International Journal of Informatics and Communication Technology (IJ-ICT)
Vol. 15, No. 3, September 2026, pp. 1408~1418
ISSN: 2252-8776, DOI: 10.11591/ijict.v15i3.pp1408-1418

Metaverse based immersive learning prototype for satellite communication using silvercoms model

Komputerio Akbar[1], Meyliana[2], Harco Leslie Hendric Spits Warnars[1], Ilvico Sonata[1]
[1]Department of Computer Science, Doctor of Computer Science Program, BINUS Graduate Program, Bina Nusantara University, Jakarta, Indonesia
[2]Department of Information Systems, School of Information Systems, Bina Nusantara University, Jakarta, Indonesia

Article Info

Article history:

Received May 6, 2025
Revised Apr 23, 2026
Accepted May 17, 2026

Keywords:

Immersive learning
Metaverse education
Satellite communication
Silvercoms model
Virtual reality

ABSTRACT

Advancements in immersive technologies and the metaverse are transforming engineering education. Satellite communication, as a complex and abstract domain, requires innovative approaches to enhance conceptual understanding and learner engagement beyond traditional methods. This study proposes the Silvercoms model, an immersive learning framework tailored for satellite communication systems education, integrating metaverse technology with pedagogical design. The model combines 3D interactive simulations, collaborative virtual environments, and systems-level content delivery, structured using the 6E instructional model and supported by the motivated strategies for learning questionnaire (MSLQ) to address both cognitive and motivational aspects of learning. The system is developed using a systems engineering approach and implemented with Unity3D in a virtual reality (VR) based metaverse environment. The prototype includes modules such as satellite orbit simulation, satellite history, and interactive satellite systems, enabling experiential and concept-driven learning. This study contributes by integrating immersive technology with structured pedagogical frameworks, offering a novel approach to improving learning effectiveness in satellite communication systems education.

Corresponding Author:

Komputerio Akbar
Department of Computer Science, Doctor of Computer Science Program, BINUS Graduate Program
Bina Nusantara University
Jakarta, Indonesia
Email: Komputerio.akbar@binus.ac.id

1. INTRODUCTION

In recent years, the field of satellite communication systems has undergone rapid development, influencing key areas such as global connectivity, disaster monitoring, and remote sensing. As these systems become more complex and essential in modern infrastructure, there is a growing demand for educational models that not only deliver theoretical knowledge but also support the development of practical, systems-level understanding. Recent advancements in immersive technologies particularly in the context of the metaverse and virtual reality (VR) offer promising opportunities for transforming how students learn technical subjects. Immersive learning environments enable learners to explore simulated systems, manipulate virtual models, and engage in scenario-based learning that closely mirrors real world applications [1]. These experiences have been shown to improve both retention and motivation, particularly in educational settings [2].

Responding to this need, the present study introduces a prototype design of an immersive learning environment for satellite communication systems education. The proposed prototype, referred to as the Silvercoms model (immersive learning metaverse satellite communication systems model), integrates interactive 3D simulations, virtual collaboration tools, and modular content delivery designed specifically for satellite engineering topics. The learning model is grounded in the 6E instructional framework, which emphasizes stages such as engage, explore, and evaluate to structure student experiences. In addition, the motivated strategies for learning questionnaire (MSLQ) is employed during the design phase to ensure that the system aligns with student motivation and cognitive strategy profiles [3]. These pedagogical components are embedded into a metaverse-based platform built using Unity3D and deployed through Oculus VR. This paper focuses on the design rationale, system architecture, and early-stage implementation of the prototype. By presenting a working model that bridges instructional theory with immersive technology, this study contributes a foundation for future deployment and empirical evaluation of immersive tools in specialized engineering education contexts.

2. RESEARCH METHOD

This study adopts a design science research (DSR) approach as the primary methodological framework to guide the development and initial implementation of the Silvercoms model, an immersive learning model for satellite communication systems education. DSR is particularly suitable for technology enhanced learning environments, as it emphasizes the systematic design, evaluation, and refinement of artifacts to address real world problems through iterative processes [4]. The research follows three interconnected cycles: (i) the relevance cycle, linking research to practical needs; (ii) the design cycle, focusing on artifact development and refinement; (iii) the rigor cycle, grounding the design in established theories.

2.1. Problem identification and contextualization (relevance cycle)

The initial phase aimed to identify key challenges in satellite communication education. Data were collected through surveys and semi-structured interviews involving students, lecturers, and practitioners with expertise in the field. The findings indicate persistent difficulties in understanding abstract and complex concepts when using traditional teaching methods. Participants highlighted the need for more interactive, engaging, and conceptually rich learning environments. These results are consistent with prior studies emphasizing the importance of immersive and experiential learning approaches in engineering education.

2.2. Theoretical grounding and design principles (rigor cycle)

To ensure pedagogical rigor, the learning environment was designed based on five core frameworks:

2.2.1. Metaverse concept

The metaverse is an immersive three dimensional (3D) virtual environment that enables interaction between users and digital systems through avatars [5]. The development of 3D models within the metaverse provides significant potential for supporting training and educational applications, particularly in maintenance related fields, including aviation maintenance information delivery and collaborative environments supported by oculus and VR technologies [6].The key characteristics of the metaverse include immersion, interactivity, persistence, and integration with emerging technologies such as VR, augmented reality (AR), and blockchain [7]. In addition, the metaverse facilitates collaborative and accessible learning by overcoming geographical and physical constraints [8]. It is anticipated to evolve into a decentralized and persistent environment enriched with user generated content [9]. The development of the metaverse is guided by core design principles, including openness, transparency, inclusivity, security, sustainability, and ethical considerations [10]. This vision places the metaverse as an innovation supporting responsible digital transformation, creating a safe, interactive, and beneficial environment for society at large, especially in the educational domain [11]. These principles position the metaverse as a transformative platform for education and digital interaction.

2.2.2. Metaverse in education

The metaverse offers significant potential across various educational domains, including engineering, healthcare, military training, satellite communication, manufacturing, and language learning [12]. It enables immersive, interactive, and collaborative environments where learners can explore concepts, interact with virtual objects, and collaborate without spatial and temporal constraints [13]. Compared to conventional approaches, metaverse-based learning provides more contextual and experiential learning experiences while supporting skill practice, access to otherwise inaccessible scenarios, and sustained engagement. It also promotes higher order skills such as critical thinking, creativity, and problem solving through authentic learning activities.

From an instructional design perspective, effective metaverse implementation requires replicating real world learning experiences in virtual environments [14]. A key challenge is designing avatar based interactions that convey not only physical movement but also non verbal communication such as facial expressions and body language [15]. Additionally, fostering collaboration requires active engagement and the development of a sense of community among learners [16]. Therefore, metaverse design must prioritize meaningful interaction and communication to create optimal learning environments [17].

Key implementation principles include replicating real world contexts, extending beyond traditional and e-learning environments, aligning pedagogy with virtual platforms, ensuring technological readiness, and developing appropriate assessment methods [18]. This includes the design of Metaverse features, the development of new learning methods, changes in teaching and assessment techniques, and the readiness and training to use relevant technologies [19]. Pedagogically, constructivism provides a strong foundation by emphasizing active participation, experiential learning, and contextual relevance [20]. Visual literacy comprising visual perception, language, thinking, and communication also plays a critical role in immersive learning environments [21]. By leveraging VR, the metaverse enhances learning through realistic simulations, direct interaction, and sensory feedback, enabling learners to connect theory with practice. Such environments have been shown to improve engagement, motivation, and knowledge retention [22]. The interactive and immersive nature of the metaverse allows these principles to be effectively applied by providing authentic, relevant, and exploration-based learning experiences [23]. Overall, the metaverse has strong potential to transform education into a more interactive, flexible, and learner centered paradigm when supported by appropriate pedagogical and technological integration.

2.2.3. Immersive metaverse using VR

Immersiveness refers to the extent to which users can experience a virtual world as if they were physically present, enhancing engagement and interaction [15]. Immersive technologies improve this experience by providing realistic and interactive environments [24] supported by convincing virtual systems [25]. This is achieved through sensory feedback, including audio/visual and haptic responses, which create active participation and spatial presence [26]. This “cause and effect” feedback generates a sense of spatial presence, encouraging users to feel more engaged in the virtual world [27]. Environmental elements such as lighting and sound also contribute significantly to immersion [28]. Digital representations, such as avatars and virtual objects, further enhance immersion [29]. VR enables natural interaction through body movement, creating more realistic experiences [30]. In education, VR supports simulation based learning, allowing learners to practice skills in safe environments [31]. High levels of immersion increase presence, engagement, satisfaction, and positively influence cognitive and affective outcomes such as memory, perception, emotion, and motivation [32].

Immersive metaverses integrate VR based presence with narrative and scenario driven learning experiences [33], shaped by evolving educational practices [34]. Effective learning occurs when learners solve real-world problems, activate prior knowledge, apply new concepts, and integrate them into their contexts [35]. Therefore, immersive learning through metaverse and VR offers strong potential to enhance interactive and meaningful learning experiences [36], particularly when knowledge is applied in real world contexts [37].

2.2.4. MSLQ

The MSLQ was first developed by Pintrich, Smith, Garcia, and McKeachie in 1991 to assess the motivational, cognitive, and metacognitive adjustments among students, as well as the use of various learning strategies in college courses [38]. The MSLQ consists of six sections that measure motivation with two scales to assess value, expectations, and affect, nine sections to measure learning strategies with two scales for cognitive and metacognitive strategies, and resource management [39]. The components of the MSLQ are visually illustrated in Table 1.

Self regulated learning refers to the application of metacognition and self regulation in the learning process. Metacognition refers to the ability to monitor and control thought processes, while self regulation involves the monitoring and control of emotions and behaviors. This concept is viewed as a dynamic interaction between the individual, the environment, and the tasks, encompassing three main components: cognition, metacognition, and motivation [40]. The MSLQ is based on a social cognitive perspective, which views students as being responsible for their own learning processes.

2.2.5. Instructional model 6E

Figure 1 illustrates the 6E instructional model, which integrates structured and hands-on learning activities to improve the effectiveness of content delivery. It consists of six stages: engage, explore, explain, engineer, enrich, and evaluate [41], which guide educators in designing and evaluating learning processes within metaverse based VR environments. This model supports adaptive and student centered learning experiences [42] and is used in this study as the primary instructional framework. The metaverse, supported by VR technology, enhances students' understanding of abstract concepts through direct interaction and immersive experiences, enabling them to bridge theory and practice more effectively [43]. This approach aims to create meaningful and authentic learning experiences connected to real world contexts while encouraging student responsibility. Its successful implementation requires alignment between learning objectives, curriculum, pedagogical strategies, and instructional design.

In the context of this study, the metaverse is not only utilized as a technological platform but also as a pedagogical medium to support structured and meaningful learning experiences in satellite communication systems. By integrating immersive environments with instructional frameworks such as the 6E model and motivational constructs from MSLQ, the proposed Silvercoms model aims to address both conceptual complexity and learner engagement. This approach distinguishes the study from prior work that primarily focuses on technological implementation without strong pedagogical integration.

Table 1. The components of MSLQ

Broad component	Specific component
Motivation	Intrinsic goal orientation
	Extrinsic goal orientation
	Task value
	Control of learning beliefs
	Self-efficacy for learning and performance
	Test anxiety
Learning strategies	Rehearsal
	Elaboration
	Organization
	Critical thinking
	Metacognitive self-regulation
Requlation strategies	Time and study environment
	Effort regulation
Social strategies	Peer learning
	Help seeking

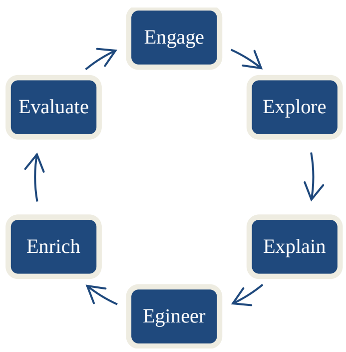

Figure 1. Instructional model 6E

2.2.6. Immersive learning metaverse satellite communication system model (Silvercoms model)

Addressing the research gap, traditional satellite communication education remains dominated by lecture-based and two dimensional approaches that inadequately capture spatial complexity and abstract concepts such as orbital mechanics and signal propagation [44]. Although immersive technologies have shown effectiveness in engineering education [45], an integrated framework combining pedagogy, technology, and learning assessment in this domain is still lacking. Figure 2 presents the Silvercoms model addresses this gap by proposing a theoretically grounded and empirically validated framework integrating three dimensions: people, process, and technology. The people dimension includes learner characteristics, instructor roles, and stakeholder engagement. The process dimension adopts the 6E instructional model (engage, explore, explain, engineer, enrich, evaluate) to support systematic knowledge construction. The technology dimension encompasses metaverse infrastructure, VR based interaction, and learning analytics, where technology acts as an enabler aligned with pedagogical goals.

A key strength of the model lies in the bidirectional interaction among these dimensions, allowing learner characteristics to dynamically influence both technological design and instructional processes.

Compared to domain agnostic frameworks [46], Silvercoms is tailored to satellite communication, enhancing its practical relevance. Furthermore, the model employs abductive reasoning to bridge theory practice gaps, extending beyond traditional deductive approaches in information systems research [47]. Learning evaluation is explicitly integrated through pre-post-tests, and MSLQ, ensuring an outcome oriented approach and addressing criticisms of technology driven metaverse applications [48].

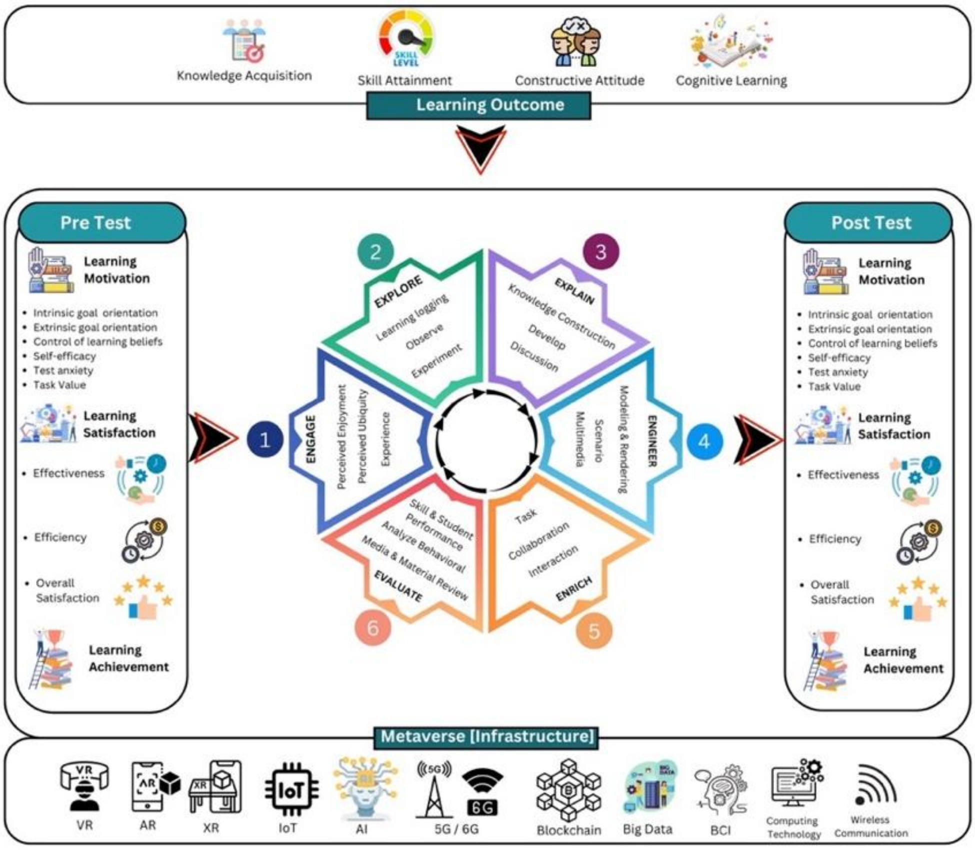

Figure 2. Silvercoms model

3. RESULTS AND DISCUSSION

3.1. Implementation of the Silvercoms model in prototype design

The overall prototype design creation process follows the feature driven development (FDD) methodology, encompassing all systematic steps to establish a comprehensive framework for the metaverse prototype. The primary objective is to construct an overarching architecture of the satellite communication systems metaverse prototype utilizing VR technology, based on empirical data and information obtained from direct surveys conducted at satellite ground control stations. Figure 3 illustrates the lobby area and the comprehensive user interface and navigation architecture of the developed prototype. The metaverse environment was designed with a systematic flow to guide users through various stages of interaction, progressing from initial entry through knowledge assessment to educational content exploration. The interface comprises six primary components that collectively form an integrated learning ecosystem: Figure 3(a) shows the disclaimer screen, Figure 3(b) the lobby area, Figure 3(c) the personal information input module, Figure 3(d) the pre-test and post-test assessment interfaces, Figure 3(e) the satellite history information, and Figure 3(f) the area map information.Each component serves a distinct pedagogical and functional purpose while maintaining seamless connectivity throughout the virtual environment. The implementation of these interface components encompasses three main user interaction scenarios.

3.1.1. Lobby area

The lobby area serves as the registration center, where disclaimers related to regulations, satellite history information, the metaverse world map, as well as pre test administration before using the prototype and post-test completion after using the prototype are provided.

a. Disclaimer: a statement provided to users to inform them about the limitations, responsibilities, or warnings related to the use of the metaverse prototype for satellite communication systems.
b. Lobby area: the initial area or main space within the metaverse platform designed to welcome users before they enter into more profound virtual experiences. This area serves a similar function to a lobby in the real world, acting as a place for registration, orientation, and setup before proceeding to the next stage or area.
c. Input personal info: the process in which users provide their personal information for identification and personalization purposes.
d. Pre-test and post-test:
   - Pre-test: an initial evaluation conducted to assess the knowledge, skills, or readiness of users before they engage in learning, training, or exploration within the metaverse environment. This pre-test serves as a baseline or reference to understand the user’s current knowledge or capabilities regarding satellite communication systems before the immersive experience begins.
   - Post-test: an evaluation or knowledge test conducted after the user completes the learning session or experience within the metaverse for satellite communication systems. The purpose of the post-test is to measure the understanding and skills gained by the user after participating in activities or simulations within the metaverse, as well as to assess how well they can apply the information learned in more realistic or practical contexts.
e. Satellite history information in Indonesia: an interactive and immersive presentation of the development of satellite technology in Indonesia. This information covers the history of satellite launches, innovations, and recent advancements designed to enhance the user’s understanding of the role of satellites in national development.
f. Area map information: a feature that provides a map or layout of the virtual world within the Satellite Communication Systems Metaverse prototype, allowing users to navigate and understand the structure and critical locations within the virtual world. This area map serves as an interactive guide, helping users find various zones or places in the metaverse while providing information about the function or purpose of each area.

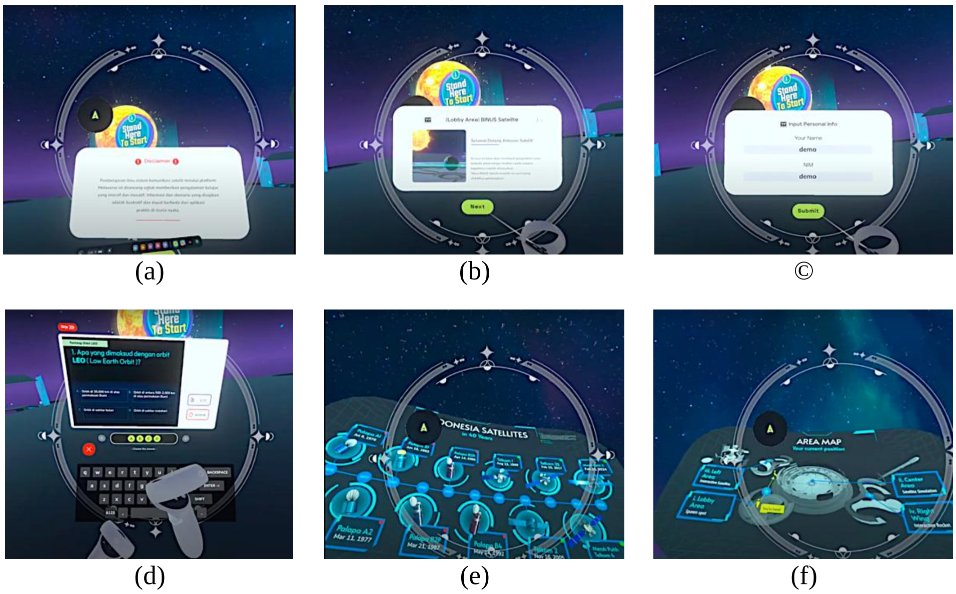

Figure 3. Lobby area; (a) disclaimer, (b) lobby area, (c) input personal info, (d) pre-test and post-test, (e) satellite history, and (f) area map information

3.1.2. Center area

Figure 4 illustrates the center area, which serves as the primary interactive space within the satellite communication systems metaverse prototype. This central hub functions as the focal point for user engagement, facilitating exploration, collaboration, learning activities, and immersive interaction with satellite communication concepts. The center area features a comprehensive visualization of the satellite launch sequence and orbital trajectory progression, depicting the transition of satellites through low earth orbit (LEO), medium earth orbit (MEO), and geostationary earth orbit (GEO). The visualization employs a sequential, user-controlled progression mechanism wherein participants must activate the “start” button to advance through each explanatory segment, ensuring deliberate engagement with the educational content. To enhance comprehension and accommodate diverse learning preferences, the area integrates multimodal instructional support through both voice narration and text-based guidance, reinforcing key concepts and providing contextual information throughout the interactive experience.

Figure 4. Center area

3.1.3. Interactive area

Figure 5 illustrates the interactive area, a dedicated virtual environment designed to facilitate direct user engagement with the technical specifications and operational data of rocket systems and satellite platforms. This area provides access to detailed engineering specifications, performance parameters, and key technical characteristics of both launch vehicles and satellite payloads. Through interactive features, users can explore and examine technical information in depth, supporting active learning and improved understanding of complex aerospace systems.

- The interface also demonstrates the organization of technical content and user interaction modalities within the immersive environment. The main interaction features include: interaction with rocket specifications: users can explore and manipulate a 3D rocket model to examine key components such as engines, fuel systems, and control systems. Each component can be selected to display detailed functional and technological information.
- Interaction with satellite specifications: users can interact with a 3D satellite model to observe structural elements such as solar panels, antennas, and communication subsystems, enabling detailed visualization and conceptual understanding of satellite design.

In addition, the presence of avatars, content designs replicating real world situations, authentic and spatial audio, and haptic controllers that provide physical feedback all contribute to enhancing the user's sense of presence in the virtual world. Coupled with eye tracking technology, which allows for focusing on the details of objects being viewed in real time, these features are designed to create an increasingly immersive and realistic metaverse experience. By integrating these elements, the prototype enables users to experience a true sense of presence, making them feel as though they are genuinely inside the virtual world, creating an enjoyable learning experience in the metaverse.

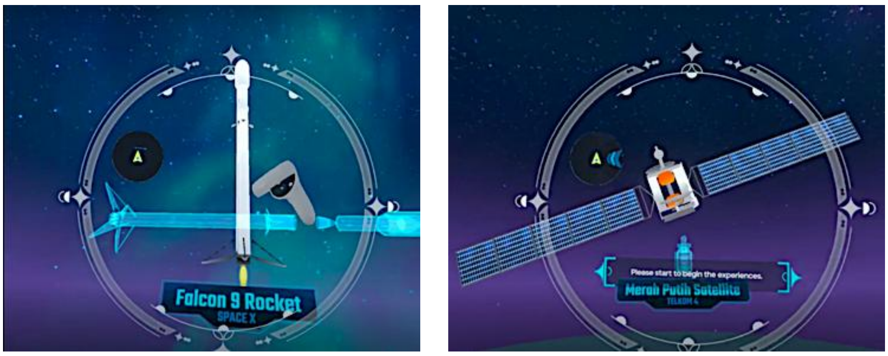

Figure 5. Interactive area

3.2. Discussion

The implementation of metaverse based learning environments in satellite communication systems education demonstrates significant potential to enhance students' understanding of complex and abstract concepts. The proposed Silvercoms model creates an immersive learning experience that enables students to interact directly with both theoretical and practical aspects of satellite communication, which are often difficult to comprehend through traditional instructional methods. One of the key findings of this study is the effectiveness of VR technology in creating an interactive and experiential learning environment. Through the developed prototype, students can simulate satellite launch processes and orbital movements, resulting in a deeper and more accurate conceptual understanding compared to conventional text-based or visual learning approaches.

Furthermore, interaction with 3D models of satellites and rockets allows learners to explore system components and functionalities in a more detailed and realistic manner. The integration of avatars, along with voice and text-based guidance, further enhances learner engagement and supports comprehension of complex concepts. This experiential and exploratory approach aligns with constructivist learning principles, encouraging active participation and knowledge construction. However, several challenges remain, including the need for adequate technological infrastructure such as VR headsets and high-performance computing devices, which may limit accessibility. In addition, successful implementation depends on instructors' readiness to adopt the technology and their ability to design meaningful and pedagogically sound learning experiences.

To maximize effectiveness, the integration of metaverse based learning with conventional teaching approaches and appropriate evaluation strategies is essential. A balanced and hybrid learning model ensures that students benefit from both immersive experiences and structured instructional support. Overall, the Silvercoms model demonstrates strong potential to improve the quality of learning in satellite communication systems by providing interactive, engaging, and contextually rich learning environments. This study contributes to the field of engineering education in three main aspects. First, in terms of pedagogical technological integration, it proposes the Silvercoms model, which combines metaverse based immersive learning with the 6E instructional framework and MSLQ to address both cognitive and motivational dimensions of learning. Second, from a domain specific perspective, it develops a structured immersive learning prototype tailored for satellite communication systems, a domain characterized by high conceptual complexity. Third, from a methodological standpoint, it provides a systematically designed and validated artifact following the DSR approach, offering a reusable framework for future immersive learning system development.

4. CONCLUSION

This study proposes the Silvercoms model for designing a metaverse-based educational system utilizing VR in the context of satellite communication. The model aims to enhance learning quality and effectiveness through an immersive and interactive environment. Through the developed prototype, students can directly interact with satellite communication processes from launch to orbital operations facilitating a clearer understanding of complex technical concepts and supporting their application in practical contexts. The model also provides a structured framework for educators to adopt immersive learning in higher education, thereby improving student engagement and competence. The findings indicate that the metaverse serves as an effective platform for satellite communication education by offering immersive and engaging learning experiences. Features such as avatars, 3D models, and voice and text-based guidance support independent learning and align with constructivist principles. However, several challenges remain, including limited access to adequate hardware and the readiness of instructors to effectively utilize metaverse technologies. Therefore, proper infrastructure and training are essential for optimal implementation. Overall, the Silvercoms model demonstrates strong potential to enhance satellite communication education. Future research is needed to evaluate and validate the proposed model and prototype, while integrating appropriate pedagogical approaches to enable more inclusive, engaging, and practical learning in the digital era.

FUNDING INFORMATION

The authors state no funding was involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Komputerio Akbar	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Meyliana	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Harco Leslie Hendric Spits Warnars	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓		
Ilvico Sonata	✓	✓		✓	✓	✓		✓	✓	✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data generated and analyzed during this study are available from the corresponding author upon reasonable request. Due to potential privacy concerns or proprietary agreements, certain datasets may require further ethical or legal considerations before dissemination. Requests should be directed to the corresponding author's contact details.

REFERENCES

[1] M. Frydenberg and S. Ohri, "Designing a metaverse for an immersive learning experience," in *9th International Conference on Higher Education Advances (HEAd'23)*, Valencia: Universitat Politècnica de València, Jun. 2023, pp. 1139–1146. doi: 10.4995/HEAd23.2023.16080.

[2] R. O. Flores-Castañeda, S. Olaya-Cotera, and O. Iparraguirre-Villanueva, "Benefits of metaverse application in education: a systematic review," *International Journal of Engineering Pedagogy (iJEP)*, vol. 14, no. 1, pp. 61–81, Jan. 2024, doi: 10.3991/ijep.v14i1.42421.

[3] B. Mulyawan, H. Prabowo, S. W. H. L. Hendric, and I. H. Kartowisastro, "The conceptual model of the student learning outcomes monitoring system for higher education institutions," in *2024 3rd International Conference for Innovation in Technology (INOCON)*, IEEE, Mar. 2024, pp. 1–5. doi: 10.1109/INOCON60754.2024.10511521.

[4] G. Wagner, J. Prester, and G. Schryen, "Exploring the scientific impact of information systems design science research: a scientometric study," in *ICIS 2017: Transforming Society with Digital Innovation*, 2017, p. 23.

[5] M. Weinberger, "What is metaverse?—A definition based on qualitative meta-synthesis," *Future Internet*, vol. 14, no. 11, p. 310, Oct. 2022, doi: 10.3390/fi14110310.

[6] A. M. Al-Ghaili *et al.*, "A review of metaverse's definitions, architecture, applications, challenges, issues, solutions, and future trends," *IEEE Access*, vol. 10, pp. 125835–125866, 2022, doi: 10.1109/ACCESS.2022.3225638.

[7] J. S. Jauhiainen, C. Krohn, and J. Junnila, "Metaverse and sustainability: systematic review of scientific publications until 2022 and beyond," *Sustainability*, vol. 15, no. 1, p. 346, Dec. 2022, doi: 10.3390/su15010346.

[8] N. A. Dahan, "Metaverse framework: a case study on e-learning environment (ELEM)," *Electronics (Switzerland)*, vol. 11, no. 10, 2022, doi: 10.3390/electronics11101616.

[9] G. D. Ritterbusch and M. R. Teichmann, "Defining the metaverse: a systematic literature review," *IEEE Access*, vol. 11, pp. 12368–12377, 2023, doi: 10.1109/ACCESS.2023.3241809.

[10] M. Zallio and P. J. Clarkson, "Designing the metaverse: a study on inclusion, diversity, equity, accessibility and safety for digital immersive environments," *Telematics and Informatics*. Elsevier, 2022.

[11] L. Ismail and R. Buyya, "Metaverse: a vision, architectural elements, and future directions for scalable and realtime virtual worlds," *arXiv preprint*, 2023, [Online]. Available: http://arxiv.org/abs/2308.10559

[12] H. Lin, S. Wan, W. Gan, J. Chen, and H.-C. Chao, "Metaverse in education: vision, opportunities, and challenges," in *2022 IEEE International Conference on Big Data (Big Data)*, IEEE, Dec. 2022, pp. 2857–2866. doi: 10.1109/BigData55660.2022.10021004.

[13] G.-J. Hwang and S.-Y. Chien, "Definition, roles, and potential research issues of the metaverse in education: An artificial intelligence perspective," *Computers and Education: Artificial Intelligence*, vol. 3, p. 100082, 2022, doi: 10.1016/j.caeai.2022.100082.

[14] E. Mogaji, J. Wirtz, R. W. Belk, and Y. K. Dwivedi, "Immersive time (ImT): conceptualizing time spent in the metaverse," *International Journal of Information Management*, vol. 72, p. 102659, Oct. 2023, doi: 10.1016/j.ijinfomgt.2023.102659.

[15] S. Richter and A. Richter, "What is novel about the metaverse?," *International Journal of Information Management*, vol. 73, p. 102684, Dec. 2023, doi: 10.1016/j.ijinfomgt.2023.102684.

[16] D. Wu, Z. Yang, P. Zhang, R. Wang, B. Yang, and X. Ma, "Virtual-reality interpromotion technology for metaverse: a survey," *IEEE Internet of Things Journal*, vol. 10, no. 18, pp. 15788–15809, Sep. 2023, doi: 10.1109/JIOT.2023.3265848.

[17] Y. K. Dwivedi *et al.*, "Metaverse beyond the hype: multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy," *International Journal of information management*, vol. 66, 2022.

[18] M. A. Al-Sharafi, M. Al-Emran, N. Al-Qaysi, M. Iranmanesh, and N. Ibrahim, "Drivers and barriers affecting metaverse adoption: a systematic review, theoretical framework, and avenues for future research," *International Journal of Human-Computer Interaction*, vol. 0, no. 0, pp. 1–22, 2023, doi: 10.1080/10447318.2023.2260984.

[19] A. S. Bale, N. Ghorpade, M. F. Hashim, J. Vaishnav, and Z. Almaspoor, "A comprehensive study on metaverse and its impacts on humans," *Advances in Human-Computer Interaction*, vol. 2022, pp. 1–11, Sep. 2022, doi: 10.1155/2022/3247060.

[20] J.-E. Yu, "Exploration of educational possibilities by four metaverse types in physical education," *Technologies*, vol. 10, no. 5, p. 104, Sep. 2022, doi: 10.3390/technologies10050104.

[21] S.-M. Park and Y.-G. Kim, "A metaverse: taxonomy, components, applications, and open challenges," *IEEE Access*, vol. 10, pp. 4209–4251, 2022, doi: 10.1109/ACCESS.2021.3140175.

[22] J. E. Yu, "Exploration of educational possibilities by four metaverse types in physical education," *Technologies*, 2022.

[23] P. Faraboschi, E. Frachtenberg, P. Laplante, D. Milojicic, and R. Saracco, "Virtual worlds (metaverse): from skepticism, to fear, to immersive opportunities," *Computer*, vol. 55, no. 10, pp. 100–106, 2022, doi: 10.1109/MC.2022.3192702.

[24] A. H. M. Aburbeian, A. Y. Owda, and M. Owda, "A technology acceptance model survey of the metaverse prospects," *AI (Switzerland)*, vol. 3, no. 2, pp. 285–302, 2022, doi: 10.3390/ai3020018.

[25] T.-S. Weng, C.-K. Li, and Y. Kawasaki, "Creating an engaging and immersive environmental, social, and governance learning experience through the metaverse," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 14099 LNCS, 2023, pp. 473–483. doi: 10.1007/978-3-031-40113-8_46.

[26] A. Saber, E. Hassan, S. Elbedwehy, and T. Z. Emara, "Learning in the Metaverse: virtual classrooms, immersive experiences, and beyond," in *Critical Ethical and Societal Implications of the Metaverse*, 2025, pp. 109–138. doi: 10.4018/979-8-3373-3043-3.ch005.

[27] Y. Liu, J. Huang, and S. SalmizaSaleh, "A review of the application of the metaverse in education," *Educational Administration: Theory and Practice*, vol. 30, no. 8, pp. 84–97, 2024, doi: 10.53555/kuey.v30i8.6986.

[28] S. Mystakidis and V. Lympouridis, "Designing simulations in the metaverse: a blueprint for experiential immersive learning experiences," in *Springer Series on Cultural Computing*, vol. Part F2842, V. Geroimenko, Ed., Cham: Springer, 2024, pp. 65–79. doi: 10.1007/978-3-031-57746-8_4.

[29] S. Kaddoura and F. Al Husseiny, "The rising trend of metaverse in education: challenges, opportunities, and ethical considerations," *PeerJ Computer Science*, vol. 9, p. e1252, Feb. 2023, doi: 10.7717/peerj-cs.1252.

[30] P. Onu, A. Pradhan, and C. Mbohwa, "Potential to use metaverse for future teaching and learning," *Education and Information Technologies*, vol. 29, no. 7, pp. 8893–8924, May 2024, doi: 10.1007/s10639-023-12167-9.

[31] Y. Huang, Y. J. Li, and Z. Cai, "Security and privacy in metaverse: a comprehensive survey," *Big Data Mining and Analytics*, vol. 6, no. 2, pp. 234–247, Jun. 2023, doi: 10.26599/BDMA.2022.9020047.

[32] T. Hennig-Thurau, D. N. Aliman, A. M. Herting, G. P. Cziehso, M. Linder, and R. V. Kübler, "Social interactions in the metaverse: framework, initial evidence, and research roadmap," *Journal of the Academy of marketing science*, vol. 51, no. 4, pp. 889-913, 2022, doi: 10.1007/s11747-022-00908-0.

[33] P. De Giovanni, "Sustainability of the metaverse: a transition to Industry 5.0," *Sustainability*, vol. 15, no. 7, p. 6079, Mar. 2023, doi: 10.3390/su15076079.

[34] D. Vidal-Tomás, "The illusion of the metaverse and meta-economy," *SSRN Electronic Journal*. Elsevier BV, 2022. doi: 10.2139/ssrn.4217701.

[35] D. Beck, L. Morgado, and P. O'Shea, "Educational practices and strategies with immersive learning environments: mapping of reviews for using the metaverse," *IEEE Transactions on Learning Technologies*, no. January, 2023, doi: 10.1109/TLT.2023.3243946.

[36] S. Abbate, P. Centobelli, R. Cerchione, E. Oropallo, and E. Riccio, "A first bibliometric literature review on metaverse," in *2022 IEEE Technology and Engineering Management Conference (TEMSCON EUROPE)*, IEEE, Apr. 2022, pp. 254–260. doi: 10.1109/TEMSCONEUROPE54743.2022.9802015.

[37] W. Suh and S. Ahn, "Utilizing the metaverse for learner-centered constructivist education in the post-pandemic era: an analysis of elementary school students," *Journal of Intelligence*, vol. 10, no. 1, p. 17, Mar. 2022, doi: 10.3390/jintelligence10010017.

[38] Ş. Şen, A. Yılmaz, and Ö. Geban, "The effects of process oriented guided inquiry learning environment on students' self-regulated learning skills," *Problems of Education in the 21st Century*, vol. 66, no. 1, pp. 54–66, Aug. 2015, doi: 10.33225/pec/15.66.54.

[39] V. D. Tran and T. A. Dong Le, "Validation of the factor structure of the motivated strategies for learning questionnaire," *International Journal of Evaluation and Research in Education (IJERE)*, vol. 13, no. 4, pp. 2517–2526, Aug. 2024, doi: 10.11591/ijere.v13i4.28703.

[40] J. de Araujo, C. M. A. Gomes, and E. G. Jelihovschi, "The factor structure of the motivated strategies for learning questionnaire (MSLQ): new methodological approaches and evidence," *Psicologia: Reflexão e Crítica*, vol. 36, no. 1, p. 38, Dec. 2023, doi: 10.1186/s41155-023-00280-0.

[41] H. M. A. Mang, H.-E. Chu, S. N. Martin, and C.-J. Kim, "Developing an evaluation rubric for planning and assessing SSI-based STEAM programs in science classrooms," *Research in Science Education*, vol. 53, no. 6, pp. 1119–1144, Dec. 2023, doi: 10.1007/s11165-023-10123-8.

[42] J. Chen *et al.*, "Developing a hands-on activity using virtual reality to help students learn by doing," *Journal of Computer Assisted Learning*, vol. 36, no. 1, pp. 46–60, Feb. 2020, doi: 10.1111/jcal.12389.

[43] H. Lee, D. Woo, and S. Yu, "Virtual reality metaverse system supplementing remote education methods: Based on aircraft maintenance simulation," *Applied Sciences*, vol. 12, no. 5, p. 2667, Mar. 2022, doi: 10.3390/app12052667.

[44] D. E. Salinas-navarro and C. L. Garay-rondero, "Education sciences digitally enabled experiential learning spaces for engineering," 2023.

[45] D. Buragohain, S. Khichar, C. Deng, Y. Meng, and S. Chaudhary, "Analyzing metaverse-based digital therapies, their effectiveness, and potential risks in mental healthcare," *Scientific Reports*, vol. 15, no. 1, p. 17066, May 2025, doi: 10.1038/s41598-025-00916-4.

[46] D. Buragohain, D. Buragohain, Y. Meng, C. Deng, and S. Chaudhary, "A metaverse based digital preservation of temple architecture and heritage," *Scientific Reports*, vol. 15, no. 1, p. 15484, May 2025, doi: 10.1038/s41598-025-00039-w.

[47] N. Levallet, J. S. Denford, and Y. E. Chan, "Following the MAP (methods, approaches, perspectives) in information systems research," *Information Systems Research*, vol. 32, no. 1, pp. 130–146, 2021, doi: 10.1287/isre.2020.0964.

[48] A. Aithal and P. S. Aithal, "Development and validation of survey questionnaire and experimental data – a systematical review-based statistical approach," *International Journal of Management, Technology, and Social Sciences*, vol. 5, no. 2, pp. 233–251, Nov. 2020, doi: 10.47992/IJMTS.2581.6012.0116.

BIOGRAPHIES OF AUTHORS

Komputerio Akbar received his bachelor's degree in informatics engineering from Bina Nusantara University, Indonesia, in 2011. He also earned his master's degree in information systems management from the same university in 2017. He is currently pursuing his doctoral degree in Computer Science (DCS) at Bina Nusantara University, Jakarta, Indonesia. He is actively engaged in research in the field of computer science. His research interests include the metaverse, artificial intelligence, digital transformation, internet of things (IoT), IT and IS governance, smart city, smart building, and smart campus. He can be contacted at email: komputerio.akbar@binus.ac.id.

Meyliana is a professor in the field of information systems at Bina Nusantara University, Indonesia. She has a doctoral degree in computer science (information systems) from the University of Indonesia, Depok, completed in 2015. She also earned a master's degree in management of information systems from Bina Nusantara University, Jakarta, in 1999 and a bachelor's degree in information systems from STMIK Bina Nusantara, Jakarta, in 1996. As an academic, Meyliana serves as a supervisor for doctoral, master's, and undergraduate students at Bina Nusantara University, guiding them in various research areas within information systems. Currently, she is active as an assessor for the Accreditation of Scientific Journals of the Ministry of Research, Technology and Higher Education Indonesia, a member of the KKNI-based Curriculum, APTIKOM Central Management for the 2018-2022 period, and an honorary member of the Indonesian Blockchain Association. Her research focuses on cutting-edge topics such as blockchain, enterprise systems, and immersive technologies, including metaverse, extended reality (XR), VR, AR, and mixed reality (MR). Meyliana has an impressive track record of publications indexed in Scopus, with 194 documents, 910 citations, and an h-index of 14. Her contributions continue to advance the field of Information Systems through impactful research and innovation. She can be contacted at email: meyliana@binus.ac.id.

Harco Leslie Hendric Spits Warnars is head of the Information Systems Concentration at Doctor of Computer Science (DCS) Bina Nusantara University and supervises some Ph.D. students in Information Systems and Computer Science. He did bachelor's degree in computer science in the Information Systems field from STMIK Budi Luhur, Jakarta Selatan, Indonesia, with the title S.Kom. (Sarjana Komputer) between 1991-1995 with a bachelor thesis topic about information systems using Budi Luhur scholarship. Between 2004 and 2006, he continued his master's degree in computer science with a major in Information Technology at the University of Indonesia, with a degree titled M.T.I. (Magister Teknologi Informasi) with a master thesis topic about Datawarehouse, which Budi Luhur University funded. His Ph.D. Computer Science was done at The Manchester Metropolitan University, Manchester, United Kingdom, with a Ph.D. Thesis topic about Data Mining between 2008-2012. His Ph.D. was funded by the Directorate General of Higher Education, Ministry of Education and Culture, Republic of Indonesia (DIKTI) scholarship. He has published over 331 papers cited by 3280 citations with h-index=28 and i10-index=88, as seen in his Google Scholar link. He has SCOPUS publication, as seen in his SCOPUS link account, with 271 documents with 1,241 citations cited by 987 documents with h-index=16. He can be contacted at email: spits.hendric@binus.ac.id.

Ilvico Sonata has experience in the satellite telecommunications industry for more than 27 years. He has a passion for teaching and is currently a lecturer at Doctoral of Computer Science Program, BINUS University. He has scientific expertise in the fields of artificial intelligence, electrical engineering, autonomous systems and computer vision. He also teaches in bachelor's and master's programs. Some of the courses taught include advanced softcomputing and internet of things. He has professional certification in the fields of satellite telecommunications and data science. He is also active in writing several conference papers and Scopus indexed journals. He can be contacted at email: ilvico@binus.ac.id.