The Role of Technology in Shaping Online Learning Effectiveness in Engineering Higher Education: A Theoretical Perspective

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Abstract: *The digitization of engineering education is reshaping the design, delivery, and effectiveness of online learning environments. This conceptual paper examines how emerging educational technologies—such as artificial intelligence, immersive technologies, learning analytics, and cloud-based platforms—can be systematically integrated to enhance learning effectiveness in online engineering education. Drawing on an integrative review of contemporary literature and established learning theories, the study proposes a multidimensional framework comprising five interrelated dimensions: technological infrastructure, pedagogical design, user experience design, feedback and learning analytics, and support systems. Grounded in constructivism, connectivism, cognitive load theory, self-determination theory, and activity theory, the framework explains how coordinated technological and pedagogical alignment can improve learner engagement, motivation, collaboration, and performance. By moving beyond tool-centric approaches, the paper offers a theory-driven lens to guide educators, administrators, and policymakers in designing effective and sustainable online engineering learning environments and provides a foundation for future empirical validation.*

Keywords: *Artificial Intelligence in Education, Conceptual Framework, Educational Technology, Learning Theories, Online Engineering Education*

1. INTRODUCTION

The digitalization of higher engineering education has developed since the emergency remote instruction generated by the COVID-19 pandemic. Instead, it is largely reacting to an offensive of repositioning that is triggered by a variety of artificial intelligence developments (AI), immersive technologies (AR/VR/XR) and innovative learning (Sá & Serpa, 2020; Su et al., 2025). While offering more agile, diverse, and future-focused learning experiences is a response to global needs in all educational institutions (Chiu et al., 2021; Radianti et al., 2020), the top paragons are the engineering programs that are required to provide experiential and collaborative design and practical experience digitally.

In particular, online engineering education is integral to national innovation systems. In countries like Germany, Singapore, and India, digital learning expands access to STEM fields and solves skills shortages in Industry 4.0 (Bitkom, 2024; World Economic Forum, 2022a; World Economic Forum, 2022b). It is not only the top institutions incorporating AI-powered systems to provide competency-based training and smart credentialing. This consists of a growing realization of the vital importance of technology-enhanced education for academic standards, employability, and economic competitiveness. Simulation-centric, cloud-based, and predictive technologies have further improved the evolution of engineering programs responding to local infrastructural needs and global educational benchmarks. The idea that our rapidly changing global context requires a theoretical framework to be developed to understand which pedagogical, motivational, and infrastructural learning effectiveness aspects can be amplified by technology.

In contrast to the humanities or management fields, which largely rely on language-based work, engineering education relies on experiential, spatial, and systems-level understanding (Ma & Nickerson, 2006; Radianti et al., 2020). To support it, an internet of things system is required, which includes data collection, cloud-based communication, and data-driven feedback (Heradio et al., 2016; Viberg et al., 2018). In addition, the anticipation about students is in change: as the students of today want customised and easily operable pathways, particularly in terms of User Experience (UX) designs (Ifenthaler & Yau, 2020), and adaptive support systems (Al-Fraihat et al., 2020).

The significance of this study is in the continued redefinition of educational effectiveness in a digital realm, particularly post-pandemic, post-recovery. With increasing global demand for technically literate graduates and increased investment in education technology, the time is ripe for a theoretical grounding in understanding how technology affects learning (Selwyn, 2019; Bates, 2015; Ifenthaler & Yau, 2020). This paper synthesizes multidisciplinary theories (i.e., constructivist, connectivist, and cognitive load theory) to serve as a theoretical framework for the effectiveness of online learning in higher engineering education.

2.   METHODOLOGY

The work in this article employs a conceptual and integrated literature review as its methodology to establish a theory-grounded framework that explains how technology influences online learning effectiveness in engineering higher education. Instead of acquiring new empirical evidence, the purpose is to combine and assimilate divergent, unsystematized theoretical and academic research, allowing the development of a rigorous conceptual framework that can inform future research and practice (Torraco, 2005; Snyder et al., 2019).

The review of literature employed a purposeful and systematic search procedure across the central scientific databases, including Scopus, Web of Science, IEEE Xplore, ERIC database, and Google Scholar. Keywords and search strings included various combinations of online engineering education, educational technology, artificial intelligence in education, learning analytics, virtual/ remote laboratories, learning theories, and online learning effectiveness. This review focused on relatively recent peer-reviewed journal papers, conference reports, and authoritative policy documents (2015–2025) in an attempt to catch up with current state-of-the-art practices. It also included earlier theoretical approaches not related to this time scope, which is conceptually important.

The inclusion criteria were defined for studies that (i) are related to technology-enhanced or online learning in a higher education context, (ii) cover engineering or STEM education and its context, and (iii) presents theoretical/conceptual/ empirical information that supports learning effectiveness, pedagogy, learner

engagement, or instructional design. Furthermore, the study excluded papers that were purely technical or lacked educational relevance, as well as those that focused solely on non-tertiary contexts. Strategic papers and institutional statements were selectively included as references to underpin global/regional advancements in digital engineering education.

Results were extracted from the chosen literature, employing a thematic synthesis method, which involves identifying common ideas, patterns, and relationships across studies. These themes were inductively grouped into the five prevalent dimensions of online learning as described from the literature: technological infrastructure, pedagogical design, user experience design, feedback, learning analytics, and support systems. Finally, existing learning theories (i.e., constructivism, connectivism, cognitive load theory, self-determination theory, and activity theory) were woven with identified dimensions during subsequent cycles to achieve theoretical alignment and explanatory utility (Torraco, 2005; Braun & Clarke, 2006).

The conceptualisation outlined in this paper evolved through a cyclic process of synthesising and abstracting, connecting technological affordances with pedagogical processes, which in turn can be related to learning. This strategy is consistent with established standards for integrative and conceptual reviews, which promote theory building, synthesis, and model generation over empirical generalization. Accordingly, the methodology is suitable for establishing a theoretical framework that can be tested and developed in empirical terms in other educational contexts (Torraco, 2005; Snyder, 2019).

3.   RESULT AND DISCUSSIONS

The following discussions align with the aims of this conceptual paper, which is to investigate how new and emerging technologies can improve online learning effectiveness in engineering education when supported by existing learning theories. Each subsection emphasizes not only the individual contribution of particular technologies and theoretical perspectives, but also their interaction within an integrated, multidimensional framework.

3.1   EMERGING TECHNOLOGIES IN ENGINEERING ONLINE EDUCATION

The revolution of engineering education online is possible due to the adoption of innovative technologies. Whole-class pedagogical methods can be replicated, and in some cases amplified, by these tools. This section describes specific categories of new technologies that have entered the learning space within engineering education.

Virtual Simulations and Remote Laboratories

In virtual simulations and remote laboratories, learners interact with a dynamic representation of a real-world system, despite any spatial and time limitations. These instruments are fundamental in fields requiring more sophisticated manipulation, such as heat and heat transfer, electronics, or fluid mechanics (Ma & Nickerson, 2006; Radianti et al., 2020). Remote labs also cover cooperative knowledge discovery and allow students to experiment with real hardware from remote places (Heradio et al., 2016; Gustavsson et al., 2009; Radianti et al., 2020). For instance, tools such as Labster and iLabs have been heavily utilized in engineering education for experimental-based learning

Immersive Technologies: AR/VR/XR

It has been proved that these immersive technologies (Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (XR)) help student in engaging, in developing the spatial reasoning, and in understanding abstract concepts in mechanics, structural analysis, and electronics (Radianti et al., 2020; Alhalabi, 2016). XR's ability in allowing students to take apart machines in a virtual space, simulate physical forces, and get their hands on potentially dangerous tasks safely, is a fundamental difference. Real-scale 3D visualizations of complex systems also make it possible to maintain better design thinking and prototyping (Ibáñez & Delgado-Kloos, 2018; Radianti et al., 2020).

Artificial Intelligence and Adaptive Learning Systems

Artificial Intelligence (AI) helps to personalize education with intelligent tutoring systems (ITS), natural language processing, and machine learning feedback. These systems adapt difficulty, give users immediate hints, and identify weaknesses in learning (Woolf, 2009; Chen et al., 2020). AI-based learning platforms such as Squirrel AI and Assessment and Learning in Knowledge Spaces (ALEKS) have shown the efficiency of learning can be

improved remarkably by providing propositional pathways to be followed by students according to the analysis of their profiles (Madhu et al., 2024; Mojarad etal., 2018).

Learning analytics and performance dashboards
Learning analytics tools record fine-grained student engagement, behavior, or academic improvement data. Real-time dashboards allow teachers and students to have a view of when to intervene and personalized feedback (Ifenthaler & Yau, 2020). Advanced analytics can predict dropout, failure, and low performance and encourage instructional redesign (Viberg et al., 2018). This is especially useful for large online engineering classes, where tracking individual students is difficult.

Learning Platforms and Collaboration Tools on the Cloud
Online engineering education is scalable, accessible, and interoperable due to cloud technologies. Platforms include Google Workspace, GitHub, and Microsoft Teams, which support sharing, documentation, versioning, coding collaboration, as well as instant communication (Sultan, 2010). Cloud-based IDEs and simulation tools, which enable all design, testing, and debugging to be performed simultaneously, are ideas that engineering PBL products should consider (Verner et al., 2024; Suansokchuak & Piriyasurawong, 2025). They introduce higher degrees of loose coupling and are more independent of high-end workstation resources.

In other words, the integration of technology and engineering education addressed logistical and access issues, transforming cognitive relationships in a blended learning environment. Artificial intelligence-based teaching assistants and virtual worlds for immersive reality are technologies that suggest constructivist pedagogy; the student learns by acting on the world rather than being acted upon, and these promises to be a significant shift in education. These advances have provided numerous new pedagogical opportunities for engineering educators seeking to shift away from lecturing and be more in touch with the individual student's learning experience, along with continuous formative assessment (Bond et al., 2020).

Collaboration tools that facilitate interactivity and real-time feedback have also transformed the way engineering students interact with courses and their colleagues. Web tools like GitHub and Onshape facilitate code collaboration

and the development of cloud-native spaces for working on industry-relevant challenges, enabling students to apply theory in practice (Verner et al., 2024). There are several case studies that account for the growing force of new-age technologies. For instance, the Taiwanese model was employed to predict potential dropouts using a deep learning tool, enabling staff to selectively intervene at an early stage and ultimately achieve increased retention (Shiao et al., 2023). State-of-the-art AR and VR infrastructure, for example, as provided by the Visualisation Lab at the University of Queensland (University of Queensland VisLab, 2025), offers potential to further develop spatial awareness in engineering students. These examples show that technology is not only a tool, but also has the potential to bring about changes in the pedagogy of engineering. When used in combination with data-driven evaluations, these tools enable a continuous curriculum development process that's responsive to the evolving requirements of students and industry.

3.2 THEORETICAL FOUNDATIONS SUPPORTING TECHNOLOGICAL INTEGRATION

The successful implementation of new technologies in teaching engineering will always rest upon a sound pedagogical base. Merely having technology tools does not ensure that learning will improve; it needs to be integrated into teaching based on legitimate learning theories to guide instruction, learner engagement, and assessment. Five key theoretical perspectives— Constructivism, Connectivism, Cognitive Load Theory, Self-Determination Theory, and Activity Theory—that can enable strategic application of educational technologies in online engineering are presented in this section to frame the discussion.

Constructivism
According to the constructivist view, learning learners are knowledge builders who construct knowledge from their environment, experience, and social context. In engineering education, this can correspond to hands-on, inquiry-based learning using virtual simulations, augmented and virtual reality (AR/VR), and remote laboratories. Such resources offer learners a 'real' workspace which is interactive, where they can experiment, change values, and be informed immediately - all being features central to constructivist learning (Jonassen & Rohrer-Murphy, 1999; Vygotsky & Cole, 1978). Such tools generate deeper cognitive processing, generally or at least when spatial or procedural understanding is a topic.

Connectivism

Siemens' (2005) Connectivism does explain the nature of learning in the digital era. It posits that knowledge is in the networks and learning is the ability to traverse, connect, and grow the networks. For example, online engineering education can be found in cloud devices and applications, coding collectively, a digital library, and a peer forum. These technologies let students co-create knowledge, reach off-site experts, and work realistically to solve problems (Downes, 2012). Connectivism reinforces the central place of the digital inter-connections in contemporary engineering pedagogy.

Cognitive Load Theory (CLT)

Cognitive Load Theory (Sweller, 1994) asserts that education design should be directed at overcoming the restrictions of working memory. Therefore, technology-supported learning environments must reduce extraneous cognitive load and exploit the benefit of germane processing related to schema construction. Engineering education with its numerous complex systems and calculations, interface design in simulations, dashboards, and multimedia resources, requires a cognitively efficient design, to which measure theory can contribute. With well-designed platforms, load can be moderated, enabling students to better absorb complex engineering concepts (Sweller, 2005).

Self-Determination Theory (SDT)

Self-Determination Theory emphasizes the development of intrinsic motivation by fulfilling three psychological needs: autonomy, competence, and relatedness (Ryan & Deci, 2000). Web portals providing personalized learning environments, self-regulation, adaptive assessment, and feedback or control over the lifelong learning process could exist. In the case of engineering education, such systems deliver tailored instruction, support for setting goals, and access to authentic relationships with the faculty and other students, particularly in ways that foster greater engagement and retention. These tools have especially motivational significance in self-paced or blended online courses.

Activity Theory

As Activity Theory (Engestrom, 2014) has observed, learning is mediated by design, which in turn is mediated by tools, communities of practice, and goals. This is particularly appropriate when working collaboratively online and students co-iterate digital artifacts (such as Computer-Aided Design/simulation models) with peers and tutors towards problem-solving in engineering. By

considering these two types of interactions, the Activity Theory provides guidelines for reflecting on how a given technology functions as a mediator, as well as general aspects to consider when thinking about the impact that a particular technology has on education. It also extends the impact of technological change or innovation on the broader learning system, highlighting the importance of relationships among learners, tools, and context.

Taken together, these theories provide a solid foundation for integrating technology in engineering education. They also need to be both technologically and pedagogically strong so that the tools foster deep learning, motivation, and collaboration.

Furthermore, this integration can serve as a second level on which each of these learning theories can leverage technologies. One such example is self-determination theory, which proposes the use of AI-enhanced learning platforms that adjust task difficulty based on learner performance; others have also included discussions of motivation or affect within their framework. At the same time, they progress through content at a pace that is appropriate for them. Similar to other constructs such as personal learning environments and personal learning networks, connectivism emphasizes the importance of many point-to-point virtual links - from peer discussion boards to distant experts' consultations - in a self-stabilizing continuum of nodes supporting an entire lifelong modulus of connected experiences. These theoretical perspectives not only legitimize but also promote the use of multiple technologies to address learners' varied cognitive and affective needs (Ryan & Deci, 2000; Siemens, 2005).

3.3. THEORETICAL FRAMEWORK: THE ROLE OF TECHNOLOGY IN EFFECTIVE ONLINE LEARNING

Most models of online learning effectiveness have emphasized single dimensions (such as information technology applications, learning management systems, or pedagogical strategies) in isolation. Approaches, which further belong to a specific model, such as technology adoption frameworks emphasizing tools or learning management system (LMS)-led instructional designs, constitute useful attempts at dissecting the practices. However, these are often partial affairs and do not address how interdependent

and systemic reforms apply to online engineering education. Alternatively, the model presented in this paper contributes to the literature by conceptualizing technological infrastructure, pedagogical design, user experience design, feedback, and learning analytics as mutually reinforcing dimensions built on contemporary learning theories. Through explicit connections of technological affordances to pedagogical mechanics and motivational and cognitive theories, the model provides a comprehensive, theory-based perspective that extends beyond fragmented or tool-oriented views. This integration is crucial in the context of engineering education, where experiential learning, teamwork, and systems thinking are key measures of learning effectiveness within digital spaces.

A model, informed by the latest theories in learning and research on education technology, is proposed to study the impact of emerging technologies on online learning outcomes in distance engineering education. In this model, as illustrated in Figure 1, five interconnected layers of the ed-tech landscape are addressed that ultimately enhance learning effectiveness: technology infrastructure, pedagogical design, user experience design, feedback & learning analytics, and support systems.

Uniform two-way arrows between each pair of the six elements indicate that there is some synergistic action and bi-directional interdependence. In other words, each dimension adds not only to the effect that online learning as a whole has on quality teaching and student outcomes, but also to how all other dimensions interact, allowing for an integrated and consistent overall model where each piece contributes to its total effectiveness.

The technology architecture utilizes AI, cloud computing platforms, and virtual simulation to create dynamic and scalable environments (Chen et al., 2020; Sultan, 2010).These are the technologies on which the content, interaction, and personalization are based.

The pedagogical design is the implementation of teaching strategies based on constructivist and authentic learning. Well-structured learning modules contain context-based learning tasks, project-based learning, and cooperative learning which contribute to deep understanding (Jonassen & Rohrer-Murphy, 1999; Vygotsky & Cole, 1978).

User experience design promotes intuitive navigation and accessibility, reducing cognitive load to enhance student engagement and retention (Sweller, 1994; Sweller, 2005). Good UI/UX design is also important in providing effective use of learning content.
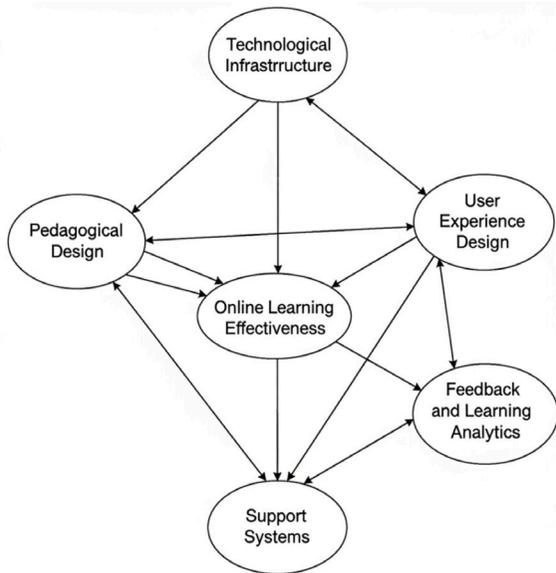

Figure 1. Conceptual model of technology's role in online learning effectiveness

Feedback and analytics for learning are the paramount data-driven views of student accomplishment. Dashboards, teaching, and real-time analytics enable teachers to provide more personalized support and interventions (Ifenthaler & Yau, 2020; Viberg et al., 2018).

The help desk, peer mentors, and teacher presence form a system of support that fosters belonging and motivation in students, as outlined by the self-determination theory (Ryan & Deci, 2000). Additionally, there were the academic and social-emotional needs that students needed to continue progressing.

Notably, the proposed framework suggests that these five dimensions do not work in isolation, but rather as an integrated whole, to influence the effectiveness of online learning. The technological infrastructure supports content and interaction delivery; however, its educational potential is only activated in the presence of best practice design principles from learning theories based on constructivist and activity-based learning. User experience design regulates learners' cognitive processing at the work level by minimizing extraneous cognitive load and initiating pedagogical strategies that are functional. Feedback and learning analytics provide ongoing data-driven feedback to support the principles of instructional adjustment and learner self-regulation, grounded in theories of cognitive load and self-determination. Facilitating factors, such as perceived teacher's virtual presence and peer support in professional networks, are positive influences on motivation and relatedness, which result in retention and involvement within the online engineering environment. The model addresses effectiveness in online learning as an outcome of alignment and infusion, rather than solely based on a single attribute, through these fledgling relationships.

This model of integration provides a lens for understanding how each of these dimensions interacts in response to learners' technology needs, preferences for learning with technologies, and comfort levels when using these technologies in online communities of practice supporting engineering education.

Observable examples of this success include increased student engagement levels, higher completion rates, and the practical application of new learning in ongoing situations. There is also evidence in certain institutions that have integrated the teaching, where students' satisfaction improved after involving all five layers of the model. In addition, it is possible to tailor the use of scales within different institutional settings, ranging from large public university campuses to smaller private technical campuses. This is one of the significant advantages of flexibility- it not only does not sacrifice logical integrity for one model, but also brings convenience to multiple scene applications (Chen et al., 2020).

The proposed conceptual, technical, and pedagogical framework generalizes and advances previous inquiry into learning effectiveness in e-learning by combining technological, pedagogical, cognitive, and motivational viewpoints

into a system-based view of how effectiveness in online learning emerges from holistic, dynamically interactive relationships among these dimensions. This inferential way of thinking has clear relevance in education for engineering, where the properties of separate technological elements must be surpassed through activities in which experience is gained, teamwork takes place, and system perspectives are acquired. Therefore, it is a structured and flexible analysis endoscope that can promote empirical validation and practical application in various online engineering contexts.

3.4. IMPLICATIONS FOR STAKEHOLDERS

Engineering education constituents and actors in the online learning space may draw on this model for change. Educators can even re-imagine their engineering education curriculum by transporting learners into immersive simulations, providing them with AI-driven, adaptive, and personalized learning experiences, as well as real-time learning analytics. These are experience-based personalized learning tools that support the development of knowledge and experiences by building on constructivist and cognitive theories (Jonassen & Rohrer-Murphy, 1999; Sweller, 2010). Teachers can also do more than just be glorified video lecturers; they can utilize collaborative spaces, virtual labs, and problem-based learning.

Administrators are urged to commit now to invest in strong digital resources (e.g., access to high-speed internet, cloud-based learning environments, and secure LMS) immediately. Also critical is the creation and deployment of sustained professional development, as well as support for faculties to effectively adopt, adapt, and scale new technologies (Chen et al., 2020; Sultan, 2010). Being institutionally prepared and digitally resilient will become increasingly important in our ability to continue regular academic business from all perspectives before this is all over.

Policy makers are required to concentrate on the equitable access to online learning. This can be done by bridging the digital divide through the provisioning of low-end devices and improving access to the internet in remote areas, creating a data privacy and cybersecurity policy. National and sub-national policies need to encourage digital pedagogical innovation via financing or accreditation mechanisms (UNESCO, 2021).

The framework can serve as a launching point and point of and reference point for scholars who, through empirical work, will work on its validation in various cultural, geographical and institutional settings. It may be useful in future studies to investigate what combination of technologies results in the greatest improvement in learning outcomes, engagement and retention in STEM disciplines.

In general, this framework proposes a compass for stakeholder engagement (all contributing to quality of education), guiding the technological transformation of engineering education to be inclusive, to become sustainable, and to be empirically driven.

Other approaches include establishing centres of excellence through the institutions for education on digital engineering, offering training, benchmarking, and innovation support. These centres would also operate as hubs for linking administrative policies with pedagogical practices, thereby enabling the organizational embedding of technology within teaching and learning (Selwyn, 2019).

3.5. CHALLENGES AND FUTURE DIRECTIONS

Although there is great potential in the emerging technologies for the engineering education, there are several bottlenecks that must be overcome before the emerging technologies can be fully utilized.

Challenges
Digital inequality: Rural or low-income students are frequently faced with unreliable internet, insufficient devices or technical support, thus becoming excluded from technology-enhanced learning (van Dijk, 2020).

Faculty Readiness and Resistance: Several lecturers find it challenging to integrate advanced tools as their digital literacy is low or because they are skeptical about online learning being effective (Aldhilan et al., 2025).

Data and Privacy and Ethical Issues: AI systems and learning analytics prompt discussion of ethical issues, surveillance, consent, and data misuse (Slade & Prinsloo, 2013; UNESCO, 2021).

Pedagogic alignment: The pace of technological development can often lead to a mismatch between the developments of effective pedagogical models that align with the functionalities of a tool (Bond et al., 2019).

Future Directions
Empirical Verification: Researchers in the future should carry out validation of the conceptual framework in diverse regions, a variety of disciplines among practitioners, as well as different types of educational institutions.

Interdisciplinary collaboration: Closer cooperation between educators, technologists, and instructional designers is a prerequisite of developing adaptive, student-centered platforms.

Policy and Governance: Regulatory bodies need to formulate agile policies which include all stakeholders so that AI can be used responsibly and equitably, and there are checks on the quality of online engineering education.

Lifelong Learning and Micro credentials: The Organization for Economic Co-operation and Development (OECD) spoke of upskilling and seeking retraining as lifelong concerns (OECD, 2019). Modules from courses centered on Education and Training Delivery using the User Interface (UI) are supported by AI (Artificial Intelligence), which could save our industry at an individual level.

This section challenges those in the field not to see this as a limitation, but rather as an opportunity to build new and innovative models that will ensure online engineering education works for all students, is inclusive, effective, and ethically centered.

As these challenges persist, future research should also investigate the ethical and social concerns, as well as the possible psychological impacts, of prolonged digital learning in engineering-based subjects. Evidence based on digital fatigue, learning equity, and inclusivity studies in online platforms will justify using the tool as a means to diversify it. Furthermore, developing longitudinal research designs to investigate the longevity of learning outcomes in digital and hybrid spaces can provide richer descriptions of what occurs over time with such technologies (Slade & Prinsloo, 2013; van Dijk, 2020).

Because this is a conceptual and theory-based article, there is no empirical data collection or statistical validation. Accordingly, the model does not claim immediate generalisability in all institutional and cultural settings. Instead, it offers an analytic construct rooted in established theories of learning and current literature on educational technology. The utility and efficacy of the framework may depend on context-specific institutional readiness, technological infrastructure, disciplinary focus, and learner types. These limitations suggest a need for further empirical studies to test, refine, and validate the framework in a wide variety of engineering education environments (institutional contexts, delivery mechanisms, and locations).

4.   CONCLUSION

Finally, advances in technology have made advanced engineering education possible: learners have never before been so close to the content, their peers, or their teachers. Building on the earlier examples, we argue that AI-based platforms contain an analysis engine that can read hundreds of students' assignments and perform other tasks on their behalf. Virtual Reality simulations will give students the ability to view ideas in a way they were previously unable to. Good online learning can be highly immersive. Learning analytics may include evaluating the effectiveness and quality of online learning as measured against established benchmarks. Based on strong theoretical foundations, such as constructivism, cognitive load theory, self-determination, and activity theory, a taxonomy of concept sets emerges, with its combination illustrating that pedagogic design, user experience, feedback, and institutional support are all significant in serving students.

Good online learning is not just about technology, but rather the strategic intersection and integration of technology with instructional design and a level playing field. As the field expands, a constellation of developing challenges continues to face all stakeholders interested in online learning – educators, school administrators, policymakers, and researchers – around topics such as digital divides, faculty readiness, and data usage ethics. It is fundamental to integrate technological development with pedagogical integrity and inclusive practices to educate future engineers for an ever-more digital world.

This article offers a new theory-grounded framework that connects new technologies with fundamental learning concepts to inform educators, designers and policy makers. Consideration of the model's practical implementation in a local context requires further research to fully conceptualize; However, the model can be employed globally and contributes to scholarly knowledge and practical advice on improving online engineering education. This framework should be empirically tested in the future with respect to its applicability in different educational settings and fields of study.

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7. AUTHORS' CONTRIBUTION

Thomas P J conceived the study, designed the work, and wrote the manuscript. The principal supervisor, Hieng Ho LAU, provided academic guidance throughout the project, helped refine the conceptual structure, and reviewed the manuscript critically. Dr. Bibiana Lim Chiu-Yiong as co- supervisor actively contributed to address the reviewers' major comments. Ajay KAPOOR, as associate supervisor, validated the theoretical constructs and also provided technical help. All authors provided constructive feedback that shaped the research from design to analysis and the manuscript.

8.   CONFLICT OF INTEREST DECLARATION

This is an original work of those authors and co-authors, all rights reserved. It is not under concurrent consideration elsewhere and has not been published previously. The authors have independently developed and executed the entire manuscript. The authors declare that the present work has not been in any stage of the scientific publication process, and there is no conflict of interest regarding the financial sources or other aspects. We also declare the originality and truth of the data provided for consideration by the International Journal of e-Learning and Higher Education (IJELHE).

9.   REFERENCES

Aldhilan, D., Afzal, A., & Gul, F. (2025). *The digital learning paradox: Enhancing engagement without eplacing educators. Gomal University Journal of Research, 41(2),* 129–142. https://doi.org/10.51380/gujr-41-02-02

Al-Fraihat, D., Joy, M., Masa'deh, R. E., & Sinclair, J. (2020). *Evaluating e-learning systems success: An empirical study. Computers in Human Behavior, 102,* 67–86. https://doi.org/10.1016/j.chb.2019.08.004

Alhalabi, W. (2016). *Virtual reality systems enhance students' achievements in engineering education. Behaviour & Information Technology, 35(11),* 919–925. https://doi.org/10.1080/0144929X.2016.1212931

Bates, A. W. (2015). *Teaching in a digital age: Guidelines for designing teaching and learning. Tony Bates Associates Ltd.* https://opentextbc.ca/teachinginadigitalage/

Bitkom. (2025, April 8). *Skills shortage: Three out of four companies train employees for Industry 4.0. Heise Online.* https://www.heise.de/en/news/Skills-shortage-three-out-of-four-companies-train-employees-for- Industry-4-0-10344000.html

Bond, M., Zawacki-Richter, O., & Nichols, M. (2019). Revisiting five decades of educational technology research: A content and authorship analysis of the British Journal of Educational Technology. British Journal of Educational Technology, 50(1), 12–63. https://doi.org/10.1111/bjet.12730

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: A review. IEEE Access, 8, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510

Chiu, T. K. F., Lin, T.-J., & Lonka, K. (2021). Motivating online learning: The challenges of COVID-19 and beyond. The Asia-Pacific Education Researcher, 30(3), 187–190. https://doi.org/10.1007/s40299-021-00566-w

Downes, S. (2012). Connectivism and connective knowledge: Essays on meaning and learning networks. National Research Council Canada. https://www.downes.ca/files/books/Connective_Knowledge-19May2012.pdf

Engeström, Y. (2014). Learning by expanding: An activity-theoretical approach to developmental research (2nd ed.). Cambridge University Press. https://doi.org/10.1017/CBO9781139814744

Gustavsson, I., Nilsson, K., Zackrisson, J., Garcia-Zubia, J., Hernandez-Jayo, U., Nafalski, A., Nedic, Z., Gol, O., Machotka, J., Pettersson, M. I., & Lago, T. (2009). On objectives of instructional laboratories, individual assessment, and use of collaborative remote laboratories. IEEE Transactions on Learning Technologies, 2(4), 263–274. https://doi.org/10.1109/TLT.2009.42

Heradio, R., de la Torre, L., Galan, D., Cabrerizo, F. J., Herrera-Viedma, E., & Dormido, S. (2016). Virtual and remote labs in education: A bibliometric analysis. Computers & Education, 98, 14–38. https://doi.org/10.1016/j.compedu.2016.03.010

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. Computers & Education, 123, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Ifenthaler, D., & Yau, J. Y. K. (2020). Utilising learning analytics to support study success in higher education: A systematic review. Educational Technology Research and Development, 68(4), 1961–1990. https://doi.org/10.1007/s11423-020-09788-z

Jonassen, D. H., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. Educational Technology Research and Development, 47(1), 61–79. https://doi.org/10.1007/BF02299477

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: A comparative literature review. ACM Computing Surveys, 38(4), Article 7. https://doi.org/10.1145/1132960.1132961

Madhu, N., Latha, P., & Savitha, N. (2024). Revolutionizing education: Harnessing AI for personalized learning pathways and student success. International Journal for Multidisciplinary Research, 6(5). https://doi.org/10.36948/ijfmr.2024.v06i05.28371

Mojarad, S., Essa, A., Mojarad, S., & Baker, R. S. (2018). Studying adaptive learning efficacy using propensity score matching. In Companion proceedings of the 8th International Conference on Learning Analytics and Knowledge (LAK '18) (pp. 5–9). Society for Learning Analytics Research. https://learninganalytics.upenn.edu/ryanbaker/LAK18-Shirin-PSM-FINAL.pdf

OECD. (2019). *Getting skills right: Future-ready adult learning systems. OECD Publishing.* https://doi.org/10.1787/9789264311756-en

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147,* 103778. https://doi.org/10.1016/j.compedu.2019.103778

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55(1),* 68–78. https://doi.org/10.1037/0003-066X.55.1.68

Sá, M. J., & Serpa, S. (2020). The COVID-19 pandemic as an opportunity to foster the sustainable development of teaching in higher education. *Sustainability, 12(20),* 8525. https://doi.org/10.3390/su12208525

Selwyn, N. (2019). *Should robots replace teachers? AI and the future of education. Polity Press.*

Shiao, Y.-T., Chou, Y.-H., Chen, C.-H., Wu, K.-F., & Wu, T.-N. (2023). Reducing dropout rate through a deep learning model for sustainable education. *Smart Learning Environments, 10(1),* Article 6. https://doi.org/10.1186/s40561-023-00274-6

Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning, 2(1),* 3–10. http://www.itdl.org/Journal/Jan_05/article01.htm

Slade, S., & Prinsloo, P. (2013). Learning analytics: Ethical issues and dilemmas. *American Behavioral Scientist, 57(10),* 1510–1529. https://doi.org/10.1177/0002764213479366

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104,* 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Su, M., Ma, L., Zhang, D., Yunusa-Kaltungo, A., & Cheung, C. (2025). *Exploring benefits and concerns of incorporating digital tools into engineering education. European Journal of Education and Pedagogy, 6(1), 45–51. https://doi.org/10.24018/ejedu.2025.6.1.909*

Suansokchuak, P., & Piriyasurawong, P. (2025). *A conceptual framework for integrating design thinking with engineering learning in cloud ecosystems. International Journal of Environmental Sciences, 11(13s), 230–239. https://doi.org/10.64252/mv37g134*

Sultan, N. (2010). *Cloud computing for education: A new dawn? International Journal of Information Management, 30(2), 109–116. https://doi.org/10.1016/j.ijinfomgt.2009.09.004*

Sweller, J. (1994). *Cognitive load theory, learning difficulty, and instructional design. Learning and Instruction, 4(4), 295–312. https://doi.org/10.1016/0959-4752(94)90003-5*

Sweller, J. (2005). *Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 19–30). Cambridge University Press. https://doi.org/10.1017/CBO9780511816819.003*

Sweller, J. (2010). *Element interactivity and intrinsic, extraneous, and germane cognitive load. Educational Psychology Review, 22(2), 123–138. https://doi.org/10.1007/s10648-010-9128-5*

Torraco, R. J. (2005). *Writing integrative literature reviews: Guidelines and examples. Human Resource Development Review, 4(3), 356–367. https://doi.org/10.1177/1534484305278283*

UNESCO. (2021). *Reimagining our futures together: A new social contract for education. UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000379707*

University of Queensland VisLab. (2025). *Equipment and tools. https://adp.uq.edu.au/VisLab/equipment-and-tools*

van Dijk, J. A. G. M. (2020). *The digital divide. Polity Press.*

Verner, I., Cuperman, D., & Mueller, M. (2024). *Student learning of engineering systems through simulation-based design using Onshape and Blender. Procedia Computer Science, 232, 2950–2958. https://doi.org/10.1016/j.procs.2024.02.111*

Viberg, O., Hatakka, M., Bälter, O., & Mavroudi, A. (2018). *The current landscape of learning analytics in higher education. Computers in Human Behavior, 89, 98–110. https://doi.org/10.1016/j.chb.2018.07.027*

Vygotsky, L. S., & Cole, M. (1978). *Mind in society: Development of higher psychological processes. Harvard University Press.*

Woolf, B. P. (2009). *Building intelligent interactive tutors: Student-centered strategies for revolutionizing e-learning. Morgan Kaufmann. https://doi.org/10.1016/B978-0-12-373594-2.X0001-9*

World Economic Forum. (2022a, March 7). *Asian workers pushed to upskill as pandemic quickens digital shift. World Economic Forum.https://www.weforum.org/stories/2022/03/asian-workers-pushed-to-upskill-as-pandemic-quickens-digital-shift/*

World Economic Forum. (2022b, October 7). *Education 4.0 India report highlights solutions to strengthen digital infrastructure for learning in India. World Economic Forum. https://www.weforum.org/press/2022/10/education-4-0-india-report-highlights-solutions-to-strengthen-digital-infrastructure-for-learning-in-india/*