	5
	Want to change characters' appearances				2			3	5	2
	Dislike unrealistic graphics		2						2	1
Freedom and Agency	Free movement and actions	3	7	9	4	1	2	6	32	7
	Interact with landscape objects	4	1	3	8		4	2	22	6
	Want to control landscape objects	1			1		2	5	9	4
	Assign different meanings to actions or objects	1	4	1	1				7	4
	Animals transporting characters	1						1	2	2
	Want automatic movement			1					1	1
Embodied and Sensorial Interaction	Like to explore landscapes **		1			3	6	1	11	4
	Each person controls their characters	4			4	1	1		10	4
	Mimic characters' gestures	4		1	2				7	3
	Incorporate sound and music *	1		1	2		1	1	6	5
	Give names to characters	1		1	1	3			6	4
	Sing	2			4				6	2

Table 5.1: Continued from previous page.

Theme		Code	Occurrences Per Group G1	G2	G3	G4	G5	G6	G7	Occurrences	Num. Of Groups
Augmented Reality Experience		Place landscapes in physical locations	3	2	2	1	1	3	1	13	7
		Like to explore landscapes **		1			3	6	1	11	4
		Prefer real world to not be visible				2	1	1	5	9	4
		Seems immersive/magical		1			1	1		3	3
	Subtheme: Issues	Hard to place landscape in the desired plane	5	1	4	6	2		6	24	6
		Elements are somewhere else	1		1	1		5		8	4
		Elements are too small			3		1	3		7	3
		Spatial drift			1	1			2	4	3
		Cover the camera			1				1	2	2
User Interface Concerns		Change elements' sizes accidentally	4		1	6	1	4	2	18	6
		Want to pause recording	2		2	1			1	6	4
		Dislike having to place all the elements again	1		3				2	6	3
		Takes too long to do things	1		2				1	4	3
	Subtheme: Handling Elements	Hard to select actions		6						6	1
		Hard to use objects	1	1	1					3	3
		Hard to change elements' size	1					1		2	2
		Hard to move elements	1					1		2	2
	Subtheme: Buttons	Not descriptive			1					1	1
		Hard to see		1						1	1
		Take up too much space							1	1	1

5.3.3 Freedom and Agency

This theme centers around participants' appreciation for, and desire to have, a high degree of control over virtual elements, and how they utilize that agency. The code "Free movement and actions" emerged as the most frequent across the study (32 occurrences spanning every group), and it highlights situations where participants engaged in actions that would not have been possible without the ability to freely control characters, as well as occasions where they expressed a preference for unrestricted interaction. In contrast, one participant claimed to "Want automatic movement". Additionally, participants were observed to "Assign different meanings to actions or objects" beyond the intended ones.

The code "Interact with landscape objects" was also prevalent, capturing instances where participants integrated static scenery objects into their narratives, pretending characters were interacting with them. Relatedly, the code "Want to control landscape objects" reflects the desire for more agency in selecting which objects should be present in the landscape and determining their placement. Lastly, "Animals transporting characters" pertains to two separate instances where groups wanted to represent animals carrying characters, but found it difficult to do so within the constraints of the system.

5.3.4 Embodied and Sensory Interaction

This theme highlights embodied aspects present during the creation of the narratives. The code "Each person controls their characters" reflects how, in four groups, participants embodied the characters, moving them and speaking for them with an altered voice, along with addressing their partner's characters in direct speech. This was often coupled with the code "Give names to characters".

Participants engaged their whole body in the experience when exploring the contents of the landscapes ("Like to explore landscapes"), which was done through holding the tablet and moving through the physical space, as seen in Figure 5.4. The code "Mimic characters' gestures" showcases further physical involvement. This sensory interaction extended to music, which was present in five stories, as participants would "Sing" as if they were the characters, and "Incorporate sound and music" through instruments and ambient effects. The latter code is also reflected in theme 5.3.2.

Figure 5.4: Participants observing the scenery and moving the virtual elements from different locations.

5.3.5 Augmented Reality Experience

This theme reflects the participants' experiences and thoughts regarding augmented reality-specific features, particularly in how they view the virtual elements encompassed in the physical space, as well as issues they encountered due to the limitations of the technology. All groups elected to "Place landscapes in physical locations", such as tables, attempting to fill the entire surface: "We don't want an island in the middle of nowhere!" (P1). Many participants attempted to hide objects and features of the real world from the camera's view, leading to the emergence of the code "Prefer real-world to not be visible". The codes "Like to explore landscapes" and "Seems immersive/magical" capture aspects that the participants enjoy about the experience. The former also appears in theme 5.3.4, as this exploration is done through physical movement.

Among the observed issues, one that affected six of the groups is reflected in the code "Hard to place landscape in the desired plane". Other complications included "Elements are somewhere else" and "Elements are too small", which were triggered by movement between locations. In addition, there were inconsistencies from "Spatial drift" or elements disappearing when participants would inadvertently "Cover the camera".

5.3.6 User Interface Concerns

This theme evidences challenges and frustrations participants encountered due to the interface design. The primary issue was that, in six of the groups, participants would "Change elements' sizes accidentally", particularly when more than one person touched the interface at once. Other recurrent problems are included in the codes "Dislike having to place all the elements again", which occurred after exiting the creator screen (either accidentally or after finishing a scene), and "Takes too long to do things". Participants also expressed a wish for the ability to pause the recording without fully stopping it, captured in the code "Want to pause recording". Specific issues regarding buttons were identified in the codes "Not descriptive", "Hard to see" and "Take up too much space".

There were also difficulties encountered while handling elements, especially when they were too small or too close together. Therefore, participants found it "Hard to select actions", "Hard to change elements' size", "Hard to move elements" and "Hard to use objects". The latter code revealed some confusion as to how to make characters use objects. For instance, one group placed an instrument in a way that its mouthpiece visually aligned with the character's mouth, rather than dragging the object so their finger would be on the character itself.

5.4 Creation Medium Preferences

The preference for three different story creation mediums—paper, Mobeybou StoryMaker[1] and our system—was ranked using a Paper Ladder [7] as a guide. The score of a medium corresponds to the rung of the ladder the participants assigned it to, with the number 1 representing the bottom rung and thus the lowest score, and the number 5 representing the top rung and the highest score. An overview of the scores is presented in Figure 5.5.

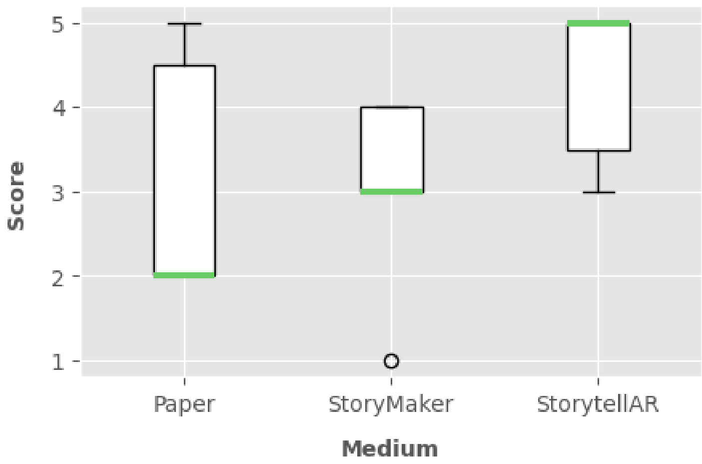


Figure 5.5: Paper Ladder [7] scores per medium.

StorytellAR was overall the preferred method for telling stories, with a median score of 5. The main reason for this was that, versus other digital devices, the participants preferred working on a tablet, as they found it better to handle and easier to use, particularly due to the touch-based interaction. They also appreciated having the ability to pick up the device and place it wherever they wanted. Regarding the story creation features, one participant valued the greater interaction with the characters. Another important reason cited for preferring this system was the augmented reality feature, which was "more immersive than the computer, because it's in the real world" (P4). Moreover, they found it fun to physically move to explore the landscapes.

On the other hand, some of the participants found the AR features cumbersome and difficult to use, particularly the landscape placement, and thus preferred using a computer program such as StoryMaker (median score = 3). One of the participants also disliked the movement-based interaction, claiming that with a computer "we don't have to keep turning from one side to the other, and the space is small so we don't have to walk around with the characters" (P13). This preoccupation with space constraints was also expressed by one other participant. As such, both P13 and her partner P12 mentioned they would enjoy using a computer program where they could explore 3D landscapes with a mouse, although only

[1] Mobeybou StoryMaker, https://mobeybou.com/apps/

P13 claimed she would definitely prefer that.

Paper had the widest range of scores, with a median score of 2. Most of the participants didn't enjoy writing as much as using digital software, as they felt it was harder to not make mistakes, and their stories could be misinterpreted by the readers. However, two groups ranked paper as their preferred method. This was not only due to the fact that they liked writing and were more familiar with it, but also because they thought that the possibility to represent anything they wanted was very important, and they could do so more easily: "You just make the illustration that allows you to do things. Like, you make the character. If you want to push someone, you stick his arm out, (...) and then you write 'push'" (P14).

6

Discussion

Contents

In this chapter, we examine the results of the system's evaluation in relation to the literature presented in Chapter 2. We address the research questions and assess the validity of our initial hypotheses from Section 1.2. The research questions we aim to answer and their associated hypotheses are:

- **RQ1:** Does the solution promote creative thinking?
  - **H1:** The solution leads to the generation of creative artifacts.

- **H2:** The materials do not constrain the story.
- **H3:** The design facilitates experimentation.
- **H4:** The solution encourages reflecting and building up on past work, as well as sharing it with peers to exchange ideas.

- **RQ2:** Does the solution promote real-time collaboration?
  - **H5:** The solution facilitates discussion during story creation, and enables equal participation in this process.
- **RQ3:** How often and in what ways do children make use of their surroundings in the stories?
  - **H6:** The physical environment is incorporated in the stories.
- **RQ4:** Does the solution increase willingness to engage in storytelling activities?
  - **H7:** The users enjoy creating their own stories and feel more motivated to do so.

Additionally, we discuss further findings from the system's usage, highlight key features, and suggest potential modifications to address identified issues. We also explore a potential application for the system beyond story creation.

6.1 Creative Outcomes

The stories created displayed a wide range of themes and significant creativity. Participants drew inspiration from the available virtual elements, using them as a foundation upon which they added further details. One participant noted, "I looked at the characters, and then [I thought] I will make a story that makes sense on an island, [with] two friends and a cat. With the objects" (P5). This approach led to original stories that were not merely copied from existing ones. Though most centered around adventurous scenarios in particular settings, some unusual and surprising ideas emerged, such as characters being trapped in a dream (Figure 6.1).

The stories showcased various aspects of creativity, including the addition of elements that enriched the narrative while not necessarily advancing the plot. Verbal creativity was evident in the naming of characters and the explicit mention of weather conditions. Visual creativity was demonstrated through the diverse use of elements and the inclusion of camera movements. Participants expressed a desire for a broader range of elements and customization options for character appearances, suggesting potential improvements for future versions of the application. Additionally, five of the stories incorporated sound and music, engaging multiple senses. In terms of performance creativity, participants consistently adjusted their voices to match the characters speaking during dialogues, and embodied their characters by imitating their gestures and singing. As such, the range of creative elements present in the generated stories supports the validity of hypothesis **H1**: "The solution leads to the generation of creative artifacts".

(a) The characters play music and dance.

(b) At night, the characters fall asleep.

(c) One of the girls begins to dream.

(d) They wake up in the dream near a volcano and become frightened.

Figure 6.1: Sequence of images from the story *An Adventure in Dreams*, created by group G7.

6.2 Freedom and Agency

The theme ”Freedom and Agency” had the highest number of occurrences, indicating that control over various aspects of the story had a high importance for the participants. Some objects and animations were assigned different meanings, allowing participants to work around the limited number of options available. For instance, in one story, a handkerchief—originally intended as a weapon——was repurposed as a map for a treasure hunt. In another example, an antelope was assigned the attack animation, which made it appear to hit its head against a pile of rocks.

The ability to manually position elements and assign actions allowed for further agency, as depicted in Figure 6.2. However, some participants lamented that certain animations were not available for specific characters. One participant preferred characters to move automatically: ”Just click a button and they move, then click that same button and they stop” (P5). This likely stemmed from her wish to represent a character flying, which she instead simulated by moving it to the top of the screen. While adding specific animations could resolve this, the fact that this code emerged only once suggests a lack of significance.

It is noteworthy, due to its specificity, that two groups wanted to have animals transporting characters, but they either failed to represent it adequately or found it too difficult. In light of this, and considering that participants occasionally moved several characters to the same location, adding the option to group multiple elements for simultaneous movement could be a possible improvement.

(a) Character dipping into the lava of a volcano.

(b) Treasure hidden behind a tree.

(c) Characters riding on an elephant's back.

(d) Animals resting on towels in a park.

Figure 6.2: Interactions with the scenery and between characters, enabled by the free positioning.

While participants could simulate interactions between characters and landscape objects, some expressed a desire for these interactions to be reflected visually: "Does the surfboard work? (...) Because if it did, I would use it. (...) Can't he go in the water?" (P6). The need for customizing landscapes was also evident, with the corresponding code occurring nine times. One participant wished for the ability to trigger events in the landscapes themselves:

> P14: When we went to the volcano, we would click it and it would say "options". Then we would click on 'options' and it would say "erupt the volcano". (...) The ground would shake, there would be a noise like a rumble, and then it would open and explode.

Objects that participants wanted to use were often located far from them or failed to appear due to randomness. This forced participants to physically move to a different place or retry placing the landscape until the objects were adequate. As this led to some frustration and wasted time, this alteration should be considered a priority.

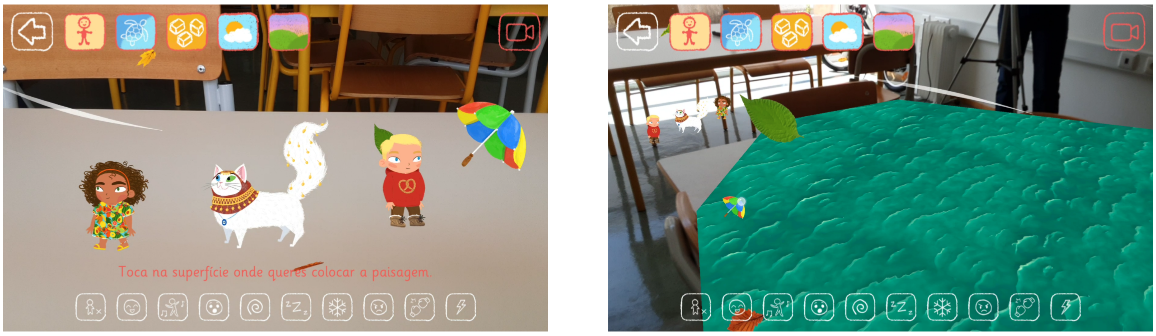
These findings partially support hypothesis **H2**, which proposed that the materials would not constrain the stories. While most plot-related ideas were incorporated without compromise, their visual representation could be improved by offering more control over landscapes and more options for moving the characters. However, care should be taken to avoid overcomplicating the interface.

6.3 Experimentation

Hypothesis **H3**, which proposed that the design facilitates experimentation, was met with several challenges. One of the most significant issues was that the size of the elements frequently changed accidentally when two participants touched the screen simultaneously, as the system interpreted this as a pinch gesture. This made it difficult to experiment with different placements of the elements simultaneously.

Additionally, three participants noted that "it took too long to do things", particularly when scaling elements, removing them from the scene, or switching landscapes. In one group, instead of removing an unwanted element from the scene, participants simply dragged it out of view. This indicates that the processes involved in managing these actions were too cumbersome, potentially limiting children's willingness or ability to experiment with different settings.

Other issues with handling characters were also relevant, particularly when participants changed their physical location. Participants often couldn't find their characters, or the elements appeared too small due to perspective shifts, as illustrated in Figure 6.3. There were some difficulties when applying actions or objects, especially when the shape of the colliders was inadequate, or when elements were too small. These issues were particularly frustrating when they occurred during the recording process. To address this, it could be beneficial to implement a minimum scale value for elements, preventing them from shrinking beyond a certain size. AR-related issues could be mitigated by ensuring that characters maintain their size regardless of distance from the camera or at least do not change size as drastically, as suggested by participant P13. Another potential solution would be adding an option to bring all elements back to the front of the camera, to prevent them from getting lost and to save time moving them.



(a) Virtual elements at their initial location.

(b) Virtual elements after moving locations.

Figure 6.3: Apparent position and size of the virtual elements varying in different locations.

One notable limitation to experimentation, although reported only six times, was the inability to pause the recording. While it was possible to end a recording and create a new scene, as group G7 did, most participants did not realize this. Besides, this method required adding all elements back to the scene. The lack of a pause option created pressure to finalize decisions before starting the recording, and limited the opportunity to explore new ideas partway through.

Nevertheless, children managed to experiment with different scenarios, and the absence of a forced structure allowed for the creation of diverse stories and the exploration of new ideas. However, given the impact of the aforementioned challenges, it can be concluded that hypothesis **H3** does not hold.

6.4 Sharing and Reflection

Two groups expressed a desire to view the stories they had created. One of these groups used an iterative process in their storytelling, depicted in Figure 6.4: they first recorded a short scene to familiarize

(a) Participants viewing the scene they have just recorded. **(b)** Discussing about the plan for the next scene.

Figure 6.4: A group employing an iterative approach to story creation.

themselves with the system, viewed the outcome, and then discussed how to improve their next attempt. They repeated this process twice, demonstrating a reflective approach to their creative process. Other groups likely did not request to view their stories due to being less comfortable with the experiment's conditions or being unaware that it was possible. However, some participants asked for access to the stories outside of the testing sessions, suggesting there was interest in revisiting their work.

An earlier version of the system included an online gallery feature, which allowed users to upload and share their stories with others. This functionality was removed due to time constraints to test it and potential privacy concerns. Despite this, the stories can still be shown to peers in person. Additionally, users can share the stories remotely by using the device's screen recorder during playback and then manually sharing the video file via external applications. Though this method is more cumbersome, it was employed with no issues for sharing the participants' stories in their classroom, after the sessions.

These findings support hypothesis **H4**, which proposed that the solution would allow users to reflect on and build upon past work, as well as to share it with peers. While the current system does not facilitate online sharing, it still enables in-person sharing and the possibility of remote sharing through manual processes. In a future version, it would be beneficial to introduce an option to export stories directly as video files to streamline remote sharing.

6.5 Support for Creative Thinking

The system's design aligns with the principles outlined by Resnick in the Creative Learning Spiral [23] and the Four P's of Creative Learning [21]. It enables children to create projects in the form of stories, providing a set of objects that serve as the initial spark for inspiration, which, as one participant noted, is often ”the hardest part” (P10). The virtual elements did not constrain participant's imaginations significantly, with any limitations relating more to the accuracy of the visual representation than to the scope of their ideas. In this sense, children can present themes that they are passionate about. Moreover, the stories resulting from the experiment possessed characteristics that demonstrated creativity.

The process of story creation encourages a fun and playful approach, as demonstrated by the participants' engagement. However, the system's ability to facilitate experimentation requires further refinement, as issues with the user interface occasionally hindered this aspect. The system is suitable to be used together with peers, and allows sharing creations in-person. Finally, it encourages users to view, reflect on, and build upon their previous creations, supporting a cycle of creative development.

With the exception of experimentation, which, while possible, was not ideal, all other aspects were successfully demonstrated. As such, we conclude that **RQ1** holds true, with the solution effectively promoting creative thinking.

6.6 Collaborative Creation

The results collected regarding the collaborative behavior of the participants during story creation support hypothesis **H5**, which proposes that the system facilitates discussion and enables equal participation. In five out of seven groups, participants actively discussed their ideas before recording. Even in the groups that did not do so, members still communicated their approval and feedback during story creation through non-verbal means. The system was used by participants to aid in visualizing ideas together and rehearse what they planned to do.

Participation was well-balanced in most groups, with five out of seven showing equitable involvement. One group was an exception due to having three members. Group members coordinated their tasks effectively and contributed equally, with participants being receptive to each other's ideas and input. Moreover, all participants reported enjoying the collaborative aspect, with 93% expressing a preference for working with others. They felt that this made the experience more enjoyable and helped spark more ideas and create a better story. Additionally, when participants encountered difficulties with certain functionalities, their partners often stepped in to help by demonstrating or explaining how to use them, promoting peer learning. Based on these findings, we conclude that the answer to **RQ2** ("Does the solution promote real-time collaboration?") is affirmative.

6.7 Interaction with the Physical Environment

An analysis of the stories suggests that hypothesis **H6** does not hold. The visibility of the real-world environment did not contribute meaningfully to the stories, with nine instances of participants preferring to cover it. One group went to great lengths to hide a surface from view, leading one member to suggest:

> P14: When we put the landscape, instead of doing it like this, we could click three times on

> the screen and the image would show up. (...) If we clicked more than three times, it would catch everything, and (...) everything would be like the image we're trying to place here.

P14's suggestion highlights a potential solution to the system's largest challenge, which was a difficulty in placing the landscape in the desired plane (occurred 24 times and affected all but one group) due to limitations inherent to the technology and the device, as well as concerns regarding spatial constraints. Though the introduction of patterned surfaces for the last three groups helped mitigate the problem to some degree, it is unrealistic to expect children to always use the system under ideal conditions. Therefore, a future iteration of the system should include an option to use landscapes without requiring physical plane detection. Additionally, incorporating a feature to use a skybox with various backgrounds would give users the flexibility to either include or hide the real world as they saw fit.

The lack of engagement with the real-world environment in the stories may be partly explained by the fact that the sessions were conducted in a library, which may not have been an inspiring setting. To draw definitive conclusions, it would be necessary to test the system in more natural, everyday contexts, such as children's rooms with their personal objects, or outdoor spaces that could provide more inspiration.

While the real world did not influence the final stories, every groupinteracted with the physical environment during the exploration phase, placing landscapes in physical locations. Viewing the elements in augmented reality significantly contributed to participants' interest in the system, as they claimed it to be more immersive and even "magical" (three instances). In five instances, participants playfully used the functionality by pointing the camera at their partners, causing virtual objects to appear on top of them. In a more natural context, these interactions could potentially be a starting point for a story. That said, it is worth noting that part of the excitement surrounding AR can likely be attributed to its novelty, as most participants had not previously been exposed to this technology.

Regarding **RQ3** ("How often and in what ways do children make use of their surroundings in the stories"), we conclude that while the real world was not directly integrated into the narrative, it was used as a source of entertainment during the exploratory phase.

6.8 Engagement and Motivation

All participants appeared to enjoy using the system, displaying a range of behaviors from playful (treating the experiment like a game) to focused and diligent. These observations were corroborated by the results from the Paper Ladder scale. While participants preferred the two digital mediums over paper for creating stories, StorytellAR was, on average, the preferred one, with participants reporting they had enjoyed using the system and would like to do so again. In line with findings from previous research [80], participants particularly enjoyed viewing the landscapes and atmospheric effects, which were featured in most of the stories. Many participants audibly expressed excitement upon seeing them. Participant

P13 remarked, ”I liked the landscapes and the weather a lot, I never thought that it could have some things like this and look so realistic. It was cool”. AR contributed significantly to engagement, not only through its visuals but also due to the type of interaction it permitted. A high degree of embodiment was observed, both through physical demonstrations of enthusiasm and in how participants used input and output to interact with the system. Given that embodied interaction is expected to enhance engagement as well [19], these findings support the verification of hypothesis **H7**, which proposes that ”The users enjoy creating their own stories and feel more motivated to do so”.

Since all but two participants already enjoyed creating stories and did so regularly on their own, it’s difficult to determine whether the system would appeal to children who typically dislike narrative creation. However, one of the two participants who didn’t generally enjoy storytelling rated StorytellAR as her preferred medium, suggesting that the system may encourage such users to engage more in these activities. Thus, we can affirmatively answer **RQ4**, concluding that the solution increases the willingness to engage in storytelling activities.

6.9 Multiculturalism and Educational Impact

Participants were already familiar with the countries associated with each character, as well as aspects of those countries’ cultures, through prior engagement with these characters as part of the Mobeybou project [71]. In our prototype, the countries corresponding to each element were not explicitly named, to avoid influencing the stories. However, the frequent references to these countries by participants suggest that explicitly indicating them could be beneficial. Thus, the system proves to be an effective vehicle for learning about different cultures. Through embodied interaction, children can explore distant lands in a more immersive manner, constructing narratives that feel truly rooted in those settings. Rather than passively viewing an image, they step into the scene and actively engage with it.

The volcanic landscape elicited the most interest, likely because the children were learning about volcanoes in school at the time of the tests. During the sessions, they discussed concepts like “dormant volcanoes” (P10), “explosive eruptions” and “magma” (P15), exchanging knowledge they had acquired.

> P14: You could, when we went to a landscape, put other animals that are from that landscape. And then if we clicked a button saying ’other animals’, we could put them. For example, dinosaurs, like volcanoes, some are extinct, and dinosaurs are extinct too. So when we went to the volcano it could be extinct, and then animals could show up there.

As a result, the system also offers potential for deepening educational content, particularly related to natural phenomena or ecosystems, in an amusing and interactive way. Augmented reality has been successfully used for this purpose and has been shown to increase learning effectiveness, making it an optimal tool for such explorations.

6.10 Limitations and Future Work

Although this study provided valuable findings, some important limitations should be noted. One key limitation is the small sample size of the user tests, which warrants caution when generalizing the findings. Additionally, all but two participants already engaged in story creation activities autonomously, which may have influenced the results. Future research should focus on children who typically do not enjoy creating stories, as it would be valuable to determine whether such a system could shift their attitudes and foster a newfound interest in storytelling.

Expanding the study to include a broader age range would also be beneficial. Investigating how younger children, in particular, interact with the system is crucial, as they may face challenges using the system, especially regarding spatial orientation within an AR environment. Since we believe that the lack of incorporation of the physical surroundings was due to the unnatural setting in which the tests were conducted, further studies should take place in locations more familiar to the children or in visually appealing and inspiring environments, such as outdoor spaces. As the application was designed with the objective of being used by children on their personal devices, long-term studies are needed to evaluate its impact when used in home settings. Additionally, exploring how the nature of the stories differs when created individually, would complement the insights gained on the effects of collaboration.

Finally, while peer collaboration was encouraged and produced positive outcomes, it would be valuable to conduct further investigation focusing on the implementation of a remote sharing solution. Such a feature could facilitate the development of a ”collaborative community” [23], where children could share their stories, provide feedback, generate new ideas, and iterate on existing narratives. This, in turn, could lead to increased motivation for continued story creation. It is important to note, however, that given the video-based nature of the stories, care should be taken to protect the privacy of the children.

7

Conclusions

In this project, we aimed to understand if augmented reality promotes the development of creative, collaborative, and storytelling skills in children, while also addressing common barriers to story creation, such as lack of inspiration and interest. To achieve this, we developed a mobile AR application that enables the creation of narratives with real-time recordings of video, audio, and animated virtual objects. By using AR, we intended to enable children to integrate their surroundings into the narratives. This approach aimed to provide inspiration and expand the range of possibilities for creative expression, while increasing engagement in the activity.

The system was evaluated through user testing with fifteen fourth-grade children, providing insights into the nature of the stories they created, their individual and collaborative behaviors, and their preferences regarding system features. Analysis of the data revealed several key findings. The system successfully promoted creative thinking, although some design issues hindered experimentation. Moreover, the AR platform encouraged collaboration, with participants indicating a preference for working together over independent storytelling. Although the physical environment was not incorporated into the stories as anticipated, the children still engaged with the physical characteristics of their surroundings. This involvement, combined with the embodied interaction provided by AR, enhanced their enjoyment of the experience, contributing to a preference for AR-based storytelling systems. The freedom to control and customize elements within the story was also highly valued by the participants. In particular, the ability to manipulate these elements helped children overcome the limited variety of available objects and actions, leading to the emergence of diverse and innovative ideas. Furthermore, the study uncovered an additional application of the system as an educational tool to learn about and explore real-world locations, cultures and phenomena in an immersive and interactive manner.

The proposed solution contributes to the field of storytelling for children by successfully addressing challenges related to inspiration and motivation in story creation, promoting creativity and collaboration, and demonstrating mobile AR to be an effective medium for these purposes.

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A

User Study Guide

Guião

Material

- Tablet Android com suporte ARCore e a aplicação StorytellAR instalada
- Câmara de vídeo e tripé
- Telemóvel ou outro dispositivo para gravar áudio (opcional)
- Projetor
- Papel e material de escrita auxiliar
- Paper ladder com 3 tokens de cartão (StorytellAR, StoryMaker, papel)

Preparação da sala

1. Apoiar o tablet no suporte e colocá-lo em cima de uma mesa, diante de duas cadeiras, deixando espaço para os participantes se deslocarem na sala
2. Pousar papel e material de escrita na mesa
3. Colocar a câmara no tripé e posicioná-la por trás dos participantes, apontada para estes. Deverá mostrar uma visão mais alargada caso os participantes se desloquem, bem como possibilitar ajustes de posição e ângulo para manter os mesmos na imagem

Explicação à turma

Introdução

Olá, o meu nome é Beatriz e estou a fazer um trabalho sobre histórias. Para isso, vou estar convosco alguns dias, e vou pedir-vos que, dois a dois, criem uma história sobre o que quiserem, mas usando uma aplicação num tablet que vos vou dar.

Essa história vai ser um vídeo pequeno, em que vocês podem filmar com a câmara do tablet e podem falar, mas também podem pôr na câmara as personagens Mobeybou que já estão habituados.

Agora vou mostrar-vos um vídeo a explicar mais ou menos como é que se usa a aplicação. Depois, vou chamar um grupo de cada vez para vir fazer a história comigo. Alguns fazem hoje, outros ficam para os próximos dias.

[Projetar vídeo explicativo]

Sessões em grupo

Preparação da sessão

1. Ligar o tablet e abrir a aplicação. Clicar em “criar história” e inserir o número do grupo
2. Iniciar a gravação da câmara
3. Se necessário, iniciar gravação de áudio num dispositivo à parte
4. Pegar na folha para escrever dados do grupo
5. Chamar grupo

Introdução

Olá, tudo bem? Vou fazer-vos primeiro umas perguntas rápidas sobre vocês, e depois podemos começar.

Recolha de informação

- Perguntar o nome e idade de cada elemento e anotar. Anotar também o género.
- Perguntar sobre frequência de uso de dispositivos móveis.
- Perguntar sobre experiência com realidade aumentada, para além dos testes com o Mobeybou.
- Perguntar se gostam de ler ou contar histórias.
- Perguntar se costumam fazer histórias em casa.
  - Se sim, perguntar se fazem porque querem, ou só quando lhes mandam. Perguntar também o meio que usam.

Uso da aplicação

- Tiveram algumas dúvidas da explicação que mostrei?
- Agora podem mexer na aplicação e experimentar como funciona, e podem ir pensando na história. Pode ser sobre o que quiserem.
- Podem pegar no tablet à vontade para apontar a câmara, e podem fazer o que quiserem na aplicação
- Têm material para escrever aí que podem usar
- Se não conseguirem fazer alguma coisa, ou se saírem da aplicação sem querer, podem chamar-me e eu ajudo
- Quando quiserem começar a fazer a história, não se esqueçam de clicar no botão de gravar

Pôr um cronómetro para ir contabilizando o tempo. Se passarem 15 minutos e não estiverem a fazer grande progresso, avisar que têm de ir pensando em acabar.

Ir observando se surgem problemas, mas não intervir a menos que estejam bloqueados. É possível auxiliar se houver problemas com a deteção de planos, caso as condições de luz da sala não sejam adequadas.

No total, esta fase deve demorar no máximo cerca de 30 minutos.

Entrevista em grupo

Sentar em frente às crianças com a folha de questões. Usar as perguntas como um guia geral, mas adaptar consoante as respostas.

1. Como é que tiveram a ideia para a história?
2. Estão satisfeitos com a história, ou havia alguma coisa que queriam ter feito diferente?
3. Houve alguma coisa que não gostaram muito de fazer / que acharam mais difícil de fazer?
4. O que é que gostaram mais?
5. Há alguma coisa que gostavam que a aplicação tivesse?
6. Acham que gostavam de usar a aplicação sozinhos? Ou preferiam assim com amigos? Porquê?

Paper ladder

Explicar o que é cada token:

- A aplicação que acabaram de usar
- O StoryMaker do Mobeybou que já usaram para fazer histórias

- Papel

Explicar que o último degrau é para coisas que preferem menos, e os degraus mais acima é para coisas que preferem mais.

Pedir para, em conjunto, colocarem os tokens por ordem de preferência.

Quando acabarem, perguntar por que escolheram aquela ordem.

No final, tirar fotografia aos tokens ou anotar o degrau dado a cada token.

Fim da sessão

Agradecer a colaboração, desligar a câmara e colocar a aplicação no menu inicial. Preparar a sessão do próximo grupo.