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Revolutionising Engineering Education: Creating Photorealistic Virtual Human Lecturers Using Artificial Intelligence And Computer Generated Images

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REVOLUTIONISING ENGINEERING EDUCATION: CREATING PHOTOREALISTIC VIRTUAL HUMAN LECTURERS USING ARTIFICIAL INTELLIGENCE AND COMPUTER GENERATED IMAGES

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ABSTRACT

The COVID-19 pandemic has disrupted traditional classroom learning, making virtual and remote education increasingly important. In this context, the use of photorealistic virtual humans, or avatars, powered by Artificial Intelligence (AI) can offer an immersive and engaging environment for delivering traditional classroom-based lectures. This paper proposes a process that combines AI and Computer-Generated Images (CGI) to create photorealistic virtual human lecturers for educational purposes.

The proposed process flow involves generating audio from text inputs, which is passed to a 3-Dimensional (3D) facial animation rig that matches lip, tongue, eye and facial movements to the audio using AI. This generates a base mesh for speech animation which is refined using morph targets and blend shapes, resulting in a highly realistic facial animation. Game engines and photogrammetry is used to generate a photo-realistic human avatar, to which the base mesh is mapped to generate a photorealistic animated avatar.

Virtual humans offer several advantages over real persons, including the ability to customise the persons appearance, voice, accent, language, location, mannerisms etc., making them an ideal solution for global education.

The process flow will describe the methods, analysis and interpretations for using AI to generate natural photo-realistic avatars, and the potential contributions to the advancements in engineering education.

In conclusion, virtual humans have the potential to revolutionise the way education is delivered in a post-COVID world. By combining AI and CGI, photorealistic virtual human avatars can be created that are highly engaging, customisable, and accessible to students all over the world.

1 INTRODUCTION

This systematic review examines previous research conducted on the use of Embodied Virtual Agent (EVA) as lecturers in higher education. The aim is to provide a comprehensive analysis of the effectiveness, advantages, and limitations of utilising these EVAs in higher educational settings – both from a student and lecturer perspective, in particular, how do lecturers perceive and respond to EVAs?. It highlights the intention of the Rethinking Engineering Education in Ireland (REEdI) project to explore the development and integration of EVAs using Artificial Intelligence (AI) and immersive or Extended Reality (XR) - which includes Augmented Reality (AR) and Virtual Reality (VR) - into Science, Technology, Engineering and Mathematics (STEM) programmes Munster Technological University (MTU), Kerry Campus. REEdI combines an innovative method of content delivery with XR to deliver a truly transformative programme to deliver fully remote, immersive, and collaborative solutions to engineering students and lecturers. Students will utilise XR as a point-of-contact with lecturers while on extensive work placement, which will extend the duration of 2 years at geographically dispersed locations. Students, lecturers, and mentors can meet virtually and collaboratively regardless of their geographical location in real-time to discuss progress and to collaborate on engineering challenges; or interact with proposed pre-created content such as lecturing sessions using EVAs.

The objective is to augment the proficiencies of engineering students and in higher educational settings and within industry. It is crucial to emphasise that the implementation of these technologies is not intended to supplant lecturers, but to supplement and empower them in their instructional roles.

2 METHODOLOGY

2.1 Identification and search strategy

Searches were conducted in the following databases: IEEE Explore, JSTOR, PubMed, Springer Link, and Taylor & Francis Online. Searches were aimed at articles published between January 2010 - 2023. Search terms included "*embodied virtual agents*", "*virtual reality*", "*virtual instructors*", "*engineering education*", "*higher education*", “*photorealistic*”, and “*artificial intelligence*”. Search terms were combined using Boolean operators AND, OR to expand/narrow the search. Figure 1 illustrates the total number of publications as inclusion/exclusion criteria were applied.

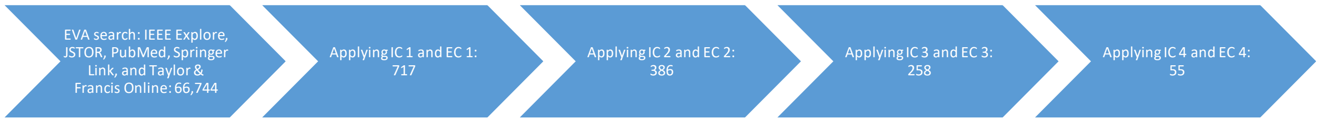

Fig. 1. Flowchart of Identification and Search strategy

Of 55 publications, 20 were identified through the inclusion/exclusion criteria highlighted in *Section 2.2, Table 1*, with 2 publications dated pre-2010 included (Maldonado and Nass 2007) (Slater 2003). These publications emphasised the presence and emotional aspects, which do not directly mirror the technological progress during the time of publication or currently. Figure 2 illustrates the publications timelines including publication methods.

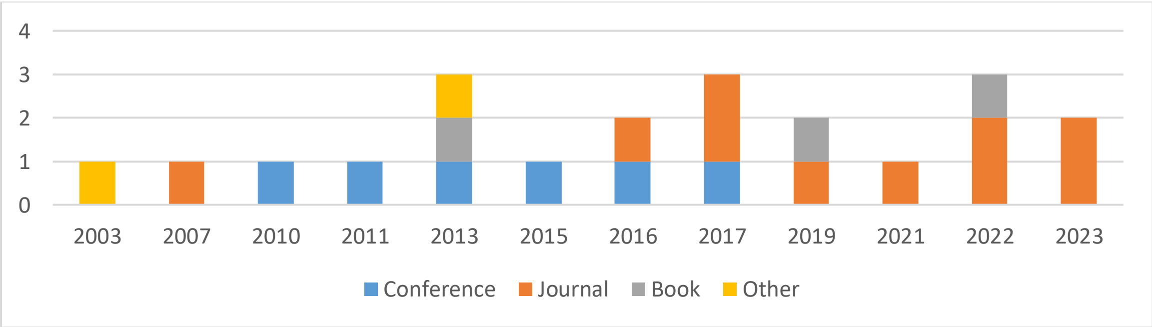

Fig. 2. Publication timelines

2.2 Inclusion and exclusion criteria

The term “*embodies virtual agent*” was used as the primary search criteria. Additional considerations and inclusions applied to studies focused on on-the-job skills-training where relating to XR (Batrinca, et al. 2013) (Gratch, DeVault and Lucas 2016) (Suárez, Jung and Lindeman 2021). Studies that focused on primary and secondary school education, duplicate studies with similar content, non-peer-reviewed sources, or articles not available in English were excluded from the review.

Table 1. Inclusion and Exclusion criteria

Inclusion Criteria: IC	Exclusion Criteria: EC
IC 1: Relevance to XR	EC 1: Not in English or open access
IC 2: Focusing on higher education	EC 2: Primary or secondary schools
IC 3: Focusing on engineering	EC 3: Duplicate studies
IC 4: Using EVAs as lecturers	EC 4: Not using AI

2.3 Study selection

Studies were selected on their relevance to education, and in particular to engineering education, as well as its relevance to using XR as a delivery method. In the case of VR, care was taken on the type of VR, focusing on Head Mounted Displays (HMDs) as opposed to screen-based VR solutions.

2.4 Data extraction

The following data points were extracted from the selected publications: (1) study characteristics, (2) sample characteristics, (3) educational context, (4) virtual agent features, and (5) key findings. The most noteworthy key findings were from Swartout et. al. (Swartout, et al. 2013). The authors demonstrated that individuals interacting with virtual humans: (1) exhibit responses akin to those elicited by real individuals, (2) display enthusiasm towards engaging with these characters, and (3) acquire knowledge and information through the communication conveyed by these characters. The use of VR in education has proven pedagogical advantages such as enhancing learning outcomes, and increased engagement, motivation, and involvement (Boyle, et al. 2022) (Fitton and Finnegan 2022).

3 RESULTS AND FINDINGS

3.1 Exploring the potential of EVAs: enhancing engagement, emotion and empathy

The use of XR in education have garnered interest and widespread implementation in recent years, while the COVID-19 pandemic prompted educational institutions worldwide to adapt to remote learning methodologies. Conversational voice assistants like Apple's Siri or Amazon's Alexa may be impressive but lack the capability of conveying emotion and empathy. This limitation lies in their lack of physical presence and visual representation.

The most extensively used XR applications revolve around training simulations for e.g., pilots, machine operators, hazardous occupations like mine workers, military personnel, and medical staff. (Boyle, et al. 2022). These applications focus on hands-on training, and typically lack virtual instructor guidance, instead relying on audio prompts and/or text instructions.

Provoost et.al. (Provoost, et al. 2017) defines EVAs as computer-generated avatars designed to replicate essential facets of interpersonal communication, encompassing both verbal and nonverbal cues. Guetterman et. al. (Guetterman, et al. 2017) describes agents that are programmed and controlled by computer algorithms, with the ability to interact with real people using verbal and non-verbal behaviours. EVAs can simulate human-like behaviours, expressions, and gestures, fostering a sense of connection and creating a conducive environment for meaningful interactions (Slater 2003). For EVAs to be successful, it is necessary for users to perceive and respond to them socially in a realistic way to elicit the feeling of presence (Kyrlitsias and Michael-Grigoriou 2022). Presence is intertwined with immersion (Slater 2003), and is influenced by attributes of the VR system and the level of immersion (Ijsselsteijn and Riva 2003). Endeavours in the field of VR have predominantly focused on presence, given its correlation with the efficacy of VR experiences. The degree to which users perceive themselves to be present within the virtual environment directly impacts the realism of their reactions and behaviours, thereby contributing to the overall success (Cummings and Bailenson 2016). Fitton et al. (Fitton and Finnegan 2022) report on the influence of an EVA and students' perception of presence on various aspects of learning including retention, satisfaction, engagement, and motivation. The study highlights the potential for EVAs to overcome limitations associated with lecturer-student ratios and classroom size. IVEs possess the capability to enhance the perception of interpersonal connectedness, enabling EVAs to evoke emotions associated with social presence (Suárez, Jung and Lindeman 2021).

3.2 Assessing the effectiveness of EVAs in higher education and remote learning environments: knowledge transfer, retention and comprehension

The role of EVAs as a teaching aid, and its integration into formal education settings is relatively infrequent. One of the most popular utilisations focus on the use of pre-recorded videos in Massive Open Online Courses (MOOCs). MOOCs encompass a video-recorded presentation by a lecturer, enabling students to fulfil assignments, and engage in scholarly discourse through online forums (Feng, et al. 2015). Despite their potential, they face challenges such as learner attrition and motivational factors (Yang, et al. 2013), and significant resource requirements from lecturers for lesson recording, and post-production editing. It can be contended that delivering lessons through platforms like Microsoft Teams (Microsoft 2023) or Zoom (ZOOM 2023) entails a lower resource burden per session. EVAs enhance the credibility and relatability of the virtual agents, making them more effective in delivering complex educational content such as engineering principles (Fitton and Finnegan 2022).

The utilisation of EVAs holds significant importance for effective pedagogy (Soliman and Guetl 2010). Prior scholarly indicate that the portrayal of artificial agents influences learners' motivation (Maldonado and Nass 2007). Learners have the option to personalise EVAs according to their preferences, and such customisation has demonstrated enhanced performance in certain cognitive tasks (Lin, et al. 2017), and it was observed that the female pedagogical agent was generally favoured (Novick, et al. 2019).

Swartout et al. (Swartout, et al. 2013) report on a system known as the Twins (Ada and Grace), who serve as virtual characters within the Cahners Computer Place at the Museum of Science, Boston, and are envisioned to possess autonomous capabilities such as independent thought processes, emulating and expressing emotions, and engaging in seamless and organic interactions through verbal and nonverbal means. The primary objective is to achieve a high level of authenticity in their appearance, communication, and behaviour, aiming to closely resemble real individuals (Swartout, et al. 2013). Functioning as digital docents and STEM role models, they engage with visitors by providing information on the exhibits and activities and responding to general inquiries. The Twins are designed to possess embodied social characteristics, exemplifying traits such as sibling rivalry through their banter, actively engaging in conversations, disclosing details about their personal backgrounds, preferences, and even relationships. This deliberate design approach aims to establish a relatable and captivating experience (Swartout, et al. 2013). The utilisation of conversational interaction enables the establishment of rapport, fostering trust, and motivation, and evaluations of these systems demonstrate that individuals interacting with virtual humans (1) exhibit responses akin to those of real individuals, (2) display enthusiasm towards engaging with these characters, and (3) acquire knowledge and information through the communication conveyed by these characters.(Swartout, et al. 2013). EVAs exhibit significant utility across diverse domains, encompassing cognitive-science investigations, training methodologies, educational practices, and recreational applications. (Campbell, et al. 2011). Recent advancements in AI, in particular Large Language Models (LLM), such as ChatGPT (OpenAI 2023) and computational processing power, allow for EVAs to be programmed with interactive capabilities to respond to students' queries, provide feedback, and engage in interactive conversations in real-time.

3.3 Potential benefits and drawbacks of EVAs in education

XR in education has numerous pedagogical advantages such as enhancing learning outcomes, increasing learner's motivation and involvement, engage in experiential learning, and facilitating deeper levels of understanding and cognition (Boyle, et al. 2022). By enabling learners to actively explore and interact with virtual objects and events, VR transcends the passive modes of observation and listening typically associated with traditional learning approaches (Boyle, et al. 2022). Additional advantages include reduced travel time and the impact it has on the environment, cost, and requirements for physical space. To realise their full advantage, it is crucial for EVAs to augment and supplement the role of a lecturer. Table 2 shows potential benefits and drawback of EVAs in higher education.

Table 2. Advantages and drawbacks of using EVAs in higher education.

Advantages	Drawbacks
Improved learning outcomes such as increased retention and improved knowledge application.	Requirements for sophisticated AI algorithms and computational resources
Can become part of the content through posture, clothing e.g. safety gear, expression, etc.	Ensuring ethical use of data and privacy protection.
Customisable attributes such as appearance, voice, accent, language, location, and mannerisms.	Concerns related to the impersonal nature of EVAs compared to human lecturers.
Accessibility and inclusivity through gender, ethnicities, or physical abilities.	
A sense of novelty and excitement which increases motivation and engagement.	
Resource savings such as travel time, cost and impact on environment	

3.4 Utilising AI and CGI for EVA generation: Understanding the technology behind photorealistic EVAs in education and overcoming technological barriers

EVA creation is becoming less resource intensive with the advancements in more sophisticated and accessible computer hardware and software. For the creation of the EVAs, this systematic review proposes the following combination of technologies: Play.ht (Play.ht 2023), NVidia Audio2Face (NVidia 2023), and Unreal Engine METAHuman (Engine 2023). The proposed process flow for the REEdI programme is described as follows: Using text and lecture material, the REEdI lecturer generates an audio file by passing in text cues. This can be enhanced by uploading a base sample of the lecturers' own voice, which can then be replicated using AI. Using the audio file, NVidia Audio2Face is used to synch the audio to a generic facial mesh rig that will mimic the audio using AI. The AI manipulates the face, eyes, mouth, tongue, and head motion to match a selected emotional range, or automatically infers emotion directly from the audio clip. METAHuman. Depending on the level of complexity required, the lecturer can choose from: (1) a premade facial template, (2) generic fictional character, or (3) scan their own features that maps and recreates their facial features to the base METAHuman. The last technique yields a photorealistic mesh of the lecturer. The total creation time requires less than 90 minutes to produce a photorealistic EVA that is fully rigged and operational. The EVA creation process, including proposed output, is shown at a high level in Figure 3.

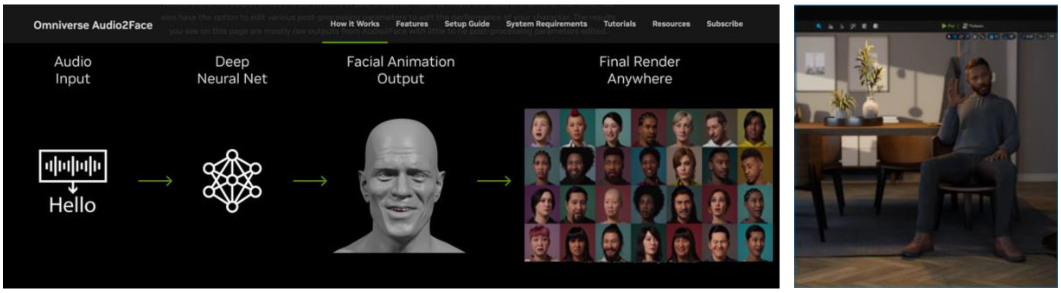

Fig. 3. EVA creation process flow (left) and proposed output (right).

4 DISCUSSION

A systematic review focusing on EVAs highlight the existence of positive outcomes such as improved learning outcomes and engagement, and enhanced student satisfaction, yet there remains gaps in the analysis that correlate directly to the benefits attributed to lecturers such as 1-to-1 interactions in large class sizes, optimal use of finite resources such as physical spaces, and diverse student needs e.g., language and disabilities. There are several limitations and challenges that need to be addressed, for instance, creating the framework on which EVAs are built is technically challenging and requires specialised skillsets such as software development which could be a potential barrier for many. The training needed by lecturer, coupled with time and resource constraints could potentially be another barrier. Further limitations relate to the existing research (small sample sizes) and lack of long-term studies due to the nature of this new cutting-edge technologies.

Potential areas for future investigation are discussed below in the form of research questions. Based on this systematic review, practical recommendations for educators, institutions, and policymakers interested in implementing EVAs as lecturers include the need for innovation, alignment with industry needs, and the importance of professional development for educators.

5 CONCLUSION AND FUTURE RESEARCH

This systematic review explored the potential of using EVAs and their contributions to the advancement of education. The methods, analysis, and interpretations presented herein demonstrate how EVAs can enhance the delivery of teaching concepts and foster a deeper understanding among students. The immersive and interactive nature of EVAs can effectively simulate real-world scenarios, enabling students to engage in experiential learning and problem-solving exercises. EVAs can be a valuable component of eLearning, but their effectiveness depends on their implementation. When they are designed poorly, they can add to the extraneous information and impede the learning process. However, when they are created with a high level of realism, they can enhance retention and facilitate the application of knowledge in real-world situations.

As highlighted in the research, the implementation and integration of EVAs into higher education is relatively infrequent. Based on this and the limitations identified in previous literature reviews, this systematic review formulated the following research questions aimed at engineering education in HEI environments using EVAs to augment student and lecturer pedagogies using XR technologies: (1) How do lecturers perceive and respond to EVAs?, (2) How do students' perceptions of the social presence and instructor support in VR-based engineering education compare to traditional classroom settings?, (3) How do students' learning preferences and attitudes towards technology influence their acceptance and adoption of EVAs and VR technologies in engineering education?, (4) What are the key design principles and considerations for creating effective EVAs for engineering education in VR?, (5) What are the best practices for integrating EVAs and VR technologies into the existing curriculum of higher education engineering programs?, (6) What is the effectiveness of AI controlled photorealistic EVAs as lecturers in engineering education?

The first question draws correlation to engineering education specifically, while the second and third questions focus on the technical design and implementation of EVAs for VR in higher education. The final 3 questions seek to explore the reciprocal interaction between students and AI controlled EVAs, and the subsequent advantages and/or drawbacks this may reveal.

The REEdI project aims to incorporate EVAs into the existing Bachelor of Engineering (Honours) Degree in Mechanical and Manufacturing Engineering to bolster and complement the instructional efforts of lecturers by leveraging XR technologies, thereby optimising the educational outcomes for students.

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