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VISUAL 2025 Editors

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VISUAL 2025

Forward

The Tenth International Conference on Applications and Systems of Visual Paradigms (VISUAL 2025), held between March 9th, 2025, and March 13th, 2025, in Lisbon, Portugal, continued a series of international events putting together complementary domains where visual approaches are considered in a synergetic view.

Visual paradigms were developed on the basis of understanding the functions of the brain and the eyes. They spread over computation, environment representation, autonomous devices, data presentation, and software/hardware approaches. The advent of Big Data, high speed images/camera, complexity and ubiquity of applications and services raises several requests on integrating visual-based solutions in cross-domain applications.

We take here the opportunity to warmly thank all the members of the VISUAL 2025 technical program committee, as well as all the reviewers. The creation of such a high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to VISUAL 2025. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the VISUAL 2025 organizing committee for their help in handling the logistics of this event.

We hope that VISUAL 2025 was a successful international forum for the exchange of ideas and results between academia and industry for the promotion of progress regarding applications and systems of visual paradigms.

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Exploring Natural Language Processing on Enhancing Learning in Immersive Applications

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Abstract— Integrating Natural Language Processing (NLP) with visualization systems and immersive technologies, such as Virtual Reality (VR), is a key area of research in simulation, training, and education. These systems enable the creation of engaging and realistic environments that improve user presence through adaptive and dynamic visualization techniques. NLP algorithms can adapt to the behaviours of the user and preferences in a dynamic simulation. This integration creates clarity, allowing users to navigate and interact with complex visual data effectively. NLP-based Competence-Oriented Training using retrieval-based and generative models in immersive learning scenarios can benefit skills acquisition through better communication and task attribution based on the learning style of the students. We aim to review how NLP impacts visualization technologies, focusing on its role in improving user interactions, training effectiveness, and learning outcomes while also highlighting future opportunities this integration can create.

Keywords-Visualization Systems; Natural Language Processing in Immersive Learning; Virtual Reality and Natural Language Processing.

I. INTRODUCTION

Virtual Reality (VR) system components aim to create sensory stimuli that produce a believable simulation of the real world, fostering brain behavioural responses in the virtual world that are analogous to those that occur in a real environment. Sensory stimulation comes in many forms. VR systems are very good at displaying visual and auditory information. Increasingly, these are approaching the sensory vividness of the physical environment [2]. According to the work of E. Krokos et al. in 2018, memory recall accuracy is improved when using VR technology compared to the traditional desktop condition in a memory recall exercise called memory palaces [4]. These results must also consider the familiarity that users have with desktop equipment compared to head-mounted displays, which impacted the performance. All users involved in the exercise have chosen the VR headset to be better suited for such a task.

VR headsets use lenses for each eye, building the phenomenon of stereopsis, and binocular vision. Combining the movements of the head, body, and gestures creates a very credible bridge between the receptors of the body and the virtual experience and creates a sense of presence. This perception of one's environment creates immersion which, as stated by Krokos et al. in 2019, can aid in higher memory recall accuracy [4][18].

Realism is not the only defining aspect determining the level of immersion. The work in [17] claimed that immersion is a result of representational fidelity and interactivity and so not a unique property. In the same study, evidence was found for an indirect effect of VR features, measured by representational fidelity and immediacy of control, on learning outcomes [18]. Current research identifies high levels of immersion and interactivity as defining characteristics of VR. In the same paper, it is also covered that immersion and interactivity are not objective aspects as they can only be ranked subjectively by the user [18]. What is not subjective, however, is the visual and auditory fidelity of the application, which can be ranked based on the existing state-of-the-art standards. It can be safely assumed that a better fidelity paired with complex interactions leads to deeper immersion [4].

Machine Learning (ML) algorithms have emerged as pioneers in enhancing immersive experiences and expanding the capabilities of such VR environments. By continuously learning and adapting in real-time to user preferences and behaviours, ML-driven advancements allow more realistic, dynamic, and personalized simulations. Moreover, ML enhances VR by enabling the creation of

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complex interactions through the generation of realistic textures, environments, and dynamic elements. These improvements increase the adaptation of VR into various fields, from education to healthcare. However, in the literature, despite the significant work in investigating the use cases of machine learning in VR, there is a lack of work focusing on the Natural Language Processing (NLP) use cases in VR from a holistic perspective. NLP is a subfield of artificial intelligence that studies how humans generate and use natural language. The purpose is to create tools and techniques for machines to grasp and manipulate the language to perform human language-involved tasks such as text analysis and modelling, speech analysis, machine translation, question answering, and chatbots [7][9]. It is a broad subject that combines various disciplines like computer science, linguistics, and statistics, among others. Two distinct but intersecting categories exist in the literature, namely Natural Language Understanding (NLU) and Natural Language Generation (NLG). The former extracts the main semantics from a given utterance. On the other hand, the latter aims to construct the corresponding sentence from a given semantics. However, there are also many challenges in NLP. One of the core challenges is the ambiguity of the human language. It describes the situations where a specific text has multiple interpretations depending on its context. Ethical and bias considerations, domain specialties, interpretability, and explainability are also among the key challenges in this field [1]. This paper reviews research on the intersection of NLP and VR, focusing on their impact on learning. Peer-reviewed studies from sources like IEEE Xplore, ACM, and Google Scholar were identified using a combination of keywords such as "NLP" AND "VR" AND/OR "immersive learning," prioritizing publications from the last 5 to 10 years.

Selection focused on practical applications in education, healthcare, engineering, and digital humanities, emphasizing studies with novel methodologies or significant findings. Key areas included immersive learning, VR-based healthcare simulations, NLP-driven engineering innovations, and historical preservation in digital humanities. This ensured a relevant and focused review process.

The introduction outlines the importance of VR and NLP integration, emphasizing the need for a comprehensive review of their synergy. Section II examines practical applications of NLP in VR across education, healthcare, and engineering. Section III focuses on the technological frameworks enabling this integration. Section IV explores future developments, such as personalized learning, advanced evaluations, and applications in digital humanities. The conclusion summarizes key findings, addresses challenges, and highlights areas for further research.

II. USE CASES OF NLP IN VR

NLP has great learning benefits when used in an immersive virtual world. The reduced learning time through the expressiveness and dynamic nature of these technologies due to a well-designed NLP interface, allows the user to learn concepts that would otherwise take significantly longer using a traditional desktop interface [16][32]. Spoken NLP methods reduce the needed channels of communication, which, in highly graphical environments, generally provide clarity and ease of interaction. While a cluttered User Interface (UI) is not always difficult to navigate, it is typically the case, making this simplification particularly beneficial. This, in turn, frees the eyes and hands to concentrate on the task at hand and use spoken language as the main channel for communication. A big increase in retention and access to training comes as a result of the accessibility of the hardware as well as the novelty of such technologies. Next, we explore the different areas where NLP intersects and improves VR applications. The main fields can be categorized under education, digital humanities, healthcare, engineering, and design, respectively [18].

The selected studies cover the areas where the integration of NLP into VR has demonstrated significant benefits for learning, training, and interaction. These studies illustrate both practical applications and innovative, immersive implementations across a diverse range of research fields.

A. Education

Immersive VR technologies have the potential to shape the traditional educational system. Recent studies such as [10][15][21][22] discuss the new opportunities and difficulties for VR to create immersive and engaging learning experiences for a wide variety of topics. For NLP-based educational VR, one of the commonly used subjects is Non-Native Language Learning and Teaching (NLLT). The authors in [3][12] explore the effectiveness of NNLT in VR. The main benefits include reflection on different learning styles, the autonomy of learners, higher motivation, and better achievement results. They also focus on the drawbacks, such as higher costs of software, and lower IT skills of teachers, and personalizing VR educational tools for NLLT for a wide range of users with different skills, abilities, and needs. They propose a method in which personalization occurs through single-sign-on connections to the social media accounts of the users [3][12]. Another topic that NLP in VR helps with is improving the educational atmosphere. One example project was carried out in 2022 to prevent bullying among peers [8]. From an academic point of view, a search tool in VR is designed to optimize the review of documents within private, public, and research-based organizational settings [1].

Information recall is an important aspect of training and education as it ensures better memory retention of a certain

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subject or activity. With the Cognitive Affective Model of Immersive Learning, or CAMIL model, it is demonstrated that heightened levels of situational interest, intrinsic motivation, self-efficacy, embodiment, and lower levels of cognitive load, have a positive effect on learning outcomes by creating agency [17]. The agency represents a feeling of generating and controlling actions. VR solutions with immersive virtual environments develop agency and thus can be used to improve memory recall in education and training. The level of agency in a virtual environment can be influenced by the level of cohesion a 3D scene can create between its elements with respect to its convention. As stated by Riva et al. [19], several applications in Virtual Reality benefit from a high level of photorealism such as medical training, diagnostic imaging and surgical simulation, architecture, engineering, industrial tasks, audiovisual production, flight simulation and others. When combining high immersion and agency with a high level of realism in a VR training experience, the results for competency-oriented education can be more than motivating.

B. Health Care

Since VR technologies are also changing the healthcare sector, there are a significant number of studies that explore the different aspects of such systems including user opinions about their functionalities and challenges [5][6][13]. Only a small percentage of the existing works incorporate NLP tools in this context to maximize the benefits of these immersive technologies. For example, to mitigate various types of stress in school, some counselling chatbots in VR have been developed by researchers [7]. By providing verbal or text conversations with the chatbot, the systems give therapist-like responses to the users after analysing the stress level of the student. In [27], the authors emphasize the sentiments of questions and the chatbot is capable of empathy-centric dialogues. Furthermore, as investigated in [7][9][14], authors present a conversational therapy VR game for patients with speech disorders like Autism or Aphasia.

The sense of immediacy and control in a simulated environment engages the user by attaining their attention to the fullest resulting in better learning outcomes [20]. In the medical field, VR can be used in teaching a range of topics from anatomy to surgery. Also, this technology can be used for patients to offer a scenario in which they can mentally prepare. The documentation attests that VR is successfully used in medical counselling, surgical training, and contemporary operating theatre training [5]. The study in [23] concludes that the repetition of practical procedures using immersive technologies was found best for medical students for improving learning motivation and learning competency.

C. Engineering and Design

VR holds the promise of enhancing the landscape of engineering and design as well, with its potential impact limited only by the bounds of imagination. One interesting article aims to evaluate the possibilities of creating a ubiquitous semantic metaverse [16]. The paper focuses on the characteristics of four fundamental system components, namely, artificial intelligence, spatiotemporal data representation, semantic Internet of Things, and semantic-enhanced digital twins. A niche topic, the process of customization of large-scale industrial transformers, is presented in [26]. The authors integrated a chatbot with VR to organize the functions of component design, assembly, and disassembly of transformers. In related work [25][28], image processing techniques synergize with NLP aiding users to model and manipulate interior architectural environments. Another interactive VR application is designed to help practice the interview process for software engineers [24]. Guinn et al. demonstrated immersive worlds, which were successfully used in NASA's virtual space shuttle to train astronauts and flight controllers to repair the Hubble space telescope as well as by the Canadian Defence and Civil Institute for Environmental Medicine, which trained ship operators in sea manoeuvres and came to the result of an overall better performance [32]. Motorola also conducted a study of robotic manufacturing plant operations coming to similar results. These examples could be elevated using NLP communication possibilities thus improving learning time, and retention and reducing errors in performing complex tasks.

III. TECHNOLOGICAL REVIEW OF NLP IN VR

The majority of the previously mentioned papers were developed through chatbot technologies. Users interact with the chatbot via speaking or typing. In the first case, speech is converted to text by Automated Speech Recognition (ASR) tools. For this purpose, state-of-the-art deep learning-based ASR models, like Google speech-to-text, are leveraged in some of the works. The acoustic model and language model are combined to create speech synthesis in such sophisticated ASR models. The research in [1] was conducted with evaluations based on the ISO 9241 standard, focus on effectiveness, efficiency, and user satisfaction. The acoustic model is for learning the statistical representations of raw text in the form of phonemes, which are distinct units of sound that make up the word. Although traditional methods such as Hidden Markov Models are still used, more sophisticated methods with Deep Neural Networks (DNN) have been preferred recently [25]. These phoneme sequences produced by the acoustic model are then fed into language models. It provides the text based on the likelihood that these phoneme sequences represent a human language. In general, there are two distinct models for language models, probabilistic methods and neural network-based ones. Probabilistic models use traditional statistics

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based on word n-grams [19][25]. More precisely, they compute the probability of the next word in a sequence depending only on a fixed-size window of previous words. Temporal Neural Networks, such as Recurrent Neural Networks (RNNs), are superseded in n-gram modelling. Graph Convolutional Networks (GCNs) and Transformers are used for enhancing knowledge graph representation and learning, employing deep learning models to capture relationships and improve data analysis [9].

IV. Potential Developments in VR with NLP

In the previous section, we discussed some specific examples of where NLP can enhance existing works across various domains. Here, we will focus on new areas for development from scratch with the help of NLP in an immersive environment.

A. *Digital Humanities*

A competence-oriented approach in vocational education and training requires comprehensive, action-oriented learning lessons and learning progress checks. The insights can be observed through reflection and evaluation, which can become inconsistent in real-life scenarios due to economic, physical, and social factors [30]. Virtual Reality and NLP technology can enable training for psychomotor coordination with a high degree of authenticity in a learning situation. The data required for creating a useful application is gathered and a first concept is developed and validated by a cross-regional committee of teachers and researchers [9][34]. Such immersive applications in vocational education aim to create a realistic representation and behaviour of the real-life tasks that students are meant to perform daily as well as be aware of budgets and limitations in carefully scripted scenarios to develop the whole skill set needed. A close collaboration with trainers and teachers in the field is maintained as well as a diverse team of computer scientists which ensures continuous evaluation and dedicated field tests [29].

1) *Digital Museums*

Based on Shehade et al.'s work, VR technologies have created new opportunities for Digital Museum applications to interact with their visitors. VR has been used for the reconstruction of historical environments and for creating interactive, engaging and immersive experiences in a historical site environment [33]. It was used to allow the visitor to experience a space that is no longer accessible. In art museums, this is usually a place depicted in a painting or even the actual studio in which the artist worked to get a sense of his/her ordinary life. VR was also used to immerse the visitor in history and places that cannot be currently experienced. In one example, VR was used to allow visitors to "experience the life on a train car in World War I" [33]. In virtual heritage preservation, simulations of environments have defined a practice where photorealism is considered a very important measure of a deep immersion and great sense of agency thus assisting memory recall and aiding education regarding historical heritage [20]. Zouboula et al., in 2008, attest that an impression of "being there" in a digital museum is defined as a capacity for visitors to navigate freely, without the necessity of being in the physical space of a museum. This proves to be a great advantage for residents of disadvantaged areas (e.g. remote or rural) who can have the opportunity to "visit" and come in direct contact with exhibits digitally. Eventually, such environments can provide students with the capacity to discover, wonder, and learn [31].

2) *Digital Preservation in Literature*

Future development of Virtual Reality experiences in conjunction with NLP, in digital heritage preservation, should aim to harness the possibilities of Artificial Intelligence (AI) by using AI agents who could offer guidance and information to the viewer. AI agent refers to an intelligent system or virtual assistant embedded within a VR environment, designed to interact with users and enhance their experience. These agents utilize AI and NLP to provide personalized guidance, present relevant information, and respond to user inquiries in real-time. In a digital museum, an immersive library with meticulously created archives from the literature corpus and historical sources can benefit from AI technology. A musical instrument with an info screen can offer multiple choices to further one's research on a certain topic, which, by choosing to explore further, would enable the user to be transposed into a 3D environment created using AI, powered by a library of predefined 3D modular assets. Based on prior behavioural responses, the system can make a connection with visual or auditory material from the same period or genre. In a digital historical environment, for example, one can choose a book from a library and have the possibility of finding out how that book would "sound" by creating a book-based song with AI. This involves leveraging machine learning models trained on data cured for that period or genre. This process involves Text Analysis, NLP-based feature extraction, model training to map text to melody, defining musical parameters, iterative refinement with human intervention, and output evaluation [35]. The use of 3D assets can be a way of interacting with information in a digital museum. Each space can represent a different level of knowledge, gradually unlocked to the viewer. As the participant progresses through the experience, they uncover clues scattered across the spaces, gradually revealing more about the history and the lives of the people who lived there. This interactive application not only offers cultural and educational value but also provides an element of enjoyment, allowing users to learn through interaction. Of course, there can also be a disadvantage in AI-generated interpretations as it may inadvertently misrepresent or oversimplify complex cultural narratives, leading to ethical concerns and potential disrespect towards the heritage being presented. The paper [36] explores the ethical implications of AI in cultural heritage, highlighting the need for context-sensitive approaches to avoid negative impacts.

B. Competence-Oriented Training

Competence-Oriented Training (COT) is focused on developing skills required in particular tasks and professions and can be heavily improved with the use of NLP by enabling the creation of personalized learning scenarios and custom evaluation mechanisms. It can deploy digital assistants to help students solve problems and aid in a suite of various learning tasks. These NLP solutions for training are currently delivered by IBM, Google, Amazon, Cerner, Nuance Communications, Microsoft, and many others [32]. We have already shown the improvements that immersive applications have on competence acquiring and in the following sub-sections we will look into the multiple ways NLP can aid in learning scenarios and the evaluation of the users [11].

1) NLP-based Personalized Learning Scenarios

NLP-powered dialogue systems in Virtual Reality applications are becoming increasingly integral in human-computer interaction and can be used both as task-based and non-task-based systems. In this case, a task-based system consists of Natural Language Understanding (NLU), Dialogue Manager (DM), and Natural Language Generation (NLG) components [1][7][24]. The adoption of deep reinforcement learning for end-to-end trainable frameworks also further enhances performance and usability. Non-task-based systems refer to chatbots that simulate natural conversations and can fall into two categories: retrieval-based or generative models. Retrieval-based models can select responses from pre-defined options, and generative models create responses from scratch based on trained data. These systems aid immersive learning scenarios by creating personalized experiences that can benefit from NLP real-time communication and enhanced task attribution based on the learning style of the students and their level of knowledge [1][7][25].

2) NLP-based Evaluation

Evaluation systems can be implemented in VR simulations through the same NLP systems mentioned before, which can monitor the actions of the users and offer suggestions as well as warnings when mistakes are being made. In a similar technique, a final evaluation is made based on motion sensor data and the evaluation of actions and choices the user made during the exercise [1][7][25].

V. Conclusion and Future Work

The integration of NLP capabilities into VR systems unlocks for developers new possibilities for immersive, interactive, and personalized experiences across various domains including education, digital humanities, entertainment, communication, healthcare, engineering, and design. The potential of NLP in VR systems can improve interactivity by using voice commands instead of pop-ups and dialogue boxes. Users could communicate and control elements in the virtual world in a much more engaging way. Real-time language translation for international collaboration can also be facilitated by an NLP system. Educational simulations and training scenarios can be improved by dynamic and responsive interactions due to enhanced dialogue systems with the use of NLP which would respond to the actions of the users and natural language inputs in contextually appropriate ways. NLP models can aid VR environments by changing and manipulating the 3D world space and 3D assets based on user inputs and thus adapting the learning content and experiences to cognitive abilities and learning styles. NLP-based assistive technologies can support individuals with disabilities by adapting to each user's needs to provide as much value as possible for the learning outcome. All these capabilities have an impact on education, particularly in NLLT. Personalized learning tools, bullying prevention, and document review optimization are also reinforced and drive intrinsic motivation and agency, which positively impact learning outcomes. Digital humanities offer innovative ways to engage with history, literature, arts, and culture through an interdisciplinary collaboration between VR and NLP to offer guidance and information to viewers based on meticulously curated sources and novel user interactions. The sector of healthcare is changing through the use of simulations in therapy and patient preparation. NLP tools are used to enhance counselling chatbots, facilitate dialogues and be involved in conversational therapy for patients with speech disorders, and much more.

It is also essential to address the challenges that arise such as ensuring accuracy, naturalness and ethical considerations in the development and deployment of NLP-based immersive applications.

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