

Design principles for generating real-time explanations to learners' questions in a virtual reality learning environment using natural language generation: Practice based lessons learned from creating multiple agents in Unreal Engine 5 using ConvAI

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Abstract

The effectiveness of a virtual reality learning environment (VRLE) can be enhanced through adaptive instruction where pedagogical agents adjust their instruction to the learner's actions. Despite advances in natural language processing, the lack of natural communication of pedagogical agents in a VRLE is reducing its effectiveness. Furthermore, there is a lack of design principles for developing pedagogical agents that respond intelligently to learners and can converse naturally. This paper is part of a larger study that investigates the design principles for effective pedagogical agents in VRLEs that provide real-time explanations using natural language generation. It reports on the lessons learned while developing a pedagogical agent using Unreal Engine and ConvAI. Two key design principles were identified, namely the importance of multiple pedagogical agents with distinct roles and well-rounded personas. A pedagogical agent was developed, and initial tests show that the agent responded intelligently in an appropriate context.

Keywords: *Virtual reality; Education; Pedagogical agent; Natural language generation*

1. Introduction

Pedagogical support tools are imperative to enhance learning and form a part of the adaptive learning system in the virtual reality learning environment (VRLE) (Steynberg, 2021; Steynberg et al., 2023). Pedagogical tools can be implemented through the environment or a pedagogical agent. A pedagogical agent is a digital, lifelike character in a digital learning environment that can provide guidance, model desired behaviour and skills, assist, and support the learner emotionally and cognitively as well as metacognitively (Dai & Ke, 2022; Grivokostopoulou et

al., 2020; Tao et al., 2022). The problem investigated in this study is that despite the advancement of technology regarding natural language processing and real-time text-to-speech conversion, the lack of fluent and natural communication of pedagogical agents in virtual reality is reducing the effectiveness and usability in electronic learning environments (Sikström et al., 2022). This inadequacy in pedagogical agents' communication implies challenges to adaptive, adequate, relational, and logical communication (Sikström et al., 2022).

The larger study attempts to answer the following question:

What are the design principles of effective and efficient pedagogical agents in immersive virtual reality learning environments that can respond to learners' questions and provide explanations in real-time using natural language generation?

This paper reports on a sub-part of the prototype development, namely lessons learned for creating pedagogical persona generated by an artificial intelligence character engine that can respond intelligently and efficiently to learner's questions and provide suitable and relevant explanations in real-time.

2. Methodology

This study adopts the Systems Development Research Methodology (SDRM) from Design Science Research (DSR), introduced by Nunamaker et al. (Nunamaker & Chen, 1990), which comprises of six key phases: problem and objective definition, design and development of a prototype, demonstration, evaluation, and communication. This paper focuses on a sub-section of the prototype development, namely using Unreal Engine 5 and ConvAI to create a persona and intelligent conversation engine for the pedagogical agent and do an initial review of the responses achieved by conversing with the agent. Unreal Engine 5 is a 3D creation tool used to build various immersive experiences. ConvAI is a character development engine that allows the creator to craft personalities, backstories and facilitate real-time, responsive conversations.

2.1. Developing the pedagogical agents and non-player characters for the VRLE

Following the guidelines proposed by Steynberg et. al. (2021), a storyboard was created to define the overall flow of the learning experience. Thereafter the non-player characters and pedagogical agent for each scene were specified. At the commencement of this study, it was envisioned that there will be a group of villagers who carry on with their daily lives but will not communicate with the character with only one pedagogical agent - a sage that will provide the learning. This was due to the perceived complexity of implementing the natural language integration into the VRLE for a specific character. As the development proceeded and testing was continuously done through the process by the authors, it became apparent that communication and interaction with the other characters could also contribute to the authenticity

and level of immersion of the learner, as a non-player character that does not communicate with the player feels unnatural. During a previous study (Steynberg, 2023), one of the participants stated that she 'felt very alone and isolated' as there were no other characters or players in the prototype that was built, only a voice that provided instructions.

Initial work done by Baylor and Ebbers (2003) found that multiple agents with separate roles have a significant positive impact on learning as well as the perceived value of the agents. They coined this principle as the split persona effect, where two distinct agent roles such as an expert and a motivator in two separate personalities is preferable to one agent with one role such as a mentor and further determined that it was simpler for learners to split or compartmentalize the information delivered by the two different agents, and this led to improved learning (Baylor & Ebbers, 2003). Baylor and Kim (2016) identified three primary roles that an agent can assume in an educational setting, namely a motivator, an expert, and a mentor. This list has been expanded to include additional roles, such as tutor, assistant, learning partner, competitor, and even troublemaker (Kim & Baylor, 2016; Tao et al., 2022; Waldner et al., 2022).

2.2. Pedagogical agent personas

The definition of a pedagogical agent states that it is a lifelike digital character, therefore it has human traits, emotions, and a persona (Alfaro et al., 2020; Alimamy & Kuhail, 2023). A well-defined, likable persona improves the learner's perceived anthropomorphism which helps to create an emotional connection with the agent, as well as enhances the trust which is crucial for learner engagement (Alfaro et al., 2020; Baylor & Ebbers, 2003; Castro-Alonso et al., 2021). By designing the agent's appearance, voice, nonverbal communication and personality to reflect and support the role its playing in the learning environment could impact specific learning and motivational outcomes (Kim & Baylor, 2016)

Referring to these guidelines derived from literature, the development of the VRLE continued with the design and development of multiple non-player characters and a sage who can all converse in natural language and respond efficiently and effectively to learners' questions, as well as guide the learner through the learning tasks. A character engine is typically used to develop characters in a game - it is a set of tools that help developers to create generative artificial intelligent characters for games. The requirements for such a character engine were derived from the literature-based guidelines as noted in Table 1.

Table 1. Requirements of a character engine to create a pedagogical agent in virtual reality

Personality aspect	Characteristics	Character capabilities	engine	Source
Agent role	The role of the agent must be distinct and easily recognisable	The agent must have a specific personality with a backstory that fits in with the role of the agent		Baylor & Ebbers, 2003; Kim & Baylor, 2016; Tao et al., 2022; Waldner et al., 2022
Agent knowledge	The agent must have appropriate knowledge to be able to fulfill the pedagogical role identified	A knowledge base should be accessible for each specific agent that forms the base of their knowledge		Baylor & Ebbers, 2003; Kim & Baylor, 2016; Waldner et al., 2022
Appearance	The agent's appearance should be likable without distracting the learner	The agent's gender, race, age and clothing should be easily configurable and changeable if needed		Alfaro et al., 2020; Baylor & Ebbers, 2003; Castro-Alonso et al., 2021; Kim & Baylor, 2016
Emotions	The agent's emotional state should be apparent by the type of language it uses, as well as body language	The agent's emotional state should be configurable		Alfaro et al., 2020; Alimamy & Kuhail, 2023
Actions	The agent's body language and movements in the VRLE must be believable and appropriate	Body language and animation should be configurable, and lip syncing should be appropriate		Kim & Baylor, 2016
Narrative flow	The agents as a collective entity should be able to guide the learner through the tasks	The narration and communication with the learner should follow a decision tree, depending on the actions and responses of the learner		Chen, 2006; Clarebout & Elen 2007; Minocha & Hardy 2016

Different character engines for creation of characters in Unreal Engine were considered. An internet search was done on 15 November 2024 with the following search criteria: "character engine for NPC AI unreal engine 5" where NPC is a non-player character. There are not many character engines currently available, and only three suitable engines were identified, namely InworldAI, ConvAI, and Replica. The support of the character engine towards the personality aspects from Table 1 were considered, and ConvAI was selected because it provides the

capability to create an agent persona that is fully rounded, its appearance can be custom built, narrative design can be done and it is affordable with a low learning curve.

2.3. Creating a pedagogical agent as a non-player character in ConvAI

To develop a character in ConvAI, there are different aspects that feed into the creation of the persona. To define the personality and style of the character, the character's name, personality traits, and distinctive features must be defined. The engine has the capability to set the character's personality in terms of openness, meticulousness, extraversion, agreeableness, and sensitivity visually with sliders. Specific speaking patterns and sample dialogues can be entered, such as favourite phrases or exclamations used by the character. A specific voice can be selected, and multiple languages are supported. Special pronunciation can be added for specific words and words that can be hard to recognise such as names can be listed explicitly.

A backstory in the form of a brief background on the character's story should be created and added to the engine. A knowledge base can be uploaded as books of information to create your character's conceptual framework and can elevate its knowledge to any level you choose. The state of mind of the character can be set by choosing a specific state on an emotions wheel. Considering long term memory, all dialogues that the pedagogical agent has completed are stored in a memory bank. This is an important consideration for developing a VRLE that will be used by various learners. Names and places should not be part of long-term memory, as confusion can arise if the agent uses the wrong name.

Narrative design allows the developer to define certain dialogue responses depending on the conversation between the agent and the learner. Dialogue sections are added to the narrative design which define the objective of the section or a set script and has a specific decision point. A decision point is when the agent asks a question and the learner responds in a certain way, or something specific is addressed in the conversation. Lastly, safety restrictions can be defined as on or off - the engine allows for moderation to form part of the narrative response. This prevents the agents from using profanities, hate speech or inappropriate content.

2.4. Prototype development

ConvAI was used to develop the first character. A backstory for the character was created through ChatGPT and uploaded to the ConvAI platform, but no specific narrative design was done. The emotion defined for the character was being "sad" and "desperate" since he is a survivor of an apocalyptic fiasco and is struggling to find a means of living. The Metahuman platform was used to create the visual appearance of the character and Unreal Engine 5 was used to implement realistic animations.

A conversation between the learner and pedagogical agent then takes place by using the learner's microphone and speakers in the virtual reality head-mounted display. The character engine captures the voice input from the microphone, translates it to text and uses a large language model, incorporating the persona definition created by the developer to generate an appropriate response. This is then converted to speech which the learner hears through their headset.

Initial testing done by a volunteer produced an example of a conversation that took place as shown in Table 2.

Table 2. Extract of a conversation between a learner and the pedagogical agent

Learner	In what town are we right now?
Pete	We're in a small, run-down village. It's not much, but it's home for a handful of survivors. Everyone's trying to make it work in this new reality. If you decide to stay a bit, you might find some interesting stories and maybe learn a few survival skills from the folks here.
Learner	What happened? Why are they survivors?
Pete	It's a long story. The world went through a huge upheaval—systems we relied on collapsed, and chaos followed. Climate disasters, power outages, and food shortages hit hard. The people here managed to survive through sheer will and resourcefulness, holding onto whatever they could from the past while adapting to the new world. It's been a struggle, but they're determined to keep going.
Learner	What methods of survival are they implementing?
Pete	The villagers have turned to some traditional methods for survival. They've been foraging for edible plants and trying to cultivate small gardens, despite the challenges with soil and climate. Some have taken up fishing or hunting, using whatever tools they can manage to find or make. They're also relying on skills passed down from older generations, like preserving food and basic craftsmanship. It's a mix of ingenuity and adaptation to make it through each day.

3. Conclusion

This paper reports on lessons learned during the design and implementation of a virtual reality learning environment reality with pedagogical agents using natural language processing and generative artificial intelligence. Lessons learned in this study include firstly the significance of implementing multiple pedagogical agents with multiple, different roles such as a motivator,

expert or mentor to improve the trust, engagement and immersion that could lead to improved learning outcomes of the learner in the VRLE. Secondly, agents with well-rounded personalities that are believable, authentic and likable personalities lead to improved engagement, higher trust and motivation. Combining these two design principles of creating multiple agents with unique, authentic personalities lead to a challenge to develop agents in a simple, clear and efficient way and tools to simplify, streamline and accelerate the development of these characters were researched. From these design principles requirements for such a character engine has been derived and include that the character engine should facilitate specifying and customising an agent's persona, role, background knowledge, appearance, state of mind, animations and the narrative flow for each agent. Another finding pertains to the selection of character engines where three different character engines were evaluated, and ConvAI was selected because of its capabilities and features, ease of use and low cost. It was used to create the first pedagogical agent for the VRLE, and initial tests show that the pedagogical agent conversed intelligently, responding with contextually appropriate responses. Future work includes the completion of the prototype by adding multiple pedagogical agents and narrative flow, where after the theoretical contribution of the study will follow. This will be a set of practice evaluated design principles that are founded in literature to guide developers of immersive virtual reality learning environments with effective and efficient pedagogical agents that can converse naturally using generative artificial intelligence and natural language processing.

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