Journal of Engineering Education Transformations, Volume 39, February 2026, Special Issue 3, eISSN 2394-1707

10.16920/jeet/2026/v39is3/26101

How the AI-Powered Metaverse Education Enhances Innovation and Commercialisation Skills for Computer Engineering Students: A Survey from the MENA region

Mostafa Mohamad[1], Dababrata Chowdhury[2], Sayed Eldebeky[3], Petr Svoboda[4], Georgina Farouqa[5], Laith Hiasat[6]

[1]Associate Professor of Digital Innovation & Analytics, Zayed University, College of Interdisciplinary Studies, Abu Dhabi, UAE (0000-0001-7172-1110)

[2]Associate Professor of Entrepreneurship and Knowledge Management, Ravensbourne University London (0000-0002-3117-3997)

[3]Assistant Professor and Learning Resources Librarian, Zayed University, Dubai, UAE (0000-0002-2917-3488)

[4]Senior Lecturer, Faculty of Business Management, Emirates Aviation University, Dubai, United Arab Emirates (0000-0001-9292-0039)

[5]Emirates Aviation University, Dubai, United Arab Emirates (0000-0001-7986-6381)

[6]Graduate Teaching and Research Assistant, Mechanical and Industrial Engineering Department, Rochester Institute of Technology (0000 0002 0276 3269)

[1]mostafa.mohamad@zu.ac.ae [2]d.chowdhury@rave.ac.uk [3]sayed.mahmoud@zu.ac.ae [4]petr.svoboda@eau.ac.ae [5]georgina.farouqa@eau.ac.ae [6]laithhiasat@gmail.com

***Abstract*— This paper examines the impact of AI-Powered Metaverse Education Ecosystem (AIME) on the innovation and commercialisation skills of computer engineering students (CES) in the Middle East and North Africa (MENA). This kind of environment gives CES a rich, hands-on experience that connects classroom learning with real-world innovation and commercial opportunities. Using a risk-free 3D virtual space, it recreates complex engineering challenges, enabling students to work together to design, prototype, and test ideas instantly, speeding up the path from concept to creation. Within this metaverse, AI-powered analytics tailor the learning journey to each student, helping them build advanced skills in software architecture, embedded systems, and AI integration, while also sparking an entrepreneurial mindset.**

Based on the Entrepreneurial Self-Efficacy (ESE) theory, the authors developed a framework that examines the following four assumptions that guide the study. *First*, students describe performance mastery experiences in AIME. *Second*, Vicarious learning (observing peers/mentors in metaverse labs) contributes to clearer mental models of commercialisation pathways, were AI agents model decision trade-offs. *Third*, AI-driven formative feedback transforms ambiguous failure into concrete learning actions, thereby accelerating the translation of technical ideas into market-oriented prototypes. And *fourth*, affordances of embodiment and artifact manipulation in the metaverse surface tacit commercialisation knowledge (e.g., cost trade-offs, user pain points) that students rarely experience in conventional labs.

To gauge educators' perspectives on the use of the Metaverse in education, the study employs a qualitative research approach, including an extensive survey of 300 participants from Academics serving in 8 Middle Eastern countries.

Our findings show that CES students can accelerate the innovation cycle by collaborating to design, prototype, and test solutions in real time while simulating challenging engineering problems in a 3D virtual environment. Additionally, AIME can simulate start-up ecosystems, enabling students to engage in virtual pitch competitions, market analysis, and product lifecycle simulations. AI tutors provide instant feedback on technical feasibility, user experience design, and cost optimisation, helping students connect engineering excellence with market viability. Moreover, the metaverse facilitates global collaboration, allowing students to co-create with peers, industry mentors, and potential investors from different regions, fostering cross-cultural innovation strategies.

Keywords*— *AI-Powered Metaverse, Metaverse Educational Ecosystem, Computer Engineering `Education, Entrepreneurship and Commercialisation Skills

***JEET Category*—Research**

I. INTRODUCTION

This study investigates how an AI Powered Metaverse Education Ecosystem (AIME) can strengthen computer engineering students' (CES) innovation and commercialization capabilities across the MENA region. AIME's authentic and risk-free 3D worlds bring together the potential of virtual prototyping, artificial intelligence, and analytics and feedback. This helps to accelerate the path from idea to market-ready stories and artifacts, such as pitches, compliance dossiers, and Technology Readiness Levels roadmaps. The study's objectives are to explore the potential of AIME's educational and technical capabilities to build entrepreneurial self-efficacy, and to explore the contextual factors that can impact the transfer of skills in higher education in the MENA region, including bandwidth, delivery languages, gender, and industry connections.

The work addresses salient gaps. Prior scholarship has primarily emphasized immersion, motivation, and generic personalization in metaverse learning, while offering limited evidence on commercialization fluency, pricing logics, compliance navigation, investor ready storytelling, and on how AI specifically accelerates these pathways in engineering programs. The authors identify a persistent “idea to market” gap and a lack of regionally attuned cases/tools that bind engineering choices to unit economics, regulatory constraints, and user value within metaverse workflows.

Entrepreneurial Self-Efficacy (ESE) is the underlying theory. It specifies the process in terms of four interaction mechanisms: mastery experiences, vicarious experiences, AI-based feedback, and embodiment-artifact manipulation. They are the proposed mediators between AIME adoption and commercialization outcomes such as the design of the value proposition, TRL/pilot planning, pricing, and compliance awareness. This is because the above perspective illustrates how telemetry, scenario-driven stress testing, and tweaking digital twins transform vague failure modes into clear action plans and sustain the entrepreneur's self-confidence.

In terms of methods, an exploratory qualitative survey of 300 engineering educators across eight countries in the MENA region provides broad insight. Reflexive thematic analysis structures coding and interpretation, emphasizing transferability rather than statistical inference.

Key findings show consistent activation of all ESE mechanisms. Educators report time compressed, safe to fail build–measure–learn cycles; avatar mediated observation that raises standards; counterfactual, next step clarity from AI tutors; and tacit insight from manipulating digital twins (e.g., BOM trade-offs, ergonomics, privacy by design, regional compliance). Salient term frequencies (“AI,” “digital twin,” “pitch,” “compliance”) reinforce the commercialization focus of AIME enabled learning. Contextual factors, bandwidth/device access, multilingual options, gender dynamics, and industry partnerships, emerge as decisive enablers or constraints.

The study contributes (i) an ESE centered framework that ties AI metaverse affordances to entrepreneurial capability building; (ii) one of the largest qualitative educator datasets in MENA on AI metaverse pedagogy; and (iii) design implications, regional compliance checkers, manufacturability simulators, culturally relevant case libraries, transparent AI governance, and low bandwidth modes, that reposition the metaverse from “immersive novelty” to a commercialization gym for engineering education.

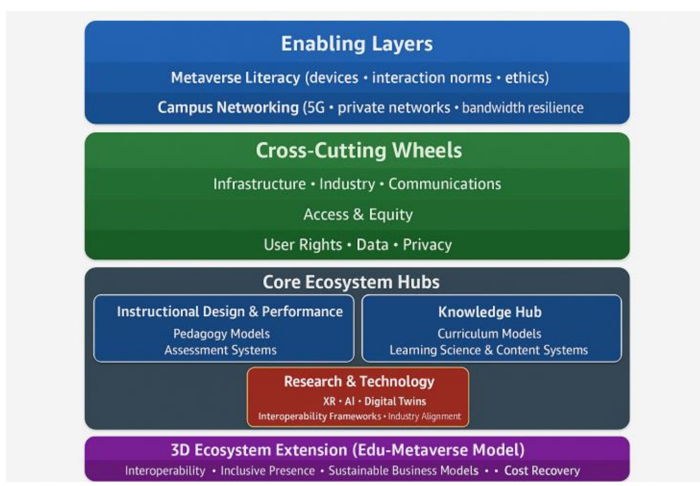
II. LITERATURE REVIEW

A. *Metaverse Education Ecosystem: The Challenge*

To understand the challenges facing the metaverse education ecosystem (MEE), we reviewed its main types and elements, and the extent to which Artificial Intelligence improves the technical, pedagogical, and social constructs of this ecosystem across different areas of engineering education.

Four archetypes of the metaverse have been identified, which frequently appear in combination in campus and local projects. The first ones we will consider are the “*Immersive Classrooms”*, which are VR or XR worlds with the ability to provide permanent 3D spaces for lectures, labs, and studios. These are often headset-first, although they can also be accessed through laptops or mobile devices in hybrid XR mode (Hussain et al., 2024). The second archetype is the “*Augmented/Blended Laboratories*”, which is AR overlays and spatial computing for hands-on tasks (e.g., safety walk-throughs, machine calibration). This type is often linked to digital twins of equipment or processes, so students can simulate before building (Alghamdi et al., 2025). The third archetype is “*Simulation-Commerce Sandboxes*”, which are incorporated in the curriculum as “*Startup Gyms*.” Within these, teams experiment with problem-solution fit, pricing, supply chain, and regulatory factors, which are treated as an early-stage practice space. There is evidence to support that these sandboxes are an emerging area, which is important for entrepreneurship education (Abaddi, 2025). The last category is the “*Platform Federations*” (or Edu metaverse), which is a network of hubs (content, assessment, identity, IP, data) orchestrated by institutional policies and standards; these aggregate multiple tools into a coherent student journey (Wang, 2022).

There are some attempts to offer a systematic framework for multi-hub educational ecosystems spanning pedagogy, technology, governance, and markets (Mohamad, 2025). The four primary hubs driving the field, as identified by Wang et al. (2022), are instructional design & performance, knowledge, research & technology, and talent & training. At the top of the three broad wheels are infrastructure/industry/communications, access & equity, and user rights/data privacy, as depicted in Figure 1. New research has pushed forward the notion of a 3D ecosystem, such as the Edu Metaverse, which focuses on interoperability, presence, and viable business models (Bobko et al., 2024). From a more applied perspective, two enabling layers are commonly mentioned: metaverse literacy, which includes devices and interaction, along with ethics, and campus networking, such as 5G or private networking. The latter is particularly mentioned when there are concerns about bandwidth (Huang, 2024; Nguyen, 2025).



(Source: Authors)

Fig. 1. Metaverse Education Ecosystems

Journal of Engineering Education Transformations, Volume 39, February 2026, Special Issue 3, eISSN 2394-1707

Our review of the literature revealed challenges facing MEE, including interoperability and access; ownership and intellectual property; modularity; cost and access to paid content; pedagogy and governance; and overall technical readiness (De Felice et al., 2023). Interoperability and access issues persist as challenges because most platforms are not integrated and operate in isolation. This results in difficulties in managing identity, moving content from one platform to another, and creating a sense of shared presence (De Felice et al., 2023).

The areas of ownership, intellectual properties, and modularity are complex and unclear. All these areas are connected to the broader discussion of the metaverse and education, including issues of ownership and the challenges of modifying the user interface (Kaddoura & Al Husseiny, 2023). There are also considerations about the cost of paid content. Hardware requirements, content fees, and event-gated access can prevent low-resource institutions from maintaining a persistent presence and keeping up with device cycles (Bakk et al., 2025). Pedagogy and governance concerns are prominent as well. Ethical use, including sl777 privacy, bias, and legal frameworks for certifying educational services in the metaverse, is actively discussed in the literature, mirroring prior sources (Hussain et al., 2024). Finally, technical readiness is a persistent challenge. Achieving appropriate immersive presence (such as stable mixed reality, real-time rendering, and robust authentication) still depends on network quality and device management. While 5G and private networks improve these conditions, they require significant investment and supportive policy frameworks (Huang et al, 2024).

Based on the above discussion, we found that AI is required to enhance the metaverse educational ecosystem (MEE) in general and, more specifically, to enhance CES' entrepreneurial & commercialization skills. AI bridges immersive reality, commercialisation, and entrepreneurship learning. Alghamdi and Alghizzi (2025) emphasize that AI is essential for adaptive coaching & feedback at scale. *AI-driven tutors, graders, and automated feedback systems* deliver immediate, formative guidance in complex simulations, freeing instructors to mentor venture design and stakeholder engagement. Reviews show measurable benefits in personalization, self-regulation, and motivation when paired with governance (FATE) and human oversight (Moore & Lee, 2024). *Digital twin intelligence* is another functionality that AI can add to the MEE, allowing students to run what-if experiments on bill-of-material costs with zero risk, greater reliability, and manufacturability, and to run regulatory scenarios (e.g., medical/energy compliance). This functionality will make Technology Readiness Level Road Mapping (TRL) road mapping and unit economics tangible before capstone demos or incubator pitches. (Moreno López et al., 2024). Artificial Intelligence Generated Content is another resource that enhances interoperability and content generation in the MEE by translating assets across engines and aligning multilingual cases with regional norms (particularly vital in MENA's Arabic–English–French contexts and diverse regulatory landscapes) (Chen, 2025). Together, such AI's functionalities offer entrepreneurial learning pathways and links metaverse environments to opportunity recognition, experimentation, and ecosystem building in entrepreneurship education; AI augments this with market intelligence, persona simulation, and adaptive venture coaching (Abaddi, 2025).

The MENA region's linguistic diversity, heterogeneous infrastructure, and sectoral priorities (Metaverse stations for healthtech, logistics, energy) heighten the value of mobile-first, bandwidth-aware AI tutors and compliance-aware simulators. The literature shows that inclusive designs (low-bandwidth modes, device-agnostic access) and AI-enabled feedback can broaden participation while improving commercialization rehearsal within regional standards.

B. AI-Powered Metaverse Education Ecosystem (AIMEE)

The literature review identifies four schools of thought on both the pedagogical and technical sides of AI-powered MEE. While techno-constructivist optimism and instrumentalist/pragmatic views support the positive impact of this emerging system, critical-ethical perspectives and socio-technical views argue against its unthinkable adoption. The "*techno constructivist optimism*" holds that AI, combined with immersive media (VR/AR/XR), unlocks highly engaging, authentic, and collaborative learning that traditional e-learning rarely achieves. In doing so, users' engagement, spatial understanding, and practical skills when learning are situated in immersive environments, particularly when design aligns with clear learning theories and tasks (Radianti et al., 2020; Llanos Ruiz et al., 2025). Where AI is layered on top (e.g., intelligent tutoring, adaptive content, real-time analytics), reviews find consistent improvements in personalization and immediacy of feedback (Almeman et al., 2025). Similarly, the "*instrumentalist/pragmatic views*" perspective on the metaverse is one in which it is used as a means to an end, and in this case, the value of AI lies in its tutorial, assessment, and analytics aspects that directly correlate with skill development and performance, rather than novelty. Studies on AI in higher education suggest its efficiency in grading, feedback, and early warning, but call for a hybrid approach in oversight and validation for its use in higher education (Alghamdi & Alghizzi, 2025).

On the other hand, the critical-ethical school of thought emphasised that AI-based MEE could exacerbate existing inequalities rather than help bridge them if we do not anchor its use in strong ethical principles. When we bring together the findings of the various meta-analytical and systematic review studies, we see a pattern of concern around privacy, algorithmic discrimination, cognitive overreliance, and preparedness, especially in less well-resourced environments (García-López & Trujillo-Liñán, 2025; Wickramasinghe et al., 2025). These concerns are reinforced in the editorial overviews, where it seems the actual impact will depend less on the tool itself and more on how it is implemented, who controls the learning, and the governance structures in place (Noroozi et al., 2025). On the same side, socio-technical scholars suggest that there is a dark side to introducing this technology into the natural sciences and engineering, and that its successful uptake will require interoperability, standards, teacher preparedness, and the quality of networks and bandwidths in place. These are all prerequisites for successful uptake, and the overall evidence base suggests that long-term studies, standardized evaluation, and a more inclusive approach to policymaking are required to break down existing barriers to access and training (Stracke et al., 2025). Table 1 summarises the pros and cons of AIMEE.

TABLE I
PROS & CONS OF AI-POWERED METAVERSE EDUCATIONAL ECOSYSTEM

Pros	Cons
1) Adaptive tutoring and feedback: AI agents and chatbots provide stepwise hints, counterfactual explanations, and formative feedback inside 3D tasks, improving personalization and time on task (Deepshikha, 2025).	**1) Evidence quality & generalizability:** Reviews still find short timeframes, small samples, and heterogeneous designs—limiting causal claims about learning and transfer (Stracke et al., 2025).
2) Autonomous NPCs and Virtual Assistants: NPCs based on large language models mimic the behavior of users, clients, or regulators. Virtual assistants facilitate navigation, scaffolding, and collaboration (Almeman, 2025).	**2) Ethics, privacy, and bias:** Data-hungry, opaque models pose equity and governance challenges; meta-reviews propose consolidated ethical principles but call for cross-cultural validation (García-López & Trujillo-Liñán, 2025).
3) Learning Analytics and Assessment: Immersive learning activities' telemetry data feeds learning analytics and assessment dashboards (Mosha et al., 2026).	**3) Infrastructure and capacity:** Costs, bandwidth, teacher training, and interoperability still throttle scale, particularly beyond well-resourced contexts (Llanos-Ruiz et al., 2025).
4) **Digital Twins and AI-Enhanced Simulation:** AI integrates IoT data streams into 3D digital twins to display manufacturability, safety, and compliance constraints in real time, becoming the primary metaverse experience for enterprise (Tang et al., 2025).	

The engineering education literature identifies important entrepreneurship skills for students and faculty, such as Opportunity recognition and entrepreneurial learning, Market, risk, and compliance simulation, AI-guided pitching, and TRL planning. Abaddi (2025) links features of the metaverse environment (including social presence, experimentation, and rapid iteration) to stronger entrepreneurial learning and opportunity exploitation, especially when students engage with realistic constraints and role-played stakeholders. Jebbor et al (2025) calls for wider applications of the digital twins in MEE to let students instrument prototypes with live or synthetic data, quantify trade-offs (e.g., BOM cost vs. performance), and practice regulatory navigation by toggling standards and data-localization rules, activities mainstream industry uses to de-risk commercialization In short, the AI-metaverse stack does more than make learning immersive. So, it seems that AIMEE with full functionalities discussed in the previous section could tie engineering choices to market consequences, a shift that nurtures the entrepreneurial mindset (opportunity recognition, evidence-driven pivots) and the commercialization toolkit (TRL planning, cost/compliance reasoning, persuasive storytelling) that computer engineering graduates and educators increasingly need.

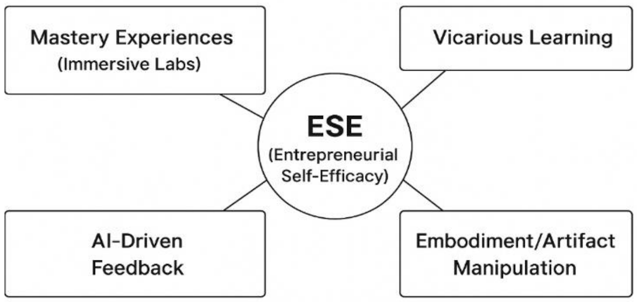
*Why does AIMEE matter for entrepreneurial and commercialization skills in computer engineering***?** An unanswered question that the most compelling strand of recent work does not explain. There is a knowledge gap about how an AIMEE can compress the path from "*technical idea*" to "*market-ready story*" for CES and the faculty who mentor them.

III. THEORETICAL FRAMEWORK

In this section we explain how the Entrepreneurial Self-Efficacy (ESE) framework helps explain "*how AI adoption in metaverse-enabled engineering labs*" (e.g., AI tutoring/feedback, debugging assistants, analytics, compliance checkers, user-persona simulators) strengthens CES' entrepreneurial and commercialisation skills, under MENA-specific contextual moderators (bandwidth/device access, multilingual delivery in Arabic/English/French, gender-responsive teamwork norms, industry ties, assessment culture). The framework synthesises three evidence streams published between 2020–2026: (i) systematic reviews on AI in higher education and the metaverse; (ii) new ESE/entrepreneurship education studies in engineering; and (iii) job-satisfaction and culture findings in AI-adopting organisations. ESE offers five pillars to help understand the context of AIMEE (See Figure 2).

Interaction Mechanisms (mediated by ESE) present mastery experiences where metaverse labs, instrumented with telemetry and scenario stress tests, enable repeated end-to-end prototyping and rapid "build–measure–learn" loops, conditions that contemporary entrepreneurship education studies show to be efficacy generative for CES (e.g., competency gains, cumulative effects across experiential touchpoints) (Ahmad et al., 2025; Wang et al., 2023). *Vicarious learning* is the second pillar that presents shared virtual spaces (e.g., scenario branching, demo-driven development, value-first pitching) allow students to observe expert/peer heuristics and adopt agile rituals, effects also noted in recent metaverse education reviews and VR classroom studies that emphasise social learning affordances and structured interaction (Woick et al., 2024).

Journal of Engineering Education Transformations, Volume 39, February 2026, Special Issue 3, eISSN 2394-1707



(Source: The authors)

Fig. 2. Entrepreneurial Self-Efficacy Framework for AI-Powered Metaverse Education

The third pillar is AI-driven feedback that addresses how educators offer personalised, actionable feedback and explainability; new work highlights counterfactual explanations, risk matrices, and automated profiling to convert ambiguity into next steps and to calibrate confidence (Günther et al., 2023). The fourth pillar is Embodiment & artifact manipulation, which addresses how the AI, digital twins, and AR/VR objects align to create metaverse pitch rooms and enable the sharing of tacit knowledge for product development, especially for factors such as comfort and battery life during data collection (Chande, 2024). At the core, the self-efficacy pillar represents the downstream Outcomes & Cultural Feedback that measure commercialisation capabilities, value proposition design, TRL/pilot planning, pricing experiments, and compliance/IP awareness. It also relates AI-driven MEE to adaptive technology, personalization, and evidence-based storytelling (Castillo-Martínez et al., 2024). AI-driven MEE is linked to adaptive technology, personalization, and evidence-based storytelling (Castillo-Martínez et al., 2024). The relationship between these pillars is subject to the environment of the MENA region. Al-Zahrani & Alasmari (2025) note the distinction between infrastructures and policies in various entities and countries, emphasizing the importance of faculty development for these initiatives.

IV. RESEARCH METHODOLOGY

This study employs an exploratory qualitative survey (eight open-ended questions aligned with entrepreneurial self-efficacy constructs and commercialization tasks) across eight MENA countries. Qualitative surveys are well-suited to capture the breadth of experiences and contextual nuance, particularly useful when an emerging socio-technical pedagogy (AIMEE) spans multiple institutions, languages, and disciplines (Radianti et al., 2020; Mohamad et al., 2025). In metaverse/AI education, recent syntheses reveal substantial variation in infrastructure, pedagogy, and ethics; an open-ended format therefore increases the information richness of responses while avoiding premature closure of variables (Sripan & Jeerapattanatorn, 2025).

We used purposive, maximum variation sampling to secure disciplinary diversity (e.g., Mechatronics, CPS, Embedded/Computer/Electrical & Computer/Software Engineering, AI & Data Science) and national diversity (eight MENA countries), yielding N = 300 educator participants. Such diversity helps surface cross-context patterns (e.g., bandwidth, language, compliance) that more homogeneous samples often miss (Almeman et al., 2025). While qualitative studies frequently achieve code saturation in much smaller samples, multi-country, multi-discipline inquiries typically require larger samples to approach meaning saturation, that is, a textured understanding of concepts across contexts (Hennink & Kaiser, 2022). Our N = 300, therefore, emphasizes breadth and transferability across heterogeneous settings, not statistical inference.

The survey asked about metaverse tasks, AI feedback moments, artifact manipulation/tacit knowledge, commercialization skills, and contextual moderators (e.g., language, device/bandwidth, institutional ties). Responses were collected in writing, then cleaned and programmatically summarized to produce the classification tables below. Our research design is based on reflexive thematic analysis. It begins with familiarization, coding, then theme development, theme review and definition, and finally creating an analytical narrative. This research design is particularly applicable to interpretive and cross-contextual qualitative research (Byrne, 2021; Braun & Clarke, 2022).

TABLE II
PARTICIPANTS' CATEGORISATION

Category	Count	Percent
Mechatronics	51	17.0
Cyber-Physical Systems	45	15.0
Embedded Systems	41	13.7
Computer Engineering	38	12.7
Electrical & Computer Engineering	37	12.3
AI & Data Science	30	10.0
Computer Science	29	9.7
Software Engineering	29	9.7
Category	**Count**	**Percent**
Lebanon	43	14.3
Jordan	42	14.0
Saudi Arabia	39	13.0
Morocco	39	13.0
Egypt	37	12.3
Oman	37	12.3
Qatar	34	11.3
United Arab Emirates	29	9.7

Descriptive statistics, in the form of counts and percentages, have been added to allow us to categorize participants by computer engineering specialty and country, and whether they are teaching or research-focused academics. In order to increase credibility and transparency, we made the following three changes: (i) we provided the exact figures based on the dataset, (ii) we mentioned the absence of the "years of experience" field, and (iii) we explained the "rule of thumb" we followed to categorize the participants based on "Teaching/Research/Both." On the ethical side of the issue, there is an ongoing debate about the role of AI in higher education. However, our strategy is in line with the current critiques of the role of AI in higher

Journal of Engineering Education Transformations, Volume 39, February 2026, Special Issue 3, eISSN 2394-1707

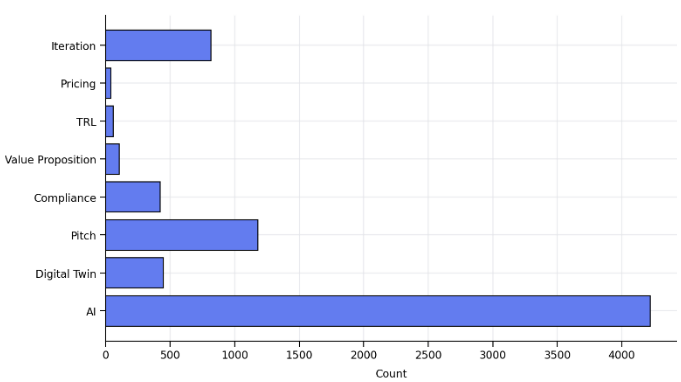
education and is based on a human-centered and pedagogically informed approach to the use of AI in higher education (Alghamdi & Alghizzi, 2025). The use type (Teaching/Research/Both) was inferred from self-descriptions (e.g., "prototype," "pilot," "students," "course," "class") and reviewed across all responses; the aggregate result is shown below.

V. RESEARCH FINDINGS

Our analysis of a survey dataset of 300 engineering educators and academics across eight Middle Eastern nations offers one of the richest qualitative accounts of how AI-powered metaverse platforms are changing engineering education and, more importantly, students' innovation and commercialization capabilities. By drawing on Entrepreneurial Self-Efficacy (ESE) Theory, this analysis examines how capabilities in performing entrepreneurial actions like opportunity recognition, experimentation, iteration, value proposition design, and pitching are developed through four main ways:

- *Mastery Experiences*
- *Vicarious Learning*
- *AI-Driven Feedback*
- *Embodiment & Artifact Manipulation*

Each ESE construct appears strongly and consistently across the dataset. After running a quantitative scan of keyword frequencies (generated by computational analysis of the full dataset) highlight the prevalence of core constructs:



(Source: The Authors)

Fig. 3. Figure Keyword Frequency in 300 responses

The above figure illustrates the ESE-Centred Framework, which links the adoption of AI-Metaverse technology with job satisfaction and the organizational culture of MENA university settings. It illustrates, in a concise manner, how the integration of AI into the metaverse labs is associated with the enhancement of engineering teachers' and students' entrepreneurial self-efficacy constructs such as mastery, learning from watching others, feedback from AI, and creating digital artifacts, which ultimately lead to commercialization capabilities and job satisfaction, which in turn enhance organizational cultures that are agile and support the adoption of AI.

The frequency of terms in the data set reveals that the terms "*AI*" were used 4,219 times, "*digital twin*" 447 times, "*pitch*" 1,179 times, and "*compliance*" 424 times, which illustrates the centrality of concepts and ideas associated with commercialization in the data set. This demonstrates the importance of integrating AI and the Metaverse, as this will be the foundation of developing our capacity to commercialize, especially with prototyping and compliance. It will also assist the engineer in developing their skills to bring their ideas to the market, and this is important in the metaverse space and related to identifying opportunities and developing real-world solutions for commerce.

In brief, therefore, we may conclude that the above diagram and keyword analysis reveal that there is a positive loop in which engineers become more proficient in utilizing and monetizing AI in metaverse platforms, and this makes employees more satisfied with their work and enhances organizational culture, which in turn drives more AI adoption in universities across the MENA region.

A. Mastery Experiences: Confidence Built Through Active Experimentation

ESE theory posits that mastery experiences are the strongest predictor of entrepreneurial self-efficacy, as hands-on success builds the belief that one can perform similar tasks again (Figueroa de la Fuente and Farhadian, 2025). Across the dataset, mastery manifested through *end-to-end virtual prototyping, evidence-driven iteration, and risk-taking in safe-to-fail simulations.*

A dominant theme in the dataset is that AI-powered metaverse labs (VR/AR digital twins, WebXR rooms, 3D physics sandboxes) turn "*end-to-end prototyping*" into a rapid, instrumented, low-risk practice. Educators repeatedly write that the metaverse "compressed weeks of iteration into hours" and "elevated confidence to transfer the workflow to a physical pilot." These are textbook mastery experiences (the most potent source of self-efficacy) now scaled through telemetry, scenario stress-testing, and replayable environments. In contemporary reviews of AI in HE, the "*combination of adaptive systems and analytics"* is consistently cited as the primary driver of personalisation and learning efficiency; our data exemplifies how that same combination enhances *engineering-entrepreneurial mastery* (e.g., building, validating, and cost-constraining prototypes) (Bond et al., 2024; Castillo-Martínez et al., 2024; Apata et al., 2025).

The implications of these findings are time compression and safe-to-fail spaces. First, *time compression* multiplies the number of entrepreneurial cycles students can experience (problem framing → prototyping → evidence gathering → pivot/persist), which recent studies link to *higher ESE and readiness for commercialisation among engineering cohorts* (Ahmad et al., 2025; Mohamad et al, 2026). Second, *safe-to-fail spaces* reduce the opportunity cost of trying bold ideas, a driver of both learning and job satisfaction (autonomy and competence) that organisational literature increasingly connects to AI-enabled work redesign (McKinsey, 2025; PwC, 2025; Mohamad et al., 2025). As demonstrated in Figure 2, the keyword frequencies across responses, the regex scan above

Journal of Engineering Education Transformations, Volume 39, February 2026, Special Issue 3, eISSN 2394-1707

shows how frequently AI, digital twin, pitch, and compliance appear in the 300 texts—signalling the ubiquity of AI-assisted learning loops, artifact embodiment, narrative skills, and regulatory awareness in the metaverse workflows. In conclusion, the prevalence of “AI” (4,219 mentions) and “digital twin” (447) aligns with recent metaverse reviews noting that simulation + analytics is the pedagogical engine behind accelerated learning and real-world transfer (Woick et al., 2024; Onu et al., 2024).

B. *Vicarious Learning: Learning by Watching Experts and Peers*

Our responses dataset is rich with *vicarious moments* such as “*observing a mentor demonstrated scenario branching and A/B simulations*; *I adopted this by restructuring sprints and check-ins… peer examples raised our quality bar.*” These are not only classic ESE pathways but also *community-of-practice effects*, students import *professional rituals* (demo-driven development, version control inside VR labs, value-first pitching) that professionalise their approach to innovation.

Recent higher-education metaverse syntheses (2024–2025) underline that *“avatar-mediated collaboration*” and “*structured interaction*” predict sustained engagement and skills transfer; our survey confirms that when those interactions are “*entrepreneurially framed”* (e.g., pitch rooms, compliance walk-throughs), students internalise *“market-facing behaviours”* rather than stopping at technical solutionism (Gualano & Campbell, 2024; Hussain et.al., 2024).

In the MENA setting, educators also note that “*multilingual environments*” (Arabic/English/French) and “*industry mentors”* broaden participation and relevance, conditions a 2025 MENA-wide study identifies as “*decisive enablers”* of AI adoption and learning outcomes (Al-Zahrani & Alasmari, 2025).

C. *AI-Driven Feedback: Turning Failure into Learning*

In 300 responses, teachers highlight that AI feedback offers “next step clarity” in complex failure situations. By utilizing counterfactual explanations, risk matrices, automatic performance profiling, and problem reproduction with personas, students receive clear information about what to do next. In Egypt, teachers report that AI feedback made “the risks legible and the next step obvious.” This represents a new trend in higher education: AI no longer just grades; it also offers explanations. Recent research supports counterfactual-based tutoring and human-centered evaluation of explanations (Günther et al., 2023).

Enhancing entrepreneurship and commercialisation skills is significant because navigating uncertainty is central to market discovery and investor communication. AI that localises root causes and suggests data-driven priorities accelerates evidence gathering and helps students justify pivots or investment requests, behaviours that the broader AI in HE Meta reviews associate with adaptive/personalised systems and analytics-driven performance gains (Bond et al., 2024; Castillo Martínez et al., 2024).

Across the eight MENA countries, we found that AIMEE provides: Immersive 3D task environments, simulated commercial ecosystems, peer-to-peer and avatar-mediated collaboration, and Risk-free experimentation spaces. Studies on metaverse adoption in entrepreneurship education show that immersive simulations significantly improve students’ learning performance, with a large aggregate effect size (d = 0.94) across 2020–2023 experiments (Al Khateeb & Alotaibi, 2024). Additionally, other systematic reviews indicate that metaverse environments enhance the efficiency of our communication processes, enable more lifelike simulations of entrepreneurial behaviour, enhance information filtering, and offer significant learning experiences, which are situations where AI feedback can be most beneficial (Corbeil, 2025; Haibin & Yunus, 2024; Mohamad et al., 2025).

TABLE III
COMBINED BENEFITS OF AI AND METAVERSE FOR ENTREPRENEURIAL AND COMMERCIALISATION SKILLS

Competency	AI-Driven Feedback	Metaverse Learning	Combined Outcome
Risk Assessment	Counterfactual and risk-matrix explanations	Market and venture simulations	Students perform evidence-based risk evaluation
Opportunity Recognition	Automated pattern detection & feedback	Immersive environments that mimic real markets	Faster and more accurate identification of business opportunities
Pitching & Communication	Persona-based AI role-playing critiques	Avatar-based investor simulations	Improved clarity, persuasion, and investor-readiness
Resilience & Iteration	Feedback-driven pivot suggestions	Safe-to-fail virtual business trials	Stronger entrepreneurial grit and iteration discipline
Commercialisation Strategy	Data-driven prioritization advice	Virtual product testing & customer interaction	Students learn to justify commercial decisions with data

In the MENA, which comprises the UAE, Saudi Arabia, Egypt, and Qatar, there is a rapid development of EdTech and metaverse-based learning environments. According to reports, the Middle East and Africa metaverse education market is projected to register a CAGR of more than 35% during 2023-2033, attributed to high government digital transformation initiatives and the inclusion of AI in national education curricula. Governments and EdTech innovators in the region have acknowledged AI's role in providing real-time analytics, enabling the delivery of content, and developing skills, which can be beneficial in enhancing workforce readiness and skill development (Guo, 2025). Moreover, forecasts from Statista indicate that there is an exponential rise in metaverse-based professional and higher education applications in the MENA region from 2025 to 2030.

D. *Embodiment & Artifact Manipulation: Tacit Knowledge Through Digital Objects*

Journal of Engineering Education Transformations, Volume 39, February 2026, Special Issue 3, eISSN 2394-1707

Tinkering with the "digital twins" and artifacts in the metaverse pitch rooms often reveals the unstated understanding of the trade-offs between ergonomics, batteries, and sampling, as well as privacy by design, import duties and sourcing risks, and regional compliance issues. These unstated understandings of the world are exactly what the digital twin education literature (2024-2025) suggests the medium is uniquely capable of bringing out in terms of the world costs and manufacturability issues that static content is unable to teach (Chande, 2024).

The effect is twofold: first, it tightens the engineering ↔ market link by anchoring technical choices in user value and risk, and second, it preloads students with regulatory awareness, a recurrent inhibitor of first-time commercialisation. Both outcomes show up in our corpus alongside narrative upgrades (pitches "*grounded in telemetry and evidence*"). Embodiment refers to learning through physical (or virtual) manipulation of artifacts—a powerful but often overlooked ESE mechanism.

The dataset includes 447 references to "*digital twin*" and hundreds more to AR/VR artifacts. The digital twin functionalities and the Internet of Things help discover Hidden Constraints and Tacit Knowledge among CES. Educators repeatedly wrote:

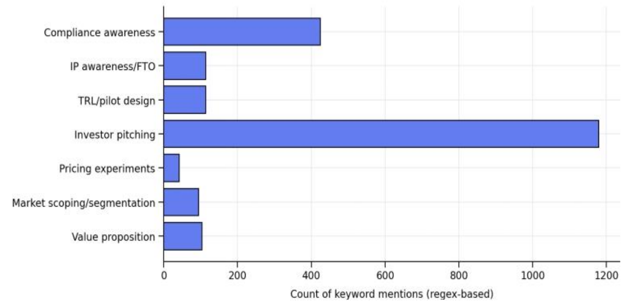
"Manipulating the digital twin revealed ergonomic constraints…"
"…battery life vs. sampling rate trade-offs…"
"…privacy-by-design implications…"
"…regional compliance requirements…"

These tacit insights traditionally require years of industry experience. The metaverse collapses that learning curve. Our responses also reveal the linkage between technical choices and business decisions, where educators at Khalifa University in the UAE wrote, **"***We mapped costs and constraints to user stories; this informed scope and MVP decisions."* This bridging of *engineering and business* is the heart of commercialisation education.

E. *Outcomes: Development of Innovation & Commercialisation Capabilities*

Our quantified signals for seven commercialisation skill areas using regex counts across the corpus (See Figure). The "*investor pitching*" and "*compliance awareness*" are highly salient, mirroring the qualitative notes on "*metaverse pitch rooms"* and "*regional standards"*. This mirrors current metaverse-in-education reviews, emphasising "*structured performance spaces***"** (including pitch/demo environments) and the need to address equity, interoperability, and governance (Woick et al., 2024; Onu et al., 2024). The "*value proposition"* and "*market scoping/segmentation"* are strong, reflecting mentor-modelled shifts from features to "value-first storytelling" and are also consistent with recent advances in entrepreneurship education in engineering cohorts (Ahmad et al., 2025).

TRL/pilot design appears consistently; educators report increased confidence to pilot and readiness for technology transfer, aligning with AI-in-HE reviews that tie adaptive/personalised analytics to applied performance (Bond et al., 2024). In other words, AI-driven metaverse experiences extend beyond the boundaries of technological capabilities to the business domain of pricing, markets, regulatory considerations, intellectual property, and freedom to operate. The integration of analytics, explanations, and embodiment of artifacts brings the business boundaries of commercialization into clear and measurable focus, providing the support for pitches that can differentiate the outcomes of entrepreneurial education.



(Source: The Authors)

Fig. 4. Commercialisation Skill Signals Found in 300 Responses

The most dramatic changes occurred in the domain of *technology readiness level* (TRL) roadmapping and the pilots themselves. The simulation data played a vital role in informing the narrative and providing concrete support for the claims made throughout the project (see the Figure above). This simulation-centric approach to the pilot design process brought much-needed clarity and order to the innovation and commercialization process (Chande, 2024; Woick et al., 2024; Onu et al., 2024).

One of the most notable aspects of the responses was the clear indication of increased confidence in translating the digital process into the physical pilots. This sentiment encapsulates the core of engineering self-efficacy (ESE): the conviction that skills and knowledge developed in virtual environments can be reliably applied in actual practice (Ahmad et al., 2025; Bond et al., 2024).

The metaverse-based pitch room was also notable for its educational potential. In a pitch room, stakeholders can interact in person and use telemetry data and user scenarios as the foundation for their assertions and decisions. The immersive experience enabled students to enter a simulated environment for productization that was data-driven for every move, reducing the gap between technical skills and other aspects of business studies such as pricing, segmentation, compliance, and IP/FTO issues (Woick et al., 2024; Onu et al., 2024; Bond et al., 2024).

F. *Contextual Factors Unique to the MENA Region*

Our respondents repeatedly cite *bandwidth/device access, multilingual support, gender dynamics, and industry ties* as decisive context factors. These are not trivial; a 2025 MENA study shows *"large adoption disparities"* tied to infrastructure and policy, and it recommends "*targeted investment, faculty* *training, and regional collaboration*", precisely the patterns that educators in our corpus identify as programme-level enablers (Al-Zahrani & Alasmari, 2025).

Two practical levers emerge: first, *mobile-first/low-bandwidth modes* for equitable access (echoed in many educator comments and in recent metaverse reviews that caution about *cost and scalability)* (Woick et al., 2024; Onu et al., 2024). Second, *"culturally relevant case libraries plus regional compliance checkers"*, which respondents request to localise learning and accelerate commercial reality checks, are fully aligned with recent integrative reviews calling for discipline and region-specific metaverse design (Almeman et al., 2025).

The integration of AIMEE across the MENA region is deeply shaped by contextual realities that meaningfully influence how students develop entrepreneurial and commercial capabilities. One of the most prominent challenges highlighted in the dataset is infrastructure inequality. As educators repeatedly noted, "*Key contextual factors were bandwidth variability and device access*," a limitation that directly undermines the scalability of immersive metaverse learning in several parts of the region. This aligns with regional market analyses that have identified reliable connectivity as a major challenge for the development of the metaverse in the Middle East and Africa (Darwish et al., 2025). The government of the UAE, however, continues to invest heavily in AI-powered EdTech systems to address identified connectivity gaps and build an innovation-oriented workforce (Poduval, 2025). The region's unique linguistic landscape also plays a significant role. In multilingual classrooms where Arabic, English, and French often intersect, educators observed that "*Language options… improved participation*." This aligns with research showing that making learning spaces in the metaverse multilingual will increase their inclusiveness and improve the quality of collaborative and entrepreneurial tasks (Chen, 2025). However, the social interactions that occur in such virtual learning spaces are equally important. Several educators noticed that gender dynamics and participation on teams with both men and women change in the metaverse, suggesting that the virtual space can facilitate participation for both men and women. In addition, research has shown that learning spaces in the metaverse in the MENA region may facilitate balanced interactions that help students become confident in identifying opportunities in entrepreneurship (Al Khateeb & Alotaibi, 2024).

Finally, strong local industry connections are indispensable. As educators put it, "*Institutional ties to industry shaped our problem selection*," ensuring that metaverse-based entrepreneurial simulations were rooted in real commercial needs. This observation closely matches regional studies demonstrating that university–industry collaboration in GCC countries is critical for aligning entrepreneurial learning with national economic transformations (Atef, 2025).

Together, these contextual factors (Such as technological access, multilingualism, gender dynamics, and industry collaboration) shape not only students' access to AIMEE but also the depth and realism of the entrepreneurial and commercial skills they acquire.

G. Desired Improvements to AI-Metaverse Learning

Our MENA dataset pointed to educators' repeated requests for five upgrades: (1) regional compliance checkers, (2) richer cost/manufacturability simulators, (3) culturally relevant case libraries, (4) AI transparency and data governance, and (5) low-bandwidth, mobile-first modes. The prominence of compliance (424 mentions) reflects the region's multi-jurisdictional reality (GCC, Levant, North Africa) and the need to rehearse standards and market entry constraints inside learning environments. Our findings align with the literature review in terms of how AIMEE stresses engagement and personalization, yet the literature often stops short of commercialization tooling. Our findings go further: educators want "enterprise-grade simulation," digital twin costings, and bill-of-materials trade-offs, so students can practice pricing, TRL road mapping, and compliance navigation before pitching (McKinsey & Company, 2022; Tang et al., 2025). This extends the metaverse study's earlier research on immersion and motivation (Radianti et al., 2020; Sripan & Jeerapattanatorn, 2025) by connecting it to unit economics and regulatory risks, which are important considerations for entrepreneurial readiness.

In the area of "*AI transparency and governance*", our study's findings on the importance of AI transparency, fairness, and privacy, as well as the educator's role as a mediator, align with the most recent reviews on the topic (Alghamdi & Alghizzi, 2025; García-López & Trujillo-Liñán, 2025). This aligns with higher education recommendations on AI adoption, emphasizing the importance of pedagogy and the human element over the tool itself (EDUCAUSE Review, 2025). However, our study's findings on regionalization of content deviate from the literature. There is an acknowledgment of the opportunities for metaverse entrepreneurship in academic literature, though often with an absence of case libraries relevant to the MENA region. There is an emerging call for educators to develop case materials in Arabic, English, and French, with templates compliant with Gulf countries' requirements, including playbooks for sectors such as healthtech, logistics, and agritech. This will enable quicker opportunity recognition and is in line with the emerging research on metaverse affordances and entrepreneurial learning and development (Abaddi, 2025; Chen, 2025).

Finally, connectivity and access are brought into sharp relief. While cost, bandwidth, and teacher training are raised as issues in the reviews, our users flesh this out into specific design requirements: mobile-first design and low-bandwidth versions that ensure 3D/pitch rooms remain accessible from Cairo to Muscat (Onu et al., 2023; Llanos Ruiz et al., 2025). So, in brief, the new reframing of AI metaverse learning in MENA, underpinned by evidence, moves from "immersive novelty" to "commercialization gym" – students learn to be aware of compliance, design, and cost-effectiveness in their pitches, designs, and MVPs, and this is directly applicable to startup and working environments.

RESEARCH DISCUSSION

The survey findings strongly align with, and in some cases extend, the existing literature on metaverse learning, AI-augmented education, and entrepreneurial self-efficacy. Our survey indicates that the four canonical ESE mechanisms, mastery experiences, vicarious learning, timely feedback, and embodied/hands-on doing, were all activated in AIMEE settings. In fact, low-risk cycles of virtual build and test enabled learners to achieve mastery by doing. Guided learning experiences, with mentors or avatars as guides, provided learners with opportunities to learn by watching others. AI tutors were always available to provide learners with timely, adaptive guidance, and learning by doing was facilitated through the manipulation of digital twins.

The current studies on metaverses and digital twins are also consistent with the above points: immersive simulations have consistently proven to improve learning effectiveness and collaboration, and digital twins allow learners to see trade-offs in manufacturability, lifecycle, and compliance that are not possible to depict in static media (Fenton et al., 2020; Al Khateeb & Alotaibi, 2024; Mohamad et al., 2025). In this sense, our results empirically support the use of embodied and feedback-rich metaverse environments as a robust lens for cultivating entrepreneurial confidence and competence. Existing scholarship suggests metaverse environments improve engagement and spatial learning (Radianti et al., 2020). Furthermore, our survey extends this by demonstrating that the metaverse improves commercialization skills, e.g., in pricing, TRL planning, and compliance analysis. Other studies, e.g., on AI in higher education, report on personalized feedback and better learning outcomes (Zawacki-Richert et al., 2019). Our findings show AI doing much more, including risk profiling, market simulation, compliance awareness, and investor pitch coaching. Past research has emphasized the importance of engagement, spatial learning, and motivation in metaverse environments. Moreover, the positive impact of immersive interventions has been significant. However, the present research extends these boundaries. Students developed skills in commercialization fluency, pricing logic, technology readiness planning, compliance scoping, and investor pitch polish. This was possible because of the constant connection between design choices and costs, risks, and user value, enabled by telemetry and artificial intelligence analytics (Chen, 2025). Moreover, although the past research has emphasized the importance of personalization and quick feedback in higher education with the integration of artificial intelligence, the present research has shown the potential of artificial intelligence in risk profiling, market simulation, and pitch polishing.

There are three notable differences between our findings and the literature. First was the "*regulatory intensity*." Students were more focused on standards, data localization, and market-entry issues than their counterparts in the Western world. This was because of the *multi-jurisdictional complexity* of the MENA region. This complexity was directly fed into the twin through the metaverse exercises (McKinsey & Company, 2022). Second was the "*substitution of AI mentorship*." This was because of the limited resources in the MENA region. This was also noted in the EdTech narratives of the MENA region. Third was the "*leapfrogging to metaverse pitch rooms*." This was because of the adoption of immersive and telemetry-grounded pitching. This showed the potential of the MENA region to "*leapfrog beyond traditional entrepreneurship education to data-driven commercialization practice*" (Al Khateeb & Alotaibi, 2024).

CONCLUSION

Our research has identified four contextual moderators that can influence the potential effectiveness and scalability of AI metaverse learning in terms of engineering education in the Middle East. The first of these is the perennial issue of bandwidth and device availability. This means that immersive 3D learning experiences are limited to already established digital hubs. This outcome reinforces the findings of previous research that emphasize the importance of the readiness of essential infrastructure in the educational metaverse in the Middle East region. Moreover, it reiterates the need to have multilingual interfaces that incorporate Arabic, English, and French in order to increase user engagement in the metaverse. In addition, it reinforces the findings of previous research that emphasize the role of the metaverse as a communication-oriented environment in entrepreneurial learning. Thirdly, in terms of the nature of participation in the metaverse in relation to learning, there is a balance and promise, with the instructor noting that men and women participate equally in mixed-gender groups. This finding reinforces meta-analytic studies that point to the positive effects of immersive learning experiences on gender balance. Fourthly, the use of realistic regional entrepreneurial challenges remains crucial for skill transfer. In terms of the actual impact, university-industry partnerships have the potential to highlight the realities of regional entrepreneurial challenges, which in turn can facilitate the connection of students to entrepreneurial learning and innovation goals in GCC/MENA higher education.

This study contributes to the global conversation by demonstrating the uptick in entrepreneurial self-efficacy in AI-driven metaverse learning, which is, in turn, influenced by cultural and infrastructural factors. There has been a lack of studies into the interplay of cultural and infrastructural factors in the context of Middle Eastern engineering programs, and the findings demonstrate that the effective integration of multilingual learning, gender, bandwidth, and university-industry partnerships is not a nicety, but a necessity. The findings expand the potential of digital and immersive technologies in the region and contribute to the overall conversation about the metaverse and its role in supporting entrepreneurship education in a fair, authentic, and impactful manner.

REFERENCES

Abaddi S (2025), Metaverse, entrepreneurial learning and opportunity exploitation. Journal of Entrepreneurship in Emerging Economies, Vol. 17 No. 3 pp. 744–773, doi: https://doi.org/10.1108/JEEE-04-2024-0163

Ahmad, A., Amry, D., Chen, Z. et al. Building entrepreneurial self-efficacy in engineering students: towards a new methodological framework. Entrep Educ 9, 21–56 (2026). https://doi.org/10.1007/s41959-025-00156-7

Al Khateeb, A., & Alotaibi, H. (2024). The upsurge of the metaverse in educational settings: a meta-analysis study. Pegem Journal of Education and Instruction, 14(3), 62-75. https://doi.org/10.47750/pegegog.14.03.06

Alghamdi, L. H., & Alghizzi, T. M. (2025). Educators' reflections on AI-automated feedback in higher education: A structured integrative review of potentials, pitfalls, and ethical dimensions. Frontiers in Education, 10. https://doi.org/10.3389/feduc.2025.1704820

Alghamdi, S., Yoon, H. Y., & Song, Y. T. (2025, May). Digital Twins in Education Applications, Challenges, and Future Directions. In 2025 IEEE/ACIS 23rd International Conference on Software Engineering Research, Management and Applications (SERA) (pp. 225-232). IEEE. DOI: 10.1109/SERA65747.2025.11154576.

Almeman, K., EL Ayeb, F., Berrima, M., Issaoui, B., & Morsy, H. (2025). The integration of AI and metaverse in education: A systematic literature review. Applied Sciences, 15(2), 863. https://doi.org/10.3390/app15020863

Al-Zahrani, A. M., & Alasmari, T. M. (2025). A comprehensive analysis of AI adoption, implementation strategies, and challenges in higher education across the Middle East and North Africa (MENA) region. Education and Information Technologies, 30, 11339–11389. [link.springer.com], [eric.ed.gov]

Apata, O. E., Ajose, S. T., Apata, B. O., Olaitan, G. I., Oyewole, P. O., Ogunwale, O. M., ... & Feyijimi, T. (2025). Artificial intelligence in higher education: a systematic review of contributions to SDG 4 (quality education) and SDG 10 (reduced inequality). International Journal of Educational Management, 1-18. https://doi.org/10.1108/IJEM-12-2024-0856

Atef, R. (2025). Leadership-driven innovation in GCC and MENA higher education: Integrating AI, entrepreneurship, and sustainability to bridge the skills–market divide. International Journal of Innovative Inventions in Social Science and Humanities, 2(7), 79–89. DOI: 10.58806/ijiissh.2025.v2i7n01

Bakk ÁK, Bényei J, Ballack P, and Parente F (2025). Current possibilities and challenges of using metaverse-like environments and technologies in education. Front. Virtual Real. https://doi.org/10.3389/frvir.2025.1521334

Bandura, A. (1997). Self-efficacy: The exercise of control. Freeman.
Edmondson, A. (1999). Psychological safety and learning behavior in work teams. Administrative Science Quarterly, 44(2), 350–383.

Bobko, T., Corsette, M., Wang, M., & Springer, E. (2024). Exploring the possibilities of Edu-Metaverse: A new 3-D ecosystem model for innovative learning. IEEE Transactions on Learning Technologies, 17, 1290–1301. https://doi.org/10.1109/TLT.2024.3364908

Bond, M., Khosravi, H., De Laat, M., Bergdahl, N., Negrea, V., Oxley, E., ... & Siemens, G. (2024). A meta systematic review of artificial intelligence in higher education: A call for increased ethics, collaboration, and rigour. International journal of educational technology in higher education, 21(1), 4.

Braun, V., & Clarke, V. (2022). Thematic analysis: A practical guide. SAGE. https://doi.org/10.4324/9781003362715

Byrne, D. (2021). A worked example of Braun and Clarke's approach to reflexive thematic analysis. Quality & Quantity, 56, 1391–1412. https://doi.org/10.1007/s11135-021-01182-y

Castillo-Martínez, I. M., Flores-Bueno, D., Gómez-Puente, S. M., & Vite-León, V. O. (2024, August). AI in higher education: A systematic literature review. In Frontiers in Education (Vol. 9, p. 1391485). Frontiers Media SA.https://doi.org/10.3389/feduc.2024.1391485

Chande, S. V. (2024). An exploratory view of application of digital twin technology in education. International Journal of Advanced Trends in Computer Science and Engineering, 13(2). https://doi.org/10.30534/ijatcse/2024/031322024

Chen, P.-K. A. (2025). Influence of metaverse on building entrepreneurship education ecosystems. Engineering Proceedings, 103(1), 3. https://doi.org/10.3390/engproc2025103003

Corbeil, J. R. (2025). The Future of Learning: AI-Driven Education in 2040. In Teaching and Learning in the Age of Generative AI (pp. 362-390). Routledge. https://doi.org/10.4324/9781032688602

Darwish, S., Mansoor, K., Abey, J. (2025). The Future of Metaverse in Higher Education in the Arab World. In: Hamdan, R.K. (eds) Sustainable Data Management. Studies in Big Data, vol 171. Springer, Cham. https://doi.org/10.1007/978-3-031-83911-5_22

De Felice, F., Petrillo, A., Iovine, G., Salzano, C., & Baffo, I. (2023). How does the metaverse shape education? A systematic literature review. Applied Sciences, 13(9), 5682. https://doi.org/10.3390/app13095682

Deepshikha, D. (2025). A systematic review on the future of educational assessment: AI-driven grading and personalised feedback in higher education. Artificial Intelligence in Education, 2(2), 75–115. https://doi.org/10.1108/AIIE-03-2025-0036

EDUCAUSE Review. (2025, June 24). Ethics is the edge: The future of AI in higher education. Available at: https://er.educause.edu/articles/2025/6/ethics-is-the-edge-the-future-of-ai-in-higher-education

Fenton, A., Mohamad, M., & Jones, A. (2020). Social media. In Digital and Social Media Marketing (pp. 204-229). Routledge. https://doi.org/10.4324/9780429280689

Figueroa de la Fuente, M., & Farhadian, G. (2025). Systematic Review of the Impact of Artificial Intelligence in Higher Education. Journal of Teaching and Learning, 19(4), 72-96. DOI: https://doi.org/10.22329/jtl.v19i4.9849

García-López, I. M., & Trujillo-Liñán, L. (2025). Ethical and regulatory challenges of generative AI in education: A systematic review. Frontiers in Education, 10. https://doi.org/10.3389/feduc.2025.1565938

Gualano, R. J., & Campbell, S. W. (2024). Classrooms in the metaverse: Educational applications and levels of learner interaction in virtual reality. Communication Education, 73(2), 212-225. https://doi.org/10.1080/03634523.2024.2312873

Günther, S.A., Haag, F., Hopf, K., Handschuh, P., Klose, M., Staake, T. (2023). A feedback component that leverages counterfactual explanations for smart learning support. In: Mrohs, L., Franz, J., Herrmann, D., Lindner, K., Staake, T. (eds) Digitale Kulturen der Lehre entwickeln. Perspektiven der Hochschuldidaktik. Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-43379-6_19

Guo, Y., Yu, T., Wu, J., Wang, Y., Wan, S., Zheng, J., & Dai, Q. (2022). Artificial intelligence for metaverse: a framework. CAAI Artificial Intelligence Research, 1(1), 54-67. https://doi.org/10.26599/AIR.2022.9150004

Haibin, T., & Yunus, M. M. (2024). Application of metaverse technology in entrepreneurship education: a systematic review. International Journal of Academic Research in Progressive Education and Development, 13(1), 1322-1326. http://dx.doi.org/10.6007/IJARPED/v13-i1/20629

Hennink, M., & Kaiser, B. N. (2022). Sample sizes for saturation in qualitative research: A systematic review of empirical tests. Social Science & Medicine, 292, 114523. https://doi.org/10.1016/j.socscimed.2021.114523

Huang, JE., Chang, LW. & Chin, HH. 5G Metaverse in Education. Mobile Netw Appl 29, 947–960 (2024). https://doi.org/10.1007/s11036-024-02354-4

Hussain, S., Meehan, K., & Qadir, J. (2024, April). Metaverse in education: opportunities and challenges. In Frontiers in Education (Vol. 9, p. 1411841). Frontiers Media SA. https://doi.org/10.3389/feduc.2024.1411841

Jebbor, I., Benmamoun, Z., & Hachimi, H. (2025). Leveraging digital twins and metaverse technologies for sustainable circular operations: A comprehensive literature review. Circular Economy and Sustainability, 5, 5795–5848. https://doi.org/10.1007/s43615-025-00615-2

Kaddoura, S., & Al Husseiny, F. (2023). The rising trend of metaverse in education: Challenges, opportunities, and ethical considerations. PeerJ Computer Science, 9, e1252. https://doi.org/10.7717/peerj-cs.1252

Kushnir, I. (2025). Thematic analysis in the area of education: a practical guide. Cogent education, 12(1), 2471645.https://doi.org/10.1080/2331186X.2025.2471645

Llanos-Ruiz, D., Abella-García, V., & Ausín-Villaverde, V. (2025). Virtual reality in higher education: A systematic review aligned with the Sustainable Development Goals. Societies, 15(9), 251. https://doi.org/10.3390/soc15090251

McKinsey & Company. (2022, October). Digital twins: The foundation of the enterprise metaverse. Available at: https://www.mckinsey.com/capabilities/tech-and-ai/our-insights/digital-twins-the-foundation-of-the-enterprise-metaverse

McKinsey & Company. (2025). The state of AI in 2025: Agents, innovation, and transformation. Available at: https://www.mckinsey.com/capabilities/quantumblack/our-insights/the-state-of-ai

Mohamad, M. (2025). Technological Innovation Ecosystem for Sustainable Development: Multi-cases from Federal Universities in UAE. https://doi.org/10.1108/978-1-83708-210-020251004

Mohamad, M., Balikel, A., Russell, C., Chowdhury, D., & Mahmoud, S. (2025). Artificial intelligence for business model innovation in digital sustainability companies: Multiple cases from the Netherlands. World Journal of Entrepreneurship, Management and Sustainable Development, 22(1-2). DOI: 10.47556/J.WJEMSD.22.1-2.2026.7

Mohamad, M., Nii Laryeafio , M., Koroye, E., Nyame , D., Ayertey , S., & Emini , A. (2026). The Impact of AI-Powered Mobile Money System on Supply Chain: Multi-Cases from SMEs in the Global South. International Journal of Interactive Mobile Technologies (iJIM), 20(01), pp. 105–121. https://doi.org/10.3991/ijim.v20i01.59279

Mohamad, M., Omeish, F., Tarabasz, A. (2025). Metaverse Fashion Ecosystem: A Sustainable Marketing Perspective. In: Ozuem, W., Ranfagni, S., Millman, C. (eds) Sustainable Digital Marketing for Fashion and Luxury Brands. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-031-82467-8_19

Moore, R. L., & Lee, S. S. (2024). Harnessing generative AI (GenAI) for automated feedback in higher education: A systematic review. Online Learning Journal. DOI: 10.24059/olj.v28i3.4593

Moreno López, G.A., Recaman Chaux, H., Molina Parra, P.A. (2024). Digital Twins, Metaverse, and Learning. Review and Proposal of Conceptual Framework. In: Bourguet, ML., Krüger, J.M., Pedrosa, D., Dengel, A., Peña-Rios, A., Richter, J. (eds) Immersive Learning Research Network. iLRN 2023. Communications in Computer and Information Science, vol 1904. Springer, Cham. https://doi.org/10.1007/978-3-031-47328-9_37

Mosha NFV, Chigwada J, Ketchiwou GF, Ngulube P. A Systematic Review of Artificial Intelligence in Higher Education Institutions (HEIs): Functionalities, Challenges, and Best Practices. Education Sciences. 2026; 16(2):185. https://doi.org/10.3390/educsci16020185

Nguyen, A., Huynh, L., Dang, B. et al. Conceptualizing and enhancing metaverse literacy for education. Educ Inf Technol 30, 17133–17153 (2025). https://doi.org/10.1007/s10639-025-13486-9

Onu, P., Pradhan, A. & Mbohwa, C. (2024). Potential to use metaverse for future teaching and learning. Educ Inf Technol 29, 8893–8924. https://doi.org/10.1007/s10639-023-12167-9

Poduval, V. (2025, July 2). Role of EdTech in MENA: How online education is enhancing workforce readiness. Integrator Media. Available at: https://integratormedia.com/2025/07/02/role-of-edtech-in-mena-region-how-online-education-is-enhancing-future-readiness-of-workforce/

PwC. (2025). The Fearless Future: 2025 Global AI Jobs Barometer. Available at: https://www.pwc.com/gx/en/issues/artificial-intelligence/job-barometer/2025/report.pdf

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

Sripan, T., & Jeerapattanatorn, P. (2025). Metaverse-based learning: A comprehensive review of current trends, challenges, and future implications. Contemporary Educational Technology, 17(3), ep584. https://doi.org/10.30935/cedtech/16434

Stracke, C. M., Bothe, P., Adler, S., Heller, E. S., Deuchler, J., Pomino, J., & Wölfel, M. (2025). Immersive virtual reality in higher education: A systematic review of the scientific literature. Virtual Reality. https://doi.org/10.1007/s10055-025-01136-x

Tang, M., Nikolaenko, M., Alrefai, A., & Kumar, A. (2025). Metaverse and digital twins in the age of AI and extended reality. Architecture, 5(2), 36. https://doi.org/10.3390/architecture5020036

Wang, M., Yu, H., Bell, Z., & Chu, X. (2022). Constructing an edu-metaverse ecosystem: A new and innovative framework. IEEE Transactions on Learning Technologies, 15(6), 685-696. DOI: 10.1109/TLT.2022.3210828.

Wang, Y., Harris, J., & Ramachandran, K. (2023, June). Measuring Engineering Students' Entrepreneurial Self-Efficacy in an Entrepreneurship Education Program. In 2023 ASEE Annual Conference & Exposition. DOI: 10.18260/1-2--43570

Wickramasinghe, M., Gunawardena, L., & Padukkage, A. (2025). Ethical principles for artificial intelligence in education: A meta-review approach. AI and Ethics, 6, 63. https://doi.org/10.1007/s43681-025-00878-3

Woick, A., Rinn, H., Grogorick, L., Mühleisen, T., & Markgraf, D. (2024). Metaverse in Higher Education–A Systematic Literature Review. 37th Bled eConference Resilience Through Digital Innovation: Enabling the Twin Transition, 57. DOI https://doi.org/10.18690/um.fov.4.2024.4