LLM-enhanced Cooperative Cross Reality for Workplace Skills Development among People with Neurodevelopmental Disorders

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Abstract

This paper explores a novel approach to promote workplace skills development among individuals with Neurodevelopmental Disorders (NDDs). The work focuses on combining several technologies such as Interactive Storytelling (IS), Extended Reality (XR), tangible interfaces, and Large Language Models (LLMs). Each of these technologies has individually shown potential in education and professional training, and has been demonstrated to support social, cognitive, and practical skills in individuals with NDDs. This paper investigates how they can be integrated into a single, unified experience. Following a thorough analysis of the State of the Art, a pioneer application was co-designed together with therapists and end users, aiming to align the final system with real needs and expectations. The resulting design, named QuesTaleXR, was implemented using cutting-edge technologies to support a Cross-Reality interactive story-telling experience enhanced by a LLM-based virtual assistant.

Keywords

Workplace Skills Development, Conversational Assistant, Large Language Models, Cross Reality, Interactive Storytelling, Tangible Interfaces, Neurodevelopmental Disorders

1. Introduction

Neurodevelopmental disorders (NDDs) are a group of conditions that typically manifest early in development, usually in early childhood [1]. NDDs are characterized by developmental deficits that produce impairments in personal, social, academic, or occupational functioning. These impairments can affect effective communication and hinder the development of essential skills [2]. Among Neurodevelopmental disorders, Autism Spectrum Disorder(ASD) is one of the most common. In general, individuals with ASD exhibit deficits in communication and social interaction, which are core diagnostic characteristics of the condition. As a result, many individuals with ASD struggle with social integration and independent functioning in daily life. These limitations significantly impact their ability to achieve autonomy, particularly in educational and workplace settings. Consequently, over 80% of autistic individuals remain unemployed [3], highlighting a critical need for effective support strategies. Through technology, it is possible to provide solutions that may improve the lives of people with ASD and their autonomy [4]. Extended Reality (XR) encompasses immersive technologies positioned along the Reality–Virtuality Continuum, a spectrum from the fully real to the fully virtual. Augmented Reality (AR) enhances the real world by overlaying digital content and maintaining a strong connection to physical surroundings. Augmented Virtuality (AV) moves further toward the virtual, embedding real-world elements within primarily digital environments. Cross Reality (CR) enables seamless interactions and transitions across real, augmented, and virtual spaces, offering flexible, adaptive experiences that can be tailored to users' needs [5, 6]. Interactive storytelling (IST) is a form of storytelling that adapts

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to user choices. In particular, IST can take on a cooperative dimension, where multiple participants contribute to shaping and advancing the narrative together, blending their perspectives into a shared creative experience [7]. Role Play Games (RPGs) are a type of interactive storytelling where the player is immersed inside the story as the protagonist and able to drive it in any direction they wish [8]. Large Language Models (LLMs) are advanced AI systems designed to understand and generate human-like text based on vast amounts of data. Crucially, through prompt engineering, developers can craft specific input prompts that steer LLMs toward desired outputs, improving coherence and relevance. This technique is especially powerful for story generation [9], even in multiparty scenarios [10]. The goal of this paper is to integrate the most effective elements of the approaches and technologies discussed to create a formative experience for persons with NDDs. Specifically, we aim to implement a cooperative, interactive storytelling environment enhanced by the capacity of LLMs to generate believable, unique, and finely tuned narratives within a cross-reality framework: transitioning from an initial augmented reality paradigm to augmented virtuality, thereby enabling users to cooperatively construct their own experiences as they unfold around them and fully embody the characters they choose to become. Given the particular needs of our users, a storyteller and assistant—embodied as a multiparty chatbot—will also be incorporated into the experience.

2. Related Work

The broad field of interactive storytelling has attracted significant interest within the research community due to the benefits of involving the user as an active participant in the storytelling experience. As example, it has been observed that in role play scenarios, NDDs re-frame their lives as ones of heroism and friendship, echoing what happens in the game narrative and in their character's journey [11].
Research has branched in several directions depending on the type of content, interaction paradigms, and technologies employed. Some of the main areas explored include Tangible Storytelling, Storytelling in XR, and the application of LLMs in storytelling. This chapter will review each of these branches to uncover the principal gaps within the research landscape, both within each subfield and at the intersections between them.
It can be observed that while the field of tangible storytelling was deeply connected to storytelling in XR during the early years of this century [12, 13], this connection has since weakened: only a few papers [14] continue to explore the integration of tangible elements with XR. One likely reason for this is the shift from desktop-based XR to mobile-based solutions [15, 16], where users intuitively could not keep their hands free during application usage. A similar factor was the initial reliance of most XR devices on handheld controllers [17], which hindered natural hand interactions; effective hand recognition has only been widely adopted with satisfactory results in recent years [18]. This gap highlights the need for further research in this area. Despite these limitations, both tangible and XR technologies have independently demonstrated their value, each proving effective in its own way. Tangible interfaces, for instance, have been used to improve social and behavioral skills in autism therapy [19], as well as to enhance engagement, support communication, and promote socialization and cognitive development [20]. In parallel, notable results have been achieved through the use of XR technology to boost social interactions and communication skills [2], support autonomy [21, 4], and facilitate learning [22] in NDDs. While some of these experiences have been adapted to support more advanced presence paradigms—such as AR [2, 4]—a recent survey indicates that the use of these technologies remains predominantly focused on focused on VR, which has been shown to be more immersive than AR [23]. However, this emphasis does not justify the limited research into other technologies across the Reality–Virtuality Continuum. Expanding the use of these intermediate paradigms opens opportunities to create more socially immersive virtual experiences that do not isolate users from one another [24]. Notably, paradigms closer to the virtual end, such as AV, have been found to be as immersive as VR—if not more so [25]—and CR has demonstrated effectiveness in training contexts involving NDDs [4].
While storytelling in XR is recognized as a promising research field, with studies showing notable results for typical individuals [26], relatively little attention has been given to the potential benefits for atypical

individuals. Only a few examples of storytelling applications in XR for NDDs can be found. This is in clear contrast with the broader research community's strong interest in leveraging XR technologies to improve the lives of atypical users, as reflected in several comprehensive surveys. Furthermore, among the few papers addressing this area, only the earlier works [27] considered possible benefits for social skills and cooperation, and even then, not as a primary focus. Other works concentrate instead on attention training [28] and emotion recognition [29]. Large language models (LLMs) have been used to generate stories, but they often struggle with coherency [30, 10]. Research has adopted diverse approaches to solving this problem, but a common factor among them is the use of a story structure — either represented as a series of steps toward a goal, organized using planning models [31], or as narrative chains of distinct elements [32]. The integration of LLMs into storytelling remains at an early stage. Storytelling is known to have a positive impact on individuals who engage with it, and with the power of AI models, there is significant potential to create tools that address specific needs, particularly for individuals with NDDs [30, 33].

In summary, recent research in interactive storytelling has predominantly focused on individual technologies rather than on integrated or hybrid approaches. Only a handful of studies explore intersections between any two of Tangible Storytelling, XR, and LLMs—and none address all three simultaneously. This gap is even more pronounced for atypical users, where almost every study remains confined to a single technological modality. Moreover, the few XR applications designed to enhance autonomy for atypical individuals are almost exclusively VR-based, single-player experiences that lack any storytelling component—highlighting yet another critical void in the literature.

3. QuesTaleXR

QuesTaleXR is a cooperative storytelling application built on cross-reality principles, its goal is to help users with neurodevelopmental disorders to learn to communicate, negotiate, and collaborate in a real-world context through a shared narrative. To engage in QuesTaleXR activities, the only hardware requirement is two Meta Quest 3 devices with camera access enabled. The application runs on Unity, a well-known game engine, and uses Photon Fusion for synchronization between headsets. The chatbot uses OpenAI's GPT-4o to generate responses, along with speech-to-text and text-to-speech modules that serve as the assistant's ears and voice. Interactions revolve around tangible cards marked with QR codes, which users place in a selection area to make choices and progress through the experience. This tangible-to-virtual mapping offers key advantages: it grounds abstract decisions in concrete actions while allowing visual and audio feedback. However, the reliance on physical cards and QR recognition requires sufficiently large cards and adequate lighting to allow MetaQuest3 cameras to detect them. The augmented virtuality paradigm is realized through three pass-through windows—cutouts in the virtual environment that reveal portions of the real world behind them:

User Window: Placed directly in front of each user, this window frames the other participant, allowing users to see one another while immersed in the virtual scene.
Table Window: Positioned just above the table, it ensures correct visualization of the real-world table surface and the physical cards used during the experience.
Floor Window: Located at floor level beneath the user's feet, this window serves a dual purpose: it reveals the user's real body and the actual floor, preserving spatial grounding and body awareness.
QuesTaleXR's LLM-powered virtual assistant is driven by two tiers of contextual information plus a stream of real time event alerts.
Global Context: Defined once at the session start by a system prompt, it contains the general rules of the application, which are provided by the assistant as part of its initial context upon application start. In addition to conveying general information, this layer also references the other layers, explaining how they function. It essentially acts as metadata for the assistant.
Current Context: It consists of two distinct parts: the current game state, which carries forward details—such as the agreed setting or selected roles— and task-specific information, which changes at

the start of each phase (setup, name selection, world selection, character choice, and theater). Both are appended at the end of the general rules. While the game state is briefly explained in the general layer and follows a self-explanatory naming convention, the task-specific information may reference specific fields of the game state to provide more targeted instructions.
Event Alerts: The application uses messages differently from simple chatbots. There are two main distinctions. First, user messages are labeled so the assistant can distinguish among users, thereby enabling multiparty functionality. Second, there are special messages called ”events,” which do not represent user-sent messages but instead specific occurrences. Some of these messages are also labeled, ensuring player-specific events are recognized by the assistant (e.g., “User 1 inactive for a long time,” “Cards conflict,” “Invalid selection”). These events are generated by interaction handlers and sent as special user messages to trigger immediate, phase-appropriate responses.
The assistant relies on components that allow it to talk with the users, more specifically: text-to-speech,

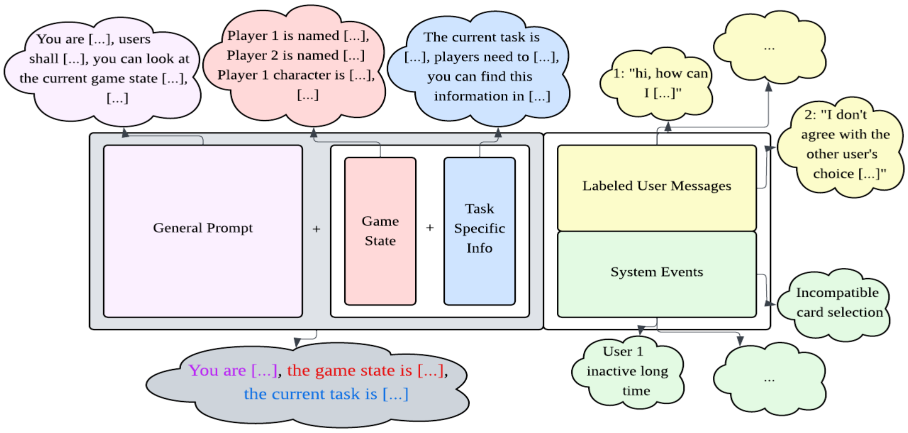

Figure 1: Simple scheme showing contextual information layers and the stream of events, along with some examples

which allows it to speak to users; speech-to-text, which enables it to listen to users.

QuesTaleXR begins the moment two participants put on MetaQuest3 headsets and face each other across a real table. A caregiver simply places a QR marker at the center, and as soon as it’s scanned, the virtual assistant, the selection pad, and the selection areas appear in augmented reality. From this anchored starting point, the system seamlessly guides users through each step of a cooperative story. The experience unfolds in five scaffolded phases:
Introduction: The Virtual Assistant (Figure 1) presents himself and the experience, explaining how to use the selection areas and the microphone card—the primary way for users to interact directly with him.
Name Selection: Each person places a microphone card and speaks their name; hearing it echoed back builds comfort without forcing direct peer conversation (Figure 2).

World Selection: Users have to agree and select the same environment cart among the proposed one (Figure 3). The chatbot mediates eventual disagreements until both users agree on the same card. The selected choice is added into the LLM’s narrative context and the system view updates, allowing both users to visualize their world at real-life scale.
Character Selection: Before entering in the chosen world, users must select their roles (Figure 4). The roles depends on the selected world, and the two players cannot select the same role.
Theater: The experience transitions from Augmented Reality to Augmented Virtuality: the selected environment surrounds the users, yet they can still see the real table, the physical cards, and the other player. This marks the culmination of the interactive storytelling experience, which evolves into a

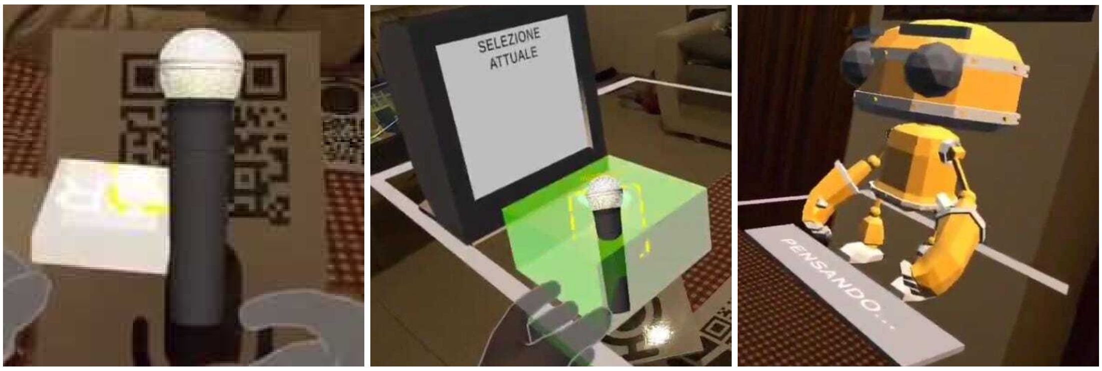

Figure 2: User looking at microphone and then selecting it in order to tell their name to the virtual assistant

role-playing game where participants are immersed within the virtual world. In this phase, players embody their characters, trade virtual items, and complete a brief cooperative task guided by the gentle narration of the Virtual Assistant.

Figure 3: User choosing among the available worlds and then seeing the chosen world appear

Figure 4: User choosing among the available roles

4. Conclusions and Future Work

This paper presents innovative approaches to integrating various interaction paradigms, with the goal of enhancing the ability of individuals with NDD to engage more effectively in the workforce, while improving their autonomy and communication skills.
The primary contribution of this work lies in the design strategy of a context-aware multiparty chatbot, which facilitates dynamic interactions among virtual and tangible elements, leveraging the MetaQuest3

Figure 5: User completing a task while immersed in the environment, in this case give to the other user the item he/she requests

camera access. Additionally, the paper introduces a cooperative storytelling approach in extended reality (XR) environments to enhance immersion, particularly within training applications.
While the application has not yet been tested with a sufficiently large user base, it has been co-designed in collaboration with the primary stakeholders, including individuals directly impacted by ASD, caregivers, and various specialized centers.
However, it is important to acknowledge certain limitations related to the technology, privacy, and safety. These include challenges in the reliability of responses provided by the virtual assistant, the effectiveness of recognizing tangible elements in the environment, and ensuring the protection of user data. Furthermore, the integration of AI raises concerns around user consent, data protection, and ethical considerations, all of which will need to be carefully addressed as the system evolves.
In the near future, we plan to conduct rigorous testing to assess the application's usability, cognitive load, performance of the virtual assistant, and overall sense of presence.
It is important to note that, due to the innovative nature of this approach, a direct comparison between the developed application and other existing solutions is currently not feasible. Rather, the primary objective of this application is to serve as a foundational prototype—a stepping stone for future research and development. It aims to establish a standard for the design and development of similar cross-reality, large language model (LLM)-powered, cooperative storytelling applications in training contexts.

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Declaration on Generative AI

During the preparation of this work, the authors used Chat-GPT-4 in order to: Grammar and spelling check. After using the tool/service, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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