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Elevating STEM Learning: Unleashing the Power of AI in Open Distance eLearning

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ABSTRACT

The integration of Artificial Intelligence (AI) into Open Distance eLearning (ODeL) represents a significant evolution in STEM education, offering transformative benefits in teaching, learning and administrative processes. This conceptual paper explores how AI-driven platforms are revolutionising ODeL by providing personalised learning experiences, real-time feedback, adaptive assessments and immersive simulations through technologies like Augmented Reality (AR) and Virtual Reality (VR). These advancements not only enhance student engagement and understanding but also support the development of critical thinking and problem-solving skills. The paper highlights successful case studies from institutions like Carnegie Mellon University and Stanford Online High School, showcasing practical implementations of AI in STEM education. However, the integration of AI also brings forth challenges, particularly concerning data privacy, security and the need for equitable access to technology. As AI continues to advance, it promises to play an important role in lifelong learning, offering modular and just-in-time educational opportunities. The paper concludes with a call for robust ethical frameworks to guide the responsible use of AI in education, ensuring that the benefits are maximized while potential risks are mitigated.

KEYWORDS

Open Distance eLearning; Artificial Intelligence; Science, Technology, Engineering and Mathematics (STEM); Education; Innovation.

INTRODUCTION

Artificial Intelligence (AI) is emerging as a transformative force in Science, Technology, Engineering and Mathematics (STEM) higher education, offering potential benefits in teaching methodologies, curriculum design and student engagement (Onesi-Ozigagun et al., 2024; Nagaraj et al., 2023). Open and Distance Learning (ODL) institutions, such as Open University Malaysia, are exploring AI applications to enhance programme advising, automated scheduling, assignment marking and learner retention (Fadzil & Munira, 2008). The COVID-19 pandemic accelerated the adoption of online learning technologies in STEM education, with institutions promoting both basic synchronous and asynchronous tools, as well as more sophisticated technologies like Virtual and Augmented Reality (Amunga, 2021). However, the transition to online STEM education raises concerns about access, equity, quality and student engagement. To address these issues, governments and institutions should invest in infrastructure, prioritize disadvantaged students and explore remote lab solutions (Amunga, 2021). AI-powered personalized learning experiences can further advance adult education in ODL settings (Grammatikos et al., 2023). Moreover, AI can serve as an educational scaffold to develop students' AI-thinking skills, enabling them to conduct in-silico experiments and improve their AI literacy (How & Hung, 2019). As AI continues to shape the future of STEM learning, it is crucial to consider ethical concerns and adopt a responsible approach to data-driven education (Nuangchalerm, 2023). AI-driven learning analytics offer opportunities to enhance STEM curriculum, improve pedagogical methods and address challenges in implementation (Nuangchalerm, 2023; Fadzil & Munira, 2008).

In higher education, AI has the potential to revolutionize teaching methodologies, curriculum design and assessment practices (Nagaraj et al., 2023). AI applications in educational settings include expert systems for program advising, automated scheduling, plagiarism detection and adaptive learning to meet different student needs (Fadzil & Munira, 2008). AI-driven learning analytics are enhancing personalised learning, tailoring content to individual student needs and pace (Jian, 2023). This approach improves student engagement and academic performance through adaptive learning systems and real-time feedback (Onesi-Ozigagun et al., 2024). AI is also transforming assessment practices, moving beyond traditional exams to more dynamic examination methods (Onesi-Ozigagun et al., 2024; Nagaraj et al., 2023). However, challenges remain, including data privacy concerns, algorithmic bias and the need for teacher training (Onesi-Ozigagun et al., 2024). Ethical considerations in AI implementation are crucial (Nuangchalerm, 2023). As AI continues to evolve, its impact on STEM education is expected to grow, offering new opportunities to improve learning outcomes and prepare students for the digital age (Onesi-Ozigagun et al., 2024; Nagaraj et al., 2023). Artificial Intelligence (AI) is revolutionising education by enhancing personalised learning experiences, transforming teaching methodologies and optimising administrative processes (Kalyani, 2023; Onesi-Ozigagun et al., 2024). AI-powered systems enable adaptive learning pathways, tailoring content to individual student needs and learning styles (Silva & Janes, 2020; Xu & Fan,

2022). These technologies facilitate real-time feedback, data-informed decision-making and improved student engagement (Kalyani, 2023; Silva & Janes, 2020). AI applications in STEM education are particularly promising, with six categories of AI applications identified across various educational elements (Xu & Fan, 2022). However, challenges remain, including ethical considerations, data privacy concerns and the need for teacher training (Kalyani, 2023; Onesi-Ozigagun et al., 2024; Silva & Janes, 2020). Despite these challenges, AI's potential to reshape the educational landscape is significant, offering opportunities to improve learning outcomes and prepare students for the digital age (Kalyani, 2023; Onesi-Ozigagun et al., 2024).

In the current era of Open and Distance Learning (ODeL), we observe a phenomenon where the traditional boundaries of classrooms are becoming less distinct. Despite the physical distance between students and teachers, they are able to stay connected through the expansive digital world (Simonson et al., 2019). The swift progress of AI, characterised by its ability to process large amounts of data, adapt to individual learning preferences and offer immediate feedback, has created opportunities for innovation in the field of education (West et al., 2020). These doors provide access to an environment where customised learning experiences are designed to fit the specific requirements of students, better equipping them for the challenging employment in STEM disciplines (Van der Kleij et al., 2015; Dede, 2010).
This study aims to analyse the mutual relationship between artificial intelligence (AI) and science, technology, engineering and mathematics (STEM) education in the context of Open and Distance e-Learning (ODeL). This conceptual paper explores the methods, benefits and challenges associated with this combination, with the goal of understanding the processes of change that are reshaping the field of education (Crawford et al., 2019; Chittum, 2021). By highlighting the capabilities of AI in fostering the development of creative and analytical minds (Blikstein, 2013; Clark & Mayer, 2016), we move towards a more promising future where STEM education is not limited by conventional constraints, but rather propelled into a time of extraordinary opportunities. By emphasising the potential of AI in promoting the development of innovative and logical thinking (Blikstein, 2013; Clark & Mayer, 2016), we move towards a more promising future where STEM education is not limited by traditional constraints, but instead move into a period of exceptional opportunities. In this study, the aim is to set the parameters for a thorough inquiry into the ways in which AI is improving STEM education, enabling it to reach its full potential in the space of Open Distance eLearning.

METHODOLOGY

Research Approach

This study employed a qualitative research approach to explore the integration of Artificial Intelligence (AI) in Open Distance eLearning (ODeL) for STEM education. The research is based on a comprehensive review of existing literature, including scholarly articles, case studies and industry reports. The methodology is designed to analyse and synthesise the findings to present

a coherent understanding of the current trends, benefits and challenges associated with AI in ODeL STEM education (Creswell, 2013; Patton, 2015).

Data Collection

The data collection process included gathering information from multiple academic databases, such as Google Scholar, JSTOR, Semantic Scholar and IEEE Xplore. The literature review focused on identifying key themes and patterns in the integration of AI into STEM education within ODeL. Keywords such as "AI in education," "ODeL," "STEM education," "adaptive learning," "virtual labs," and "personalised learning" were used to filter relevant studies (Bryman, 2016). Additionally, reports from educational institutions, government bodies and technology firms were analysed to understand practical implementations and real-world applications of AI in ODeL (Yin, 2014).

Data Analysis

The data analysis process of data analysis consisted of the utilisation of thematic analysis. The collected literature was categorised into major themes relevant to the research objective. These themes include AI-driven personalisation, real-time feedback, adaptive learning paths, augmented and virtual reality applications and ethical considerations (Das et al., 2023). The analysis involved a thorough evaluation of the methodologies, findings and conclusions of each study to identify similarities, differences and gaps in the existing body of knowledge. Thematic coding was used to systematically organise the data, ensuring comprehensive coverage of the research topic (Skjott & Korsgaard, 2019).

Case Study Selection

Two case studies were chosen to demonstrate the practical applications of AI in ODeL STEM education, specifically highlighting their effective use of AI technologies. The selected case studies are Carnegie Mellon University (CMU) and Stanford Online High School (Stanford OHS). The selection of these universities was based on their innovative approaches of integrating artificial intelligence (AI) to improve personalised learning, offer virtual laboratories and support adaptive learning paths (Gligorea et al., 2023). The case studies were analysed to emphasise the specific AI applications, their influence on student learning outcomes and the challenges faced during implementation (Robert et al., 2024).

Ethical Considerations

The ethical considerations in this research involve ensuring the accuracy and reliability of the data sources and maintaining objectivity in the analysis. The study acknowledges the possible biases present in the literature, such as the overemphasis on successful implementations and the underreporting of challenges (Silverman, 2016). Additionally, the research discusses the ethical implications of AI in education, specifically focussing on issues related to data privacy, algorithmic biases and the digital divide (Floridi & Cowls, 2019; Ungerer & Slade, 2022).

Limitations

The methodology recognises certain limitations, including the dependence on secondary data, which may not fully capture the most recent developments in AI and ODeL. Furthermore, the

study is limited by the availability of detailed case studies and the generalizability of findings across different educational contexts (Denscombe, 2014).

AI-Driven Personalisation in ODeL STEM Education

Adaptive Learning Systems

Adaptive learning systems powered by artificial intelligence (AI) are transforming e-learning by personalising educational experiences. These systems analyse learner performance, preferences and traits to create personalised learning systems and content (Akavova et al., 2023; Colchester et al., 2017). AI algorithms continuously monitor student progress, identifying strengths and weaknesses to provide targeted interventions and optimize learning outcomes (Akavova et al., 2023; Gligorea et al., 2023). The integration of AI in adaptive learning has shown promising results, with some studies reporting increased test scores and improved student engagement (Gligorea et al., 2023). Additionally, AI-powered systems can assist teachers by automating administrative tasks and generating comprehensive progress reports (Akavova et al., 2023). However, challenges such as data privacy concerns and the complexity of AI systems need to be addressed (Akavova et al., 2023; Gligorea et al., 2023). Despite these challenges, adaptive learning using AI has the potential to revolutionise education by creating more effective and personalised learning experiences.

Furthermore, adaptive learning systems fosters self-directed learning, a skill highly valued in STEM fields. By allowing students to choose their learning direction within certain parameters, AI encourages autonomy and critical thinking (Dede, 2010). This empowerment can be particularly beneficial in ODeL environments, where students must manage their learning independently. AI-driven learning analytics in STEM education offer valuable insights for educators and policymakers, though ethical considerations must be addressed (Nuangchalerm, 2023). A systematic review of AI-based adaptive learning literature reveals the increasing development of such environments, utilising various AI algorithms to achieve adaptation goals (Ezzaim et al., 2023). These systems not only improve learning outcomes but also enhance student engagement and motivation (Akavova et al., 2023). However, challenges remain, including privacy concerns, ethical considerations, and the need for teacher training in utilising these technologies effectively (Akavova et al., 2023; Nuangchalerm, 2023). Despite these challenges, AI-powered adaptive learning holds significant promise for creating personalised and effective learning experiences in STEM education.

Real-time Feedback and Assessment

Artificial Intelligence (AI) is transforming real-time feedback and adaptive assessment in education, particularly in open and distance learning environments. AI-driven systems can provide immediate, personalised feedback to students, enhancing their learning outcomes and understanding (Hooda et al., 2022; Bulut & Wongvorachan, 2022). These systems utilise various AI branches, including Natural Language Processing, Educational Data Mining and Learning Analytics, to analyse student data and generate tailored feedback (Bulut & Wongvorachan, 2022). AI-powered mechanisms can monitor student understanding, assess prior knowledge

and build individual learner profiles in real-time classroom conditions (Samarakou et al., 2014). For instance, in mathematics education, intelligent assessment systems combine human and electronic evaluation to provide semi-automatic feedback, helping students overcome challenges and boost their confidence (Bescherer et al., 2012). During this process, AI can instantly notify a student if they make a calculation error, providing the correct solution and explanation. AI-enhanced feedback and assessment tools are transforming education by offering timely, personalised support to students, ultimately improving their learning experiences and outcomes.

AI-driven adaptive assessments are designed to determine a student's understanding and adjust the difficulty and content of following questions accordingly (Baker & Inventado, 2014). Through the integrating cognitive and contextual information, adaptive assessments can better select and classify questions to meet students' needs and interests (Salazar et al., 2018). These assessments continuously adapt to the student's performance, offering questions that challenge their current level of knowledge without overwhelming them (Dede, 2010). This approach allows for real-time, classroom-based evaluation that adapts to students' performance levels (Samarakou et al., 2014). Knowledge-based systems can create user-adapted tests on demand, using rule-based expert systems to determine exercise difficulty based on the learner's progress (Hatzilygeroudis et al., 2006). Personalised feedback in adaptive assessments further enhances the learning experience, especially in open distance learning environments (Saul et al., 2010). These adaptive assessment models have shown promise in improving learning efficiency and effectiveness (Hatzilygeroudis et al., 2006; Samarakou et al., 2014). Additionally, AI also excels in collecting and analysing limitless amounts of data generated by student interactions with educational materials (West et al., 2020). This data-driven approach allows teachers to gain deep insights into student performance and engagement patterns. Teachers can use this information to make data-informed decisions, adjusting teaching strategies and curriculum design to better support student success (Siemens & Gasevic, 2012). As AI continues to evolve, it is crucial to emphasise critical thinking and self-regulated learning to effectively implement formative assessment in this new digital age (Hopfenbeck et al., 2023).

Natural Language Processing (NLP) for Enhanced Interaction

NLP-powered tools, such as chatbots and virtual assistants, have significantly improved the educational experience by bridging the gap between students and teachers, often separated by geographical distances. These tools offer immediate assistance, answer queries and provide explanations, thereby creating a more interactive and supportive learning environment (Patel et al., 2023; Alhawiti, 2014). NLP technologies in education are particularly effective in managing large-scale interactions, providing personalised responses and facilitating learning in multiple languages. This ability is especially beneficial in ODeL settings, where students may come from different linguistic backgrounds. NLP is able to translate content, support communication among students from different regions and ensure equitable access to educational resources (Picciano, 2017; Zawacki-Richter et al., 2019).

Beyond basic query responses, NLP-powered virtual assistants and chatbots is able to assist in more complex tasks such as facilitating discussions, managing group projects and even conducting assessments. Through the promotion of advanced NLP techniques, these tools can understand and respond to complicated human language, fostering active participation and collaboration among students (West et al., 2020; Blikstein, 2013). They can also tailor learning experiences, suggesting supplementary resources and study strategies based on individual needs (Liu et al., 2022). Moreover, NLP technologies enhance traditional discussion forums by introducing intelligent features like automated thread identification, content summarisation and sentiment analysis. These features help in maintaining the relevance and quality of interactions, stimulating critical thinking, knowledge sharing and peer learning in ODeL environments (Clark & Mayer, 2016; Siemens & Gasevic, 2012).

However, the integration of NLP in education comes with challenges, including data privacy concerns and the need for continuous improvement of NLP algorithms to accurately interpret and respond to complex educational contexts. Ethical considerations, such as ensuring transparency and avoiding biases in AI systems, are critical to the responsible use of NLP in educational settings (Harrington, 2020; Vanderbilt, 2017). As NLP continues to advance, its role in ODeL is expected to expand, making it an important component in creating dynamic, personalised and effective learning environments. The technology promises to transform the educational landscape by offering more engaging and tailored learning experiences, thus enhancing the overall effectiveness of digital education (Litman, 2016; Liu et al., 2022).

Augmented Reality (AR) and Virtual Reality (VR) in ODeL STEM

Immersive Learning Environments

In the context of Open Distance eLearning (ODeL), Augmented Reality (AR) and Virtual Reality (VR) technologies are revolutionising the educational experience, particularly in STEM subjects. These immersive technologies provide students with the opportunity to engage with complex concepts through interactive and hands-on experiences. For example, AR and VR simulations can create virtual environments where students explore biological ecosystems, interact with virtual organisms, or visualise abstract scientific principles like gravitational forces (Dede, 2010; Bouhnik & Marcus, 2006). The ability of AR and VR to transcend traditional two-dimensional representations allows students to manipulate virtual objects, observe cause-and-effect relationships and conduct experiments in a simulated space. This immersive approach promotes a deeper understanding and retention of STEM concepts, as students are not just passive recipients of information but active participants in their learning process (Peters, 2014; Cai et al., 2017). Furthermore, these technologies facilitate access to STEM education regardless of geographical constraints, enabling students from various locations to participate in simulations that might otherwise be inaccessible due to physical limitations (West et al., 2020).

AR and VR are not limited to STEM fields, but they are increasingly being used across various educational domains, from K-12 to higher education and professional training. These technologies enhance student engagement and motivation by making learning more dynamic

and interactive (Ntaba & Jantjies, 2019; Guerra et al., 2023). Despite some challenges, such as usability issues, the integration of AR and VR in education is showing significant potential for improving student performance and creating more engaging learning environments (Kuhail et al., 2022; Algerafi et al., 2023). In particular, VR's ability to create fully immersive, computer-generated environments has proven valuable, especially in the wake of the SARS-CoV-2 pandemic, which has increased the reliance on online education. VR can simulate classroom experiences, allowing for an engaging and immersive learning experience that traditional e-learning platforms cannot provide. This has been particularly beneficial in STEM education, where practical, hands-on learning is important (Maheshwari & Maheshwari, 2020). Real-life case studies have demonstrated the effective implementation of VR in various educational settings, emphasising its potential to transform education and suggesting a broader adoption of this technology in the future (Maheshwari & Maheshwari, 2020).

Hands-on Experiences in a Virtual Space

Virtual labs and experiments, powered by Virtual Reality (VR) technology, have become instrumental in providing hands-on learning experiences for STEM students in Open Distance eLearning (ODeL) environments. These virtual labs recreate realistic laboratory settings, allowing students to conduct experiments, manipulate equipment and analyse data just as they would in a physical lab (Siemens & Gasevic, 2012; Bouhnik & Marcus, 2006). This capability is particularly valuable for experiments that might be hazardous, costly or logistically challenging to perform in a traditional lab setting. For instance, chemistry students can safely practice experiments with volatile substances, while physics students can explore complex experiments without financial limitations (Dede, 2010; Peters, 2014). Virtual labs offer a wide range of experimental opportunities across various STEM disciplines, accommodating different skill levels and educational needs. They provide a platform for students to engage with different learning materials, thus broadening their exposure to different scientific phenomena (Cai et al., 2017). Additionally, these labs generate substantial amounts of data, which students can analyse, thereby enhancing their analytical and critical thinking skills—skills important for modern STEM professions (Bouhnik & Marcus, 2006). This data-driven approach not only aligns with the practical demands of the industry but also prepares students for real-world applications (Coble et al., 2010).

The integration of virtual labs in education also addresses issues of equity and accessibility. Through the elimination of geographical and financial barriers, these labs enable students from various backgrounds to access high-quality educational experiences (Lynch & Ghergulescu, 2017; Ndunagu et al., 2023). However, the implementation of these technologies is not without challenges. The cost of VR equipment and content development, the need for reliable hardware and software and potential user discomfort, such as motion sickness, are significant considerations (West et al., 2020). Despite these challenges, the ongoing development and increased accessibility of AR and VR technologies hold promise for transforming STEM education. These immersive tools offer an interactive and engaging way for

students to explore and understand complex scientific concepts, thereby enhancing the overall learning experience in ODeL settings (Ntaba & Jantjies et al., 2019). As these technologies continue to expand, they are expected to play an increasingly central role in providing comprehensive, hands-on STEM education, complementing traditional learning methods rather than replacing them.

Ethical Considerations and Challenges in ODeL

Data Privacy and Security

The integration of Artificial Intelligence (AI) in Open Distance eLearning (ODeL) raises serious ethical concerns, particularly regarding data privacy and security. AI systems in educational contexts often require access to wide amounts of personal data to personalise learning experiences and provide tailored feedback, which inevitably brings up issues around the protection of student information (Crawford et al., 2019; Singh & Ramutsheli, 2016). To mitigate these risks, it is of importance that educational institutions collect, store and use data in strict compliance with privacy regulations, ensuring that explicit consent is obtained from students (Harrington, 2020; Devi et al., 2023). As the reliance on AI-powered platforms increases, these systems become attractive targets for cyberattacks. Therefore, safeguarding student data must be a priority to prevent potential breaches that could expose sensitive information. This suggests the implementation of robust cybersecurity measures, including strong encryption protocols and regular security audits (West et al., 2020; Vavekanand, 2024).

Moreover, there is a risk that AI algorithms could prolong existing biases present in the data they are trained on, leading to discriminatory outcomes that unfairly disadvantage certain groups of students. This issue could affect various aspects of education, including grading, feedback and resource allocation (Blikstein, 2013; Weber, 2020). To prevent such outcomes, it is essential to regularly audit and refine these algorithms to identify and correct biases, ensuring fairness and equity in educational practices (Devi et al., 2023). Transparency in AI usage is also critical for building trust among students and teachers. It is important that students are fully informed about how AI technologies are used in their education, what data is collected and how it is utilised to make decisions. Transparent communication allows students to make informed choices about their engagement with these technologies and builds confidence in the ethical use of AI (Crawford et al., 2019; Vavekanand, 2024). Additionally, while AI can offer substantial benefits in educational settings, it should be designed to complement rather than replace human teachers. This approach ensures that the educational process remains inclusive and supportive, capitalising AI's abilities to enhance, rather than diminish, the role of teachers (Devi et al., 2023). Developing comprehensive ethical and legal frameworks is essential to navigate the challenges of AI integration in education, aiming to maximise its potential while minimising associated risks (Weber, 2020).

Ensuring Inclusivity

A primary concern in AI-driven STEM education in ODeL is the digital divide, where not all students have access to necessary technology and reliable internet connectivity, worsening

educational inequalities, especially in technology-dependent STEM fields (Dede, 2010). To bridge this gap, efforts must focus on providing disadvantaged students with essential hardware and connectivity resources, ensuring they have the tools needed to participate fully in ODeL (Siemens & Gasevic, 2012). Inclusivity also involves designing educational content and AI-driven tools to accommodate different student needs, including those with disabilities. This entails offering alternative content formats and ensuring that AI interfaces are compatible with assistive technologies. The Universal Design for Learning (UDL) framework and digital accessibility standards play a crucial role in creating flexible and inclusive learning experiences, particularly in environments like Massive Open Online Courses (MOOCs) (Mrayhi et al., 2023; McPherson et al., 2019). Given the different linguistic and cultural backgrounds of ODeL students, AI systems must support multiple languages and be culturally sensitive to avoid bias or insensitivity in content and interactions (Zawacki-Richter et al., 2019; Bouhnik & Marcus, 2006). AI-driven learning experiences should strive to reflect and respect the cultural diversity of the student body, providing equitable learning opportunities for all (Mohammed & Watson, 2019).

Furthermore, the absence of physical classroom interactions in ODeL can lead to a lack of emotional and motivational support for students. It is important to implement support mechanisms that address these psychological and emotional needs, ensuring that students feel supported and engaged (Jung et al., 2018). This includes providing robust online support services and ensuring that AI-driven systems are not only instructional but also supportive of students' well-being (Anis, 2023). In assessment and grading, AI must be used judiciously to ensure fairness and transparency, avoiding any biases that might disadvantage certain student groups. It is essential to develop and maintain ethical standards that guide the implementation of AI in educational settings, balancing the potential for improved learning outcomes with the safeguarding of student rights and access (Clark & Mayer, 2016).

The goal is to create an inclusive and supportive learning environment where all students, regardless of their backgrounds or abilities, can succeed. This involves careful consideration of instructional design, improving technology to meet different needs and promoting an environment that supports equity and inclusivity (Roshanaei et al., 2023). The effective integration of these strategies is vital for addressing persistent imbalance in educational outcomes and ensuring that all students have the opportunity to thrive in AI-driven ODeL settings.

Case Studies: Successful Implementations in ODeL

Highlight Real-World Examples of Institutions Effectively Integrating AI into their ODeL STEM Programs

The integration of Artificial Intelligence (AI) into Open Distance eLearning (ODeL) has transformed the landscape of STEM education, offering innovative ways to enhance learning and engagement. Several institutions have successfully adopted AI technologies to revolutionise

their ODeL STEM programs. Below are two notable case studies illustrating these successful implementations:

Case Study 1: Carnegie Mellon University (CMU) - ODeL STEM Programs Enhanced by AI

Carnegie Mellon University (CMU) has been a pioneer in integrating AI to enhance its ODeL STEM programs. CMU employs AI-driven adaptive learning platforms that tailor educational content to individual students' needs and learning styles, thereby personalising the educational experience (Picciano, 2017). Key features of CMU's implementation include:

AI algorithms analyse students' performance and preferences, allowing the system to dynamically adjust the curriculum and pacing. This personalisation helps in fostering deeper comprehension and retention of STEM concepts. The university utilises AI-powered chatbots and virtual assistants to provide immediate feedback, answer questions and guide students through coursework. This support system enhances engagement and helps reduce feelings of isolation, a common challenge in ODeL settings. CMU offers virtual labs and simulations that allow students to conduct experiments and interact with complex scientific concepts in a virtual environment. This approach ensures hands-on learning experiences, which are crucial in STEM education, even in a distance learning format.

Case Study 2: Stanford Online High School (Stanford OHS) - Enabling Global STEM Education with AI

Stanford Online High School (Stanford OHS) provides a rigorous online education for talented students worldwide, integrating AI to enhance its STEM programs. The key aspects of their implementation include:

AI systems at Stanford OHS analyse student performance and adapt the curriculum in real-time, ensuring that each student is appropriately challenged and receives targeted support in STEM subjects. The school uses AI-powered tutoring systems to offer personalised assistance, helping students understand complex STEM topics beyond regular coursework. These virtual tutors provide additional support, making challenging subjects more accessible. AI algorithms facilitate matching students with similar interests and complementary skills for collaborative STEM projects. This fosters teamwork and cross-cultural exchanges among the global student body, enhancing the learning experience.

These case studies highlight how leading institutions like CMU and Stanford OHS are integrating AI to improve personalised learning, provide immediate support and enable global access to quality STEM education through ODeL platforms. Among the two institutions mentioned, there are also other ODeL institutions that integrated AI in their teaching such as Open University Malaysia and Georgia Institute of Technology. These two institutions explore AI applications in program advising, automated scheduling and plagiarism detection, enhancing the administrative and learning experience (Fadzil & Munira, 2008). In their online AI courses, the use of intelligent tutoring agents has resulted in student performance improvements comparable to traditional residential courses (Goel & Joyner, 2017). As mentioned on the preceding sections, while AI offers substantial benefits, challenges such as data privacy,

equitable access to technology and the need for teacher training must be addressed to ensure ethical and effective implementation (Pedra et al., 2024). Institutions must develop robust frameworks for AI use, involving collaboration among educators, researchers and technology developers to maximise the benefits of AI in ODeL STEM education. These case studies and examples demonstrate the potential of AI to revolutionise ODeL STEM programs, providing personalised, engaging and accessible education to students worldwide.

Prospects in ODeL

Predicting Future Trends in AI-Driven STEM Education within the ODeL Context, Including the Potential for AI to Support Lifelong Learning

The future of AI-driven STEM education within Open Distance eLearning (ODeL) is poised to transform the educational landscape significantly. AI will continue to advance, providing highly personalised learning experiences tailored to each student's unique strengths, weaknesses and learning preferences. Even in large-scale online courses, AI will be able to offer individualised content, pacing and assessments, thereby enhancing student engagement and mastery of STEM subjects (Siemens & Gasevic, 2012). This personalisation will be crucial for addressing different and complex learning needs and promoting deeper understanding. The integration of AI in ODeL will see the rise of virtual mentors and career advisors who can guide students through their educational and professional journeys. These AI-driven advisors will offer personalised recommendations on course selection, career pathways and skill development, thus supporting lifelong learning and helping students stay relevant in an ever-changing job market (West et al., 2020).

Virtual labs and simulations are expected to become more sophisticated, offering realistic and immersive experiences that replicate real-world scenarios. AI will facilitate real-time data analysis and expand the range of experiments that can be conducted online, making hands-on STEM learning accessible to a broader audience (Bouhnik & Marcus, 2006). This will be particularly valuable in providing practical experience to students who may not have access to physical lab facilities. AI-driven social learning platforms will enhance collaborative problem-solving in STEM fields. These platforms will connect learners with similar interests and complementary skills, encouraging knowledge sharing, group projects and peer support, thus fostering a sense of community in the ODeL environment (Jung et al., 2018). AI will enable ongoing assessment and provide continuous feedback on student progress. Automated tools will not only evaluate knowledge but also assess critical thinking and problem-solving skills. This continuous feedback loop will help identify areas where students need improvement, allowing both students and teachers to focus on those areas (Van der Kleij et al., 2015).

AI will support multimodal learning by integrating text, video, audio and interactive content, catering to different learning styles and accessibility needs. This inclusive approach will ensure that all students, regardless of their abilities or preferences, have equal opportunities to succeed (Clark & Mayer, 2016). AI-driven STEM education will play an important role in lifelong learning. It will provide modular, just-in-time courses and resources that students can access

throughout their lives to acquire new skills or stay current in rapidly changing fields. This will be particularly important in helping individuals adapt to new technologies and job market demands (Dede, 2010). Institutions and teachers will increasingly rely on AI-driven analytics to make data-informed decisions regarding curriculum design and teaching strategies. This will involve monitoring student performance, identifying gaps in knowledge and tailoring educational programs to better meet the needs of students (Picciano, 2017).

As AI becomes more integrated into ODeL, ethical considerations such as data privacy, algorithm transparency and fairness will become increasingly important. Institutions will need to develop and adhere to robust ethical guidelines to ensure that AI technologies are used responsibly and equitably (Harrington, 2020). AI will increasingly integrate with other emerging technologies, such as augmented reality (AR) and virtual reality (VR), to create even more immersive and engaging STEM learning experiences. This will enable students to interact with virtual instructors and environments in ways that traditional methods cannot offer, further enhancing the learning experience (Bouhnik & Marcus, 2006). The future of AI-driven STEM education in ODeL promises to be dynamic and transformative. As AI technologies continue to change, they will provide more personalised, accessible and engaging learning experiences, supporting lifelong learning and equipping students with the skills needed for the future. However, it is important to address the accompanying challenges, particularly in terms of ethics, data privacy and equitable access, to fully realise the benefits of AI in education (Masrek et al., 2024; Fadzil & Munira, 2008).

CONCLUSION

The integration of Artificial Intelligence in Open Distance eLearning (ODeL) has the potential to fundamentally transform STEM education by making it more personalised, accessible and engaging. AI-driven tools and platforms enable customised learning experiences, real-time feedback and adaptive assessments, which cater to the unique needs of individual students. The use of technologies such as Augmented Reality (AR) and Virtual Reality (VR) further enhances the learning experience by providing immersive and hands-on educational opportunities. The successful implementation of AI in institutions like Carnegie Mellon University and Stanford Online High School demonstrates the significant benefits that can be achieved in ODeL settings. Despite the promising prospects, the deployment of AI in education is not without challenges. Data privacy and security concerns, potential biases in AI algorithms and the digital divide are critical issues that need to be addressed to ensure equitable access to quality education. Moreover, the ethical implications of AI use in education must be carefully considered, with a focus on transparency, fairness and the protection of student rights. Looking forward, AI's role in supporting lifelong learning is expected to grow, providing continuous educational opportunities that help individuals adapt to changing technological landscapes and job market requirements. To fully realise the potential of AI in ODeL, stakeholders must develop and adhere to comprehensive ethical guidelines and frameworks. This paper reinforces the importance of

ongoing research and innovation in integrating AI to enhance STEM education, ultimately preparing students to thrive in a digital and interconnected world.

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Availability of data and material

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REFERENCES

Akavova, A., Temirkhanova, Z., & Lorsanova, Z. (2023). Adaptive learning and artificial intelligence in the educational space. *E3S Web of Conferences*. https://api.semanticscholar.org/CorpusID:265422298

Algerafi, M. A. M., Zhou, Y., Oubibi, M., & Wijaya, T. T. (2023). Unlocking the potential: A comprehensive evaluation of augmented reality and virtual reality in education. *Electronics*. https://api.semanticscholar.org/CorpusID:262097421

Alhawiti, K. M. (2014). Natural language processing and its use in education. *International Journal of Advanced Computer Science and Applications*, 5. https://api.semanticscholar.org/CorpusID:17814728

Amunga, J. (2021). Leveraging technology to enhance STEM education amidst the COVID-19 pandemic: An overview of pertinent concerns. *International Symposium on Information Technology*. https://api.semanticscholar.org/CorpusID:234873511

Anis, M. (2023). Promoting equity and inclusion in online learning environments: Strategies for ensuring access and success for all students. *Proceedings of The 6th International Academic Conference on Teaching, Learning and Education*. https://api.semanticscholar.org/CorpusID:261569516

Baker, R. S., & Inventado, P. S. (2014). Educational data mining and learning analytics: Applications to constructionist research. *Technology, Knowledge and Learning, 19*(1-2), 205-220.

Bescherer, C., Herding, D., Kortenkamp, U., Müller, W., & Zimmermann, M. (2012). E-learning tools with intelligent assessment and feedback for mathematics study. *International Conference on Educational Research and Innovation*. https://api.semanticscholar.org/CorpusID:64157946

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratisation of invention. In J. Walter-Herrmann & C. Büching (Eds.), FabLabs: Of Machines, Makers, and Inventors (pp. 203-224). Transcript Verlag.

Bouhnik, D., & Marcus, T. (2006). Interaction in distance-learning courses. *Journal of the American Society for Information Science and Technology, 57*(3), 299-305.

Bryman, A. (2016). Social Research Methods (5th ed.). London: Oxford University Press.

Bulut, O., & Wongvorachan, T. (2022). Feedback generation through artificial intelligence. *The Open/Technology in Education, Society, and Scholarship Association Conference*. https://api.semanticscholar.org/CorpusID:255122053

Cai, S., Wang, X., Chiang, F. K., & Wu, C. H. (2017). Investigating students' cognitive engagement, motivation and learning achievement in augmented reality-based science courses. *British Journal of Educational Technology, 48*(6), 1612-1625.

Chittum, J. R. (2021). Artificial intelligence and higher education: Promises and perils. In S. Wang, H. Ni, & Y. Zhou (Eds.), Handbook of Research on Educational Technology Integration and Active Learning (pp. 162-181). IGI Global.

Clark, R. C., & Mayer, R. E. (2016). E-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning. Wiley.

Coble, A., Smallbone, A., Bhave, A., Watson, R. J., Braumann, A., & Kraft, M. (2010). Delivering authentic experiences for engineering students and professionals through e-labs. *IEEE EDUCON 2010 Conference*, 1085-1090. https://api.semanticscholar.org/CorpusID:25880741

Crawford, K., Dobbe, R., & Whittaker, M. (2019). AI Now 2019 Report. AI Now Institute.

Creswell, J. W. (2013) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches.* 4th Edition, SAGE Publications, Inc., London.

Das A, Malaviya S, Singh M. (2023). The impact of AI-driven personalisation on learners' performance. *International Journal of Computer Sciences and Engineering, 11*(8), 15-22, doi: 10.26438/ijcse/v11i8.1522
(PDF) AI'S Impact on Vocational Training and Employability: Innovation, Challenges, and Perspectives. Available from: https://www.researchgate.net/publication/382428263_AI'S_Impact_on_Vocational_Training_and_Employability_Innovation_Challenges_and_Perspectives [accessed Jul 24 2024].

Dede, C. (2010). Comparing frameworks for 21st century skills. In J. Bellanca & R. Brandt (Eds.), 21st Century Skills: Rethinking How Students Learn (pp. 51-76). Solution Tree Press.

Denscombe, M. (2014) (5th Ed) *The Good Research Guide*, Maidenhead: Open University Press.

Devi, S., Boruah, A. S., Nirban, S., Nimavat, D., & Bajaj, K. K. (2023). Ethical considerations in using artificial intelligence to improve teaching and learning. *Tuijin Jishu/Journal of Propulsion Technology, 44*(4), 966. https://api.semanticscholar.org/CorpusID:265625075

Ezzaim, A., Dahbi, A., Haidine, A., & Aqqal, A. (2023). AI-based adaptive learning: A systematic mapping of the literature. *Journal of Universal Computer Science*, *29*(10), 1161-1198. https://api.semanticscholar.org/CorpusID:264537152

Fadzil, M., & Munira, T. A. (2008). Applications of artificial intelligence in an open and distance learning institution. *2008 International Symposium on Information Technology*, 1-7. https://api.semanticscholar.org/CorpusID:18713715

Floridi, L., & Cowls, J. (2019). A Unified Framework of Five Principles for AI in Society. *Harvard Data Science Review, 1*(1). https://doi.org/10.1162/99608f92.8cd550d1

Gligorea, I., Cioca, M., Oancea, R., Gorski, A. T., Gorski, H., & Tudorache, P.(2023). Adaptive learning using artificial intelligence in e-learning: A literature review. *Education Sciences, 13*(12), 1216. doi: 10.3390/educsci13121216
(PDF) Digital Methods to Promote Inclusive and Effective Learning in Schools: A Mixed Methods Research Study. Available from: https://www.researchgate.net/publication/382220263_Digital_Methods_to_Promote_Inclusive_and_Effective_Learning_in_Schools_A_Mixed_Methods_Research_Study [accessed Jul 24 2024].

Goel, A. K., & Joyner, D. A. (2017). Using AI to teach AI: Lessons from an online AI class. *AI Magazine, 38*(2), 48-59. https://api.semanticscholar.org/CorpusID:32301079

Grammatikos, N. A., Anagnostopoulou, E., Apostolou, D., & Mentzas, G. (2023). A conversational digital assistant for STEM education. *2023 14th International Conference on Information, Intelligence, Systems & Applications (IISA)*, 1-7. https://api.semanticscholar.org/CorpusID:266234730

Guerra, A. R., de Medeiros, L. F., & Gericota, M. G. O. (2023). A review of immersivity in distance higher education STEM subjects. *International Conference on Immersive Learning Research Network*. https://api.semanticscholar.org/CorpusID:269214983

Harrington, C. (2020). Biometric data and student privacy: Balancing the scales in education. *Journal of Educational Technology Systems, 48*(4), 418-434.

Hatzilygeroudis, I., Koutsojannis, C., Papavlasopoulos, C., & Prentzas, J. (2006). Knowledge-based adaptive assessment in a web-based intelligent educational system. *Sixth IEEE International Conference on Advanced Learning Technologies (ICALT'06)*, 651-655. https://api.semanticscholar.org/CorpusID:10805366

Hooda, M., Rana, C., Dahiya, O., Rizwan, A., & Hossain, M. S. (2022). Artificial intelligence for assessment and feedback to enhance student success in higher education. *Mathematical Problems in Engineering*. https://api.semanticscholar.org/CorpusID:248609337

Hopfenbeck, T. N., Zhang, Z., Sun, S. Z., Robertson, P., & McGrane, J. A. (2023). Challenges and opportunities for classroom-based formative assessment and AI: A perspective article. *Frontiers in Education, 8,* 1270700. https://api.semanticscholar.org/CorpusID:265425669

How, M.-L., & Hung, W. L. D. (2019). Educing AI-thinking in science, technology, engineering, arts, and mathematics (STEAM) education. *Education Sciences, 9*(184), 1- 41. https://api.semanticscholar.org/CorpusID:199125104

Jian, M. J. K. O. (2023). Personalised learning through AI. *Advances in Engineering Innovation*. https://api.semanticscholar.org/CorpusID:266558453

Jung, Y., Kim, H., & Cho, D. (2018). Development of a chatbot with knowledge acquisition capabilities from text-based sources. *Expert Systems with Applications, 113*, 341-354.

Kalyani, D. L. K. (2023). Revolutionizing education: Artificial intelligence's pioneering role in shaping tomorrow's scholars. *International Journal of Multidisciplinary Research in Arts, Science and Technology, 1*(2), 1- 7. https://api.semanticscholar.org/CorpusID:266791058

Kuhail, M. A., Elsayary, A., Farooq, S., & Alghamdi, A. A. (2022). Exploring immersive learning experiences: A survey. *Informatics, 9*, 75. https://api.semanticscholar.org/CorpusID:252612418

Litman, D. J. (2016). Natural language processing for enhancing teaching and learning. *Proceedings of the AAAI Conference on Artificial Intelligence*, *30*(1). https://doi.org/10.1609/aaai.v30i1.9879

Liu, S., Man, S., & Song, L. (2022). An NLP-empowered virtual course assistant for online teaching and learning. *2022 IEEE International Conference on Teaching, Assessment and Learning for Engineering (TALE)*, 373-380. https://api.semanticscholar.org/CorpusID:259157969

Lynch, T., & Ghergulescu, I. (2017). Review of virtual labs as the emerging technologies for teaching STEM subjects. *INTED2017 Proceedings*, 6082-6091. https://10.21125/inted.2017.1422

Maheshwari, I., & Maheshwari, P. (2020). Effectiveness of immersive VR in STEM education. *2020 Seventh International Conference on Information Technology Trends (ITT)*, 7-12. https://api.semanticscholar.org/CorpusID:231681981

Masrek, M. N., Susantari, T., Mutia, F., Yuwinanto, H. P., & Atmi, R. T. (2024). Enabling Education Everywhere: How artificial intelligence empowers ubiquitous and lifelong learning . *Environment-Behaviour Proceedings Journal*, *9*(SI18), 57–63. https://doi.org/10.21834/e-bpj.v9iSI18.5462

McPherson, E., Lister, K., Pearson, V. K., Colwell, C., Gallen, A., & Collins, T. D. (2019). Embedding and sustaining inclusive practices in STEM. *In: 13th International Technology, Education and Development Conference, 11-13 Mar 2019, Valencia, Spain, 2717–2722*. https://api.semanticscholar.org/CorpusID:146084686

Mohammed, P. S., & Watson, E. (2019). Towards Inclusive Education in the Age of Artificial Intelligence: Perspectives, Challenges, and Opportunities. In: Knox, J., Wang, Y., Gallagher, M. (eds) *Artificial Intelligence and Inclusive Education. Perspectives on Rethinking and Reforming Education*. Springer, Singapore. https://doi.org/10.1007/978-981-13-8161-4_2

Mrayhi, S., Khribi, M. K., & Jemni, M. (2023). Ensuring inclusivity in MOOCs: The importance of UDL and digital accessibility. *023 IEEE International Conference on Advanced Learning*

Technologies (ICALT), Orem, UT, USA, 2023, pp. 44-46. doi: https://doi.org.10.1109/ICALT58122.2023.00018

Nagaraj, B. K., Kalaivani, A., Begum, S., Akila, S., Sachdev, H. K., & Kumar, N. S. (2023). The emerging role of artificial intelligence in STEM higher education: A critical review. *International Research Journal of Multidisciplinary Technovation, 5*(5), 1- 19. https://api.semanticscholar.org/CorpusID:261026999

Ndunagu, J. N., Ukhurebor, K. E., & Adesina, A. (2023). Virtual laboratories for STEM in Nigerian higher education: The National Open University of Nigeria learners' perspective. *Proceedings of the Technology-Enhanced Learning in Laboratories workshop (TELL 2023.* https://api.semanticscholar.org/CorpusID:259115588

Ntaba, A., & Jantjies, M. (2019). Open distance learning and immersive technologies: A literature analysis. *16th International Conference on Cognition and Exploratory Learning in Digital Age (CELDA 2019).* https://api.semanticscholar.org/CorpusID:212790590

Nuangchalerm, P. (2023). AI-driven learning analytics in STEM education. *International Journal of Research in STEM Education, 5*(2), 77-84. https://api.semanticscholar.org/CorpusID:267167668

Onesi-Ozigagun, O., Ololade, Y. J., Eyo-Udo, N. L., & Ogundipe, D. O. (2024). Revolutionizing education through AI: A comprehensive review of enhancing learning experiences. *International Journal of Applied Research in Social Sciences, 6*(4), 589-607. https://api.semanticscholar.org/CorpusID:269057776

Patel, H., Vemuri, V. P., Kaur, J., Kumar, G. M. P., Moharekar, T. T., & Chakravarthi, M. K. (2023). Enhancing student support and engagement with natural language processing in academic chatbot's. *2023 10th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, 10, 354-358. https://api.semanticscholar.org/CorpusID:268034035

Patton, M. Q. (2015). *Qualitative Evaluation and Research Methods.* Thousand Oaks, CA: Sage.

Pedra, R. R., Vieira, A. A., Martins, O. F., Silva, P. E. C., & Baldassini, R. S. (2024). Navigating in the digital age: The impact of artificial intelligence on distance learning. *RCMOS - Revista Científica Multidisciplinar O Saber, 1*(1), 1- 4. https://api.semanticscholar.org/CorpusID:269022533

Peters, V. (2014). The impact of virtual reality on perceived anxiety in performing a learning task. *Procedia-Social and Behavioural Sciences, 159*, 427-432.

Picciano, A. G. (2017). The evolution of big data and learning analytics in American higher education. *Journal of Asynchronous Learning Networks, 21*(3), 3-15.

Robert, A., Potter, K., & Frank, L. (2024). The Impact of Artificial Intelligence on Students' Learning Experience. Wiley Interdisciplinary Reviews: Computational Statistics. https://doi.org/10.2139/ssrn.4716747

Roshanaei, M., Olivares, H., & Lopez, R. R. (2023). Harnessing AI to foster equity in education: Opportunities, challenges, and emerging strategies. *Journal of Intelligent Learning*

Systems and Applications, 15(4), 123-143. https://api.semanticscholar.org/CorpusID:265074653

Salazar, O. M., Ovalle Carranza, D. A., & Prieta, F. (2018). Towards an adaptive and personalized assessment model based on ontologies, context, and collaborative filtering. *Distributed Computing and Artificial Intelligence, Special Sessions, 15th International Conference.* DCAI 2018. *Advances in Intelligent Systems and Computing, 801*. Springer, Cham. https://doi.org/10.1007/978-3-319-99608-0_35

Samarakou, M., Papadakis, A. E., Fylladitakis, E. D., Hatziapostolou, A., Tsaganou, G., & Früh, W. G. (2014). An open learning environment for the diagnosis, assistance, and evaluation of students based on artificial intelligence. *International Journal of Emerging Technologies in Learning, 9*(3), 36-44. https://api.semanticscholar.org/CorpusID:9495191

Saul, C., Runardotter, M., & Wuttke, H. D. (2010). Towards feedback personalisation in adaptive assessment. *In Proceedings of the 3rd International Conference on Computer Supported Education* (CSEDU-2011), pages 117-122. https://api.semanticscholar.org/CorpusID:69984192

Siemens, G., & Gasevic, D. (2012). Guest editorial-Learning and knowledge analytics. *Educational Technology & Society, 15*(3), 1-2.

Silva, A. de O., & Janes, D. dos S. (2020). Exploring the role of artificial intelligence in education: A comprehensive perspective. *Review of Artificial Intelligence in Education, 1*(e5). https://api.semanticscholar.org/CorpusID:260909186

Simonson, M., Smaldino, S., Albright, M., & Zvacek, S. (2019). *Teaching and Learning at a Distance: Foundations of Distance Education* (7th ed.). Routledge.

Singh, D., & Ramutsheli, M. P. (2016). Student data protection in a South African ODL university context: Risks, challenges and lessons from comparative jurisdictions. *Distance Education, 37*, 164-179. https://api.semanticscholar.org/CorpusID:58859571

Skjott, L. M. and Korsgaard, S. (2019), "Coding qualitative data: a synthesis guiding the novice", Qualitative Research Journal*, 19*(3), 259-270. https://doi.org/10.1108/QRJ-12-2018-0012

Ungerer, L., & Slade, S. (2022). Ethical considerations of artificial intelligence in learning analytics in distance education contexts. In Learning analytics in open and distributed learning: Potential and challenges (pp. 105–120). Springer.

(2) (PDF) Integración de la inteligencia artificial en la enseñanza universitaria para optimizar el proceso de aprendizaje. Available from: https://www.researchgate.net/publication/380418204_Integracion_de_la_inteligencia_artificial_en_la_ensenanza_universitaria_para_optimizar_el_proceso_de_aprendizaje [accessed Jul 24 2024].

Van der Kleij, F. M., Feskens, R. C. W., & Eggen, T. J. H. M. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. *Review of Educational Research, 85*(4), 475-511.

Vanderbilt, T. (2017). Personalized learning: A compelling research agenda. International Society for Technology in Education (ISTE).

Vavekanand, R. (2024). Impact of artificial intelligence on students and ethical considerations in education. *SSRN Electronic Journal*. https://api.semanticscholar.org/CorpusID:269642311

West, D. M., Goldstein, A., & Candelon, F. (2020). *Artificial Intelligence for Education and Training.* Brookings Institution Press.

Xu, W., & Fan, O. (2022). The application of AI technologies in STEM education: A systematic review from 2011 to 2021. *International Journal of STEM Education, 9*, 1-20. https://api.semanticscholar.org/CorpusID:252370184

Yin, R. (2014). *Case Study Research: Design and Methods* (5th ed.). Thousand Oaks, CA: Sage Publications, Inc.

Zawacki-Richter, O., Marín, V. I., Bond, M., Gouverneur, F., Hämäläinen, R., Pallitt, N., & Nsoga, N. (2019). Deconstructing the Open Distance and e-Learning (ODeL) Environment: A Conceptual Framework for Research and Practice. *Journal of Learning for Development, 6*(3), 245-260.