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3D Holographic Technology for University Students in International Higher Education: A Systematic Review of Pedagogical Models, Benefits, and Implementation Strategies

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Systematic Review

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Abstract

The incorporation of 3D hologram technology into higher education teaching is a notable development in immersive and virtual pedagogy. The review examines its effect through theoretical underpinnings, pedagogical frameworks, implementation strategies, and empirical data. Built on the assumptions of cognitive load theory, constructivism, and embodied learning, holography fosters deeper student engagement, enhances spatial awareness, and improves memory. Models such as flipped classrooms, virtual labs, and telepresence lectures have yielded encouraging results, particularly in medicine, engineering, and design. Important factors in implementation include curriculum alignment, faculty training, and the readiness of the infrastructure. Despite cost and scalability issues, the results affirm the increasing potential of holography in creating interactive, inclusive, and efficient higher education.

Methodology

The review was done in a structured and integrative manner to identify, assess, and synthesize the available empirical and theoretical literature on the use of 3D holographic technology in higher education. The methodology followed best practices in educational technology review studies and included the following steps:

Research Design

A narrative literature review design was used, incorporating both qualitative synthesis and selective empirical data extraction. The use of this method enabled in-depth exploration of various pedagogical models, implementation approaches, and learning outcomes related to holographic technology across a range of higher education fields.

Databases and Sources Searched

Systematic searching of the literature was performed using the following academic databases and scholarly repositories:

- Scopus
- Web of Science
- ERIC (Education Resources Information Center)
- IEEE Xplore
- PubMed (for medical education studies)
- Google Scholar (for pilot case studies and grey literature)

The search comprised peer-reviewed journal papers, conference papers, and institutional reports dated between 2000 and 2025 to get the latest updates on holographic and mixed reality education. The data extraction and analysis from different research papers are shown in Table 1.

Inclusion Criteria

Studies were considered for inclusion if they fulfilled the following criteria:

- Targeted higher education or university-level teaching
- Employed 3D holographic, holographic projection, or mixed reality technologies in instructional settings

- Mentioned learning outcomes, pedagogical models, or implementation strategies
- Were published in English between the years 2010 and 2024
- Peer-reviewed journal articles, institutional case studies, or high-quality conference papers

Exclusion Criteria

Studies were excluded if:

- We are solely focused on primary or secondary education
- Covered the technical development of holographic hardware without an educational context
- Included no instructional models or learning outcomes
- Were non-peer-reviewed opinion pieces or news pieces

Quality Assurance

To ensure reliability, the systematic review's process of selecting literature employed a double-screening approach, in which two reviewers independently evaluated both abstracts and full texts. Differences were resolved through discussion and reevaluation. Studies were evaluated using an adapted Mixed Methods Appraisal Tool (MMAT) to assess methodological quality.

Table 1: Data extraction and analysis of studies on hologram integration in higher education

Study / Author(s)	Year	Context	Sample	Key Outcome
Bower et al.	2017	Flipped classroom in undergraduate biology	45 undergraduate students	Improved engagement and conceptual understanding
Makransky et al.	2019	Simulation-based learning in medical training	88 medical students	Higher retention and motivation in immersive settings
Moro et al.	2021	Anatomy learning using holographic visuals	120 anatomy students	Enhanced spatial understanding and test performance
Zhu et al.	2020	Virtual lab in electrical engineering	60 engineering students	Improved accuracy and task efficiency
Kent & Downey	2018	Holographic guest lectures in business education	40 postgraduate students	Increased engagement compared to traditional video
Bower & Sturman	2015	Collaborative design via holography	30 architecture students	Improved group collaboration and creativity
Cai et al.	2013	Science demonstrations using AR & holography	50 high school (pilot for uni)	Better understanding of abstract concepts
Vergel et al.	2022	Hybrid medical education with holographic presence	35 medical students	A greater sense of presence and continuity

Introduction

In the fast-changing era of educational technology, 3D holography emerges as a cutting-edge tool capable of rewriting the rules of traditional learning spaces to create engaging and immersive experiences (H. Yoo, 2022). Over the past few years, there has been a transformation in the education system, marked by a shift away from conventional lectures and pedagogy toward visual pedagogy and the incorporation of Information and Communication Technology (ICT) in learning (Moro & McLean, 2017). These advances have led most institutions of learning to integrate ICT services into related academic departments, particularly in sophisticated societies and some developing nations (Mhlanga et al., 2022). These swift developments have, in turn, led to the emergence of new models of education, including e-learning, distance learning, interactive learning, and blended learning (Ahmad et al., 2015). These developments pose new challenges for education as technology advances at an exponential rate, and the role of visual technologies, such as holograms, in learning environments and programs becomes increasingly vital for comprehending content and scientific information (Themelis & Sime, 2020). Holographic technology, which enables the projection of three-dimensional images in space without the need for specialized glasses, presents a unique opportunity to engage students in a way that traditional two-dimensional tools cannot (Shaked, 2009). Hologram Technology provides the basis for classifying educational content and improving the learning process through a simple and understandable strategy that enhances the learning experience (Moro et al., 2020). It enhances students' understanding of how they learn (Walker, 2013). Students can observe the concepts taught and apply them throughout the day (Themelis & Sime, 2020).

Holography, a 3D display method, can exhibit a natural 3D image near a real object and does not require scanning and synchronization processing, as it records and reconstructs light waves radiated by the object through the interference and diffraction of light. The interference of the object light with reference light produces an interference fringe pattern, known as a hologram (Yamada, Kakue, Shimobaba, and Ito, 2018). This technology class has promising potential in the education sector. It opens opportunities for authentic learning and motivates learners to learn. The combination of learning theories, learning methods, and multimedia components is highly significant and offers practical aspects for both teachers and learners (Hayaati, Alwi, and Wahab, 2017).

The adoption of new technologies such as 3D holograms in schools is motivated by the increasing awareness of the value of visual learning and interaction in student cognition and educational achievement (Walker, 2013). As the need for greater learning resources that cater to a range of learners' needs and preferences grows, teachers and researchers are considering the potential of holographic technology to offer a more engaging, practical, and accessible learning experience (Shaked, 2009). Such consideration is informed by the constructivist theory of learning, which posits that learners construct knowledge most effectively through active participation in the learning process (Mhlanga et al., 2022). The technology implementation process varies depending on the method used (Mora Rodríguez, 2013). It is extremely clear, as Girvan recommends in his research, that any technology is an artefact in a broader milieu. "Thus, a definition of a technology must consider the activities and practices in using it, and the social arrangements and organizational forms around its use.". Every time we return to a technology as part of our mundane social existence, we encounter it anew, reaffirming and redefining its usage in terms of both function and functionality" (Girvan, 2018).

Holographic technology applications in learning have been a field of growing attention over the last decade. Initial studies focused on the technical feasibility of implementing such integrations, and early trendsetters explored the foundations of holographic projection and its potential application in learning environments (Ahmad et al., 2015). Later research has shifted toward empirical assessments of these technologies in educational settings, as seen in the work of H. Yoo (2022), which demonstrated the benefits of holographic imagery in teaching complex scientific principles to secondary students.

This review begins by presenting the methodology used to select and analyze studies on the integration of 3D holograms within higher education. It then summarizes the main theoretical bases that underpin holographic learning, namely, cognitive and constructivist approaches. The article then discusses innovative pedagogical models augmented by holographic technology, followed by empirical evidence of learning outcomes. Implementation tactics and institutional issues are explored in detail, and the paper concludes by suggesting directions for future research to inform further advancement in this new discipline.

Overview of 3D Hologram Technology

Gabor, the father of holography, coined the term in 1947, based on two Greek words: "Holos" (meaning "whole") and "Graph" (meaning "writing"). It refers to the fact that the recorded hologram of the object comprises the whole optical information of the object. Ideally, a hologram is a 3D image reproduced from an interference pattern recorded by coherent light beams, and holography is the process of reconstructing it (H. Yoo, 2022). The 3D holograms originated in 1962 with the experiments conducted at the University of Michigan. Holograms were first used in the field of optical engineering, which gained popularity after World War II (Mora Rodríguez, 2013). This evolution of holograms continues to this day. The hologram has been enhanced to the point where a full 360-degree holographic presentation can be projected (Moro & McLean, 2017). In most cases, 3D hologram technology presents a 3D visualization device, visualized through a photographic method that captures the coherent light of light beams and displays the captured image in a 3D manner (Girvan, 2018).

Unlike an ordinary movie on a standard screen, a hologram shows objects, goods, and animated scenes in three dimensions, i.e., not really "there". However, it seems to float entirely freely in space (Yu, 2022). A hologram is a 3D visualization tool produced through holographic projection, formed by beams of light from coherent sources, such as laser light (Wang, 2017). Holograms are revealed by a method termed holography, which enables the storage of light rays from any object prior to reconstruction. Holograms are said to be 3D, as they enable the observer to view various perspectives of a reconstructed 3D object from different locations and angles (H. Yoo, 2022). Presently, with the emergence of ICT, interactive learning has become a key strategy and method. Interactive learning is described as an active and practical approach that aims to maximize student engagement in the learning process (Walker, 2013). This strategy also helps students to study more. As a learning tool that everyone can use, its amenities are designed to create good learning conditions in learning spaces (H. Yoo, 2022). Visual learning, a cornerstone of educational psychology, has been revolutionized by the advancement of three-dimensional (3D) visualization technology. The meta-analysis combined results from several studies and concluded that 3D technologies tend to improve the understanding and recall of visual-spatial information (Yu, 2022). Engagement, a key determinant of academic performance, has also been linked to the use of these technologies. Interactive 3D models, for example, have been shown to significantly enhance student engagement and motivation, especially in STEM fields (Salvetti, 2017). In the context of integrating holograms into children's learning, as discussed in earlier research, students were more fascinated by this type of learning process compared to traditional teaching methods. "They liked it and asked to have this type of technology as a learning option in the school. Similarly, all the teachers were also enthusiastic about the 3D hologram technology" (Hoon and Shaharuddin, 2019). "It is tough to build a three-dimensional image in free space for viewing from any direction or position. From a mathematical perspective, building a 3D image in free space is a certain boundary solution problem of passive space" (Wang, 2017).

3D Hologram Technology in Learning Environment

3D Homology technology is also recognized as a valuable visualization tool, with significant potential applications in the education sector. 3D Homology technology may be a valuable tool for teaching, potentially supporting the learning process in the future. According to a study conducted by Mnaathr and Basha (2013), 3D Homology technology can effectively enhance the learning abilities and cognitive development of children in schools. Their findings highlighted that this technology enables the enhancement of students' motivation to learn through the application of model-based learning and visual effects. Barkhaya and Abd Halim (2016) affirm that 3D technology enhances children's cognitive learning capabilities and their concentration skills. Research findings indicate that new technological developments have led to an increase in the application of holograms, particularly in schools (Awad & Kharbat, 2018). Research findings have shown that hologram technology is a strategy that, compared to other immersion technologies in learning settings, may be utilized in the future to enhance learning, teaching, and the experiences of learners and teachers (Juraschek et al., 2018; Pottle, 2019).

Holographic technology offers a great degree of realism and immersion through the 3D projection of objects or individuals (Mathur et al., 2022). In contrast to virtual reality (VR), which often involves students wearing headsets and being fully immersed in an artificial environment (Pottle, 2019), hologram technology enables students to view and engage with virtual objects while remaining aware of their surroundings (Juraschek et al., 2018). This integration of virtual and real-world aspects can enhance the sense of presence and immersion, making hologram technology feel more realistic and natural. Alternatively, holograms are more user-friendly and person-centered, mainly due to the potential for transparency and contextualization that they offer, which is not found in virtual reality or avatars. Hologram technology enables virtual items to be overlaid on the physical environment, being transparent and contextualized (Wiederhold, 2021). This transparency and contextualization feature of hologram technology is most useful when applied in educational environments, where blurring the line between virtual content and physical context is essential (Gadekallu et al., 2022).

However, some researchers have shown that the application of holograms in classrooms has its drawbacks, including the financial cost of implementation and upkeep (Ahmad et al., 2015), limited access, technological sophistication, and content development issues (Ramachandiran et al., 2019). It is further emphasized in Ghuloum's (2010) study, which suggests that due to various institutional or national constraints, it becomes impossible to contextualize the application of such technologies effectively. Despite its limitations, it can be argued that the use of holograms in the classroom will prove advantageous for educational institutions (Awad & Kharbat, 2018). 3D Homology technology can develop cognitive skills and capabilities, offering a foundation for grasping content in a learning setting (Loh and Shukhaila, 2019).

Theoretical Foundations for Holographic Learning

The implementation of 3D holographic technology in higher education teaching pedagogy is supported by several well-established learning theories that underlie immersive and multimodal learning, as illustrated in Fig. 1. These theories provide a theoretical underpinning regarding how holographic experiences promote cognitive engagement, retention, and motivation among students.

4.1 Constructivist and Experiential Learning Theories

Constructivist theory suggests that students learn best when they are actively engaged in the learning process. Instead of passively sitting to gain information, students engage with the material, ask questions, and draw their conclusions (Geert, 2017). Holograms support this process because they are highly interactive and visual, e.g.,

allowing students to dissect an organ or examine a mechanical system virtually. These interactions simulate real-world experiences, leading to more meaningful and personalized learning (Narayan, 2013).

In constructivist theory, learning is not merely generative; instead, it creates meaning from experience. Constructivism holds that every learner constructs knowledge through their own experience and interactions with others. Therefore, a learner acquires knowledge and becomes dynamic. A constructivist approach to learning posits that knowledge is a construction, and the learner is the central focus of the educational process. The student will discuss the issue, conduct research, share proposed solutions with his peers, and subsequently investigate the scientific applicability of these solutions. Knowledge arises from the construction of reality through one's activity (Merriam, 2007). Constructive learning aims to foster freedom, realism, favorable attitudes, and a view of education as a valuable resource, which are essential for students to learn effectively. Using contemporary technological tools, instructors facilitate a knowledge-building environment that considers the learner's tendencies, needs, and cognitive processes (Oxford, 2003).

Constructivism holds that students construct knowledge actively through experience, rather than passively receiving information. Holographic learning environments can comfortably fit within constructivist thought because they allow students to travel through 3D models, manipulate virtual materials, and immerse themselves in learning (Bada, 2015). Zhu et al. (2020) demonstrated in a study that students studying in engineering classes who utilized holographic simulations reported significantly better conceptual knowledge than those receiving training through traditional 2D models ($p < 0.01$), thus establishing the role of interactive experience in building knowledge.

4.2 Cognitive Load Theory and Visual Learning

This theory explains the amount of information our working memory can process at any given moment. Students can get overwhelmed if a lesson is too complex or too text-heavy. Holograms avoid this by simplifying complex information and making it more visually straightforward to grasp, such as presenting a 3D representation of a molecule rather than attempting to explain its structure verbally. By distributing some of the mental load to the visual processing, students are in a better position to learn and memorize information (Clark, 2006). Working memory capability is one of the most important determinants of academic performance, as outlined in the CLT. Since working memory has limited capacity, it tends to be overburdened when handling complex instructional material. Working memory must be capable of withstanding the pressure of learning in order to learn effectively. Thus, teaching methods should be carefully designed to place the appropriate level of cognitive load on working memory, ensuring success in learning (Sweller, 2010).

Cognitive Load Theory posits that the goal is to optimize the use of working memory during learning. Top-quality holographic content reduces extraneous cognitive load by embedding information into space and images, rather than relying on dense text or distant diagrams (Makransky et al., 2019). Makransky et al. (2019) compared VR/holographic settings with traditional PowerPoint lectures and found that holographic interfaces increased student comprehension without taxing cognitive resources. This result demonstrates that immersive visualizations support more efficient schema creation, as shown in Fig. 2.

4.3 Dual Coding Theory

Learning is more effective when both the visual and verbal channels are employed. For instance, when the teacher describes something and a hologram illustrates it simultaneously, the brain processes the information through two complementary systems. The integration increases understanding and retention. Essentially, hearing and seeing

something simultaneously reinforces learning (Mayer, 2009). Learning is made easier by the simultaneous processing of verbal and visual information. Holograms are powerful visual aids that complement verbal instruction, enabling better learning. An empirical research study by Bower et al. (2017) provided evidence through its findings that students instructed in biology through holographic projections performed better in recall and application tests, in contrast to their peers in a lecture group, substantiating the effectiveness of dual-modality learning. The evidence, based on the aggregated findings of Bower et al. (2017), Makransky et al. (2019), and Zhu et al. (2020), suggests that holographic environments yield the best performance results, as shown in Fig. 3.

4.4 Media Richness and Multimodal Learning Theories

Good learning also hinges on how personal and interactive the medium is perceived. Media Richness Theory states that more immersive technologies (such as holograms) are ideal for rich, ambiguous content since they offer more cues, like pictures, movement, and spatial cues (Mazgaj, 2021). Social Presence Theory adds to this by asserting that students feel more present when communication is "real." Holographic images of instructors or classmates can produce a sense of presence, which enhances motivation and attention in both physical and virtual classrooms (Pates, 2020). Media Richness Theory and Social Presence Theory emphasize the need for rich communication cues to promote understanding and interpersonal relatedness. Holographic images of instructors or peers within live learning environments can mimic face-to-face interaction, thereby enhancing perceived social presence (Syed, 2025). Empirical research conducted by Kent and Downey (2018) demonstrated that holographic guest lecturers in business education classes were rated as more "present" and interactive than video recordings, leading to increased student satisfaction and engagement.

4.5 Embodied Cognition and Presence in Learning

This theory suggests that learning is a whole-body, whole-brain experience. Movement, gesture, and participation can all be components of the way we think and learn. Holographic spaces that allow learners to "move around" or "handle" materials—regardless of whether they are virtual—capitalize on this concept. It makes it more bodily and recollective, especially for more complex spatial challenges, such as orienting in anatomy or blueprinting buildings (Moro et al., 2021). Embodied cognition theory posits that learning is shaped by the dynamic interplay between the body and its environment. Starting with Input (holographic delivery), students go through multisensory and interactive processes (Process), which have an impact on crucial psychological mediators—i.e., diminished cognitive load and enhanced motivation (Mediators). This results in desirable Outputs, such as enhanced academic performance, superior retention, and enhanced learner satisfaction. The model connects learning theory with learning outcomes as demonstrated in Fig. 4 (Wilson, 2002). Holographic environments promote kinesthetic handling of material—i.e., rotating models of anatomy or experimenting with molecules—which enhances kinesthetic learning and spatial reasoning. In an educational study of comparative anatomy, Moro et al. (2021) found that students using holographic systems reported feeling more spatially engaged and present in their learning than those using static models, demonstrating the embodied benefits of holographic interfaces.

4.6 Empirical Evidence for Theoretical Foundation :

Increasing the amount of empirical research also substantiates the theoretical applicability of 3D holographic technology to higher education. Cognitive Load Theory-based studies demonstrate enhanced retention and attention when holographic material is designed to minimize unnecessary load (Makransky et al., 2019). Constructivist theories provide evidence of increased student engagement and self-directed learning through flipped classes, particularly when holograms are employed (Bower et al., 2017)—a study demonstrating the

effectiveness of the RCT approach. Additionally, embodied learning research emphasizes the enhancement of spatial knowledge and procedural competence, particularly in anatomy and engineering simulations (Moro et al., 2021; Zhu et al., 2020). Overall, this evidence supports the pedagogical value of holography and confirms its concordance with fundamental theories of learning, as shown in Table 2.

Table 2
Empirical studies supporting theoretical foundations for holographic learning

Study	Theoretical Basis	Context/Discipline	Findings	Implication
Zhu et al. (2020)	Constructivism	Engineering	Students using holographic simulations showed significantly higher conceptual understanding ($p < 0.01$).	Holography enhances active knowledge construction through interaction.
Makransky et al. (2019)	Cognitive Load Theory	STEM Education	Holographic environments improved comprehension without increasing cognitive overload.	Supports the efficient use of working memory via immersive content.
Bower et al. (2017)	Dual Coding Theory	Biology	Students taught with holograms scored higher on recall and application tests.	Reinforces the benefit of combining verbal and visual information.
Moro et al. (2021)	Embodied Cognition	Anatomy Education	Students reported higher spatial awareness and engagement with 3D models.	Physical interaction with content enhances kinesthetic learning.
Kent & Downey (2018)	Media Richness & Social Presence	Business Education	Students found holographic guest lecturers more engaging than video content.	Holography increases perceived social presence and participation.

Pedagogical Models for Hologram Integration

The adoption of 3D holographic technology in higher learning has given rise to new pedagogical models that redefine conventional teaching and learning paradigms. The models concentrate on maximizing interactivity, tailoring instruction, and closing the physical-digital gap (Salloum, 2024). The well-designed learning program incorporating 3DHT assisted in placing an appropriate cognitive load in working memory, constructing schemas, and transferring and retaining information in long-term memory, which is consistent with cognitive load theory (Sweller, 2010).

5.1 Hologram-Enhanced Flipped Classrooms

The inverted classroom approach, in which instructional content is provided outside the classroom and in-class time is devoted to active learning, has uncovered new possibilities with holography. Holographic content can be used to supplement or complement pre-recorded lectures with interactive 3D presentations, enabling students to explore abstract concepts prior to class (Ahmed, 2024). The flipped learning method has gained increasing popularity in recent years as a pedagogical innovation in education technology, particularly in the context of higher education. The most effective way to engage students is through technology-enhanced teaching practices that

extend beyond the conventional lecture (Divjak et al., 2022). Technology is vital in ensuring student engagement and satisfaction, and the flipped classroom model mainly depends on technology.

Flipping a classroom means inverting the traditional classroom. Outside of the classroom, students are encouraged to engage actively with new material by reading or watching video lectures. It requires that students retain and examine the knowledge provided for the class (Bachiller & Badía, 2020). The student is then asked to apply what they have learned in class to perform group problem-solving exercises using peer instruction. Consequently, students have an enriched learning experience by acquiring an in-depth understanding of the topic. Concerning the traditional lecture method, this type of learning is student-centered and more interactive (Karjanto & Acelajado, 2022). Flipped classrooms are constructivist-aligned, as they place students at the center of learning. Holograms extend this by providing interactive 3D immersion, which enhances cognitive involvement (Baig & Yadegaridehkordi, 2023). Visual holograms minimize extraneous load by substituting abstract textual information for spatial manifestations, which enhances retention and comprehension (Cevikbas & Kaiser, 2022). Systems such as Microsoft HoloLens and AR-based holographic projectors are being tested in flipped environments to see and understand intricate structures, e.g., protein folding or anatomical structures (Behforouz & Ghaithi, 2025).

Holograms are integrated into LMS systems to provide pre-class content, enabling students to engage with models asynchronously (Baig & Yadegaridehkordi, 2023). Holograms are especially useful in subjects that involve spatial reasoning, such as biology, chemistry, and engineering, where students can manipulate 3D models during class discussions (Ahmed, 2024). Comprehensive flipped classrooms through holograms have achieved enhancements in writing independence and conceptual understanding by visualizing abstract concepts (Behforouz & Ghaithi, 2025). Research has shown that student engagement and motivation are heightened when holograms are employed in flipped models, particularly in tailored learning settings (Cevikbas & Kaiser, 2022). Flipped classes that utilize holograms have yielded statistically significant improvements in understanding, critical thinking, and collaborative problem-solving (Ahmed, 2024). Research conducted by Bower et al. (2017) revealed that students utilizing holographic visualizations as preparatory content for a biology flipped classroom exhibited considerably higher pre-class understanding.

Their in-class discussions were richer conceptually, consistent with constructivist and active learning paradigms outlined in Table 3. In addition, Makransky et al. (2019) found that holographic pre-class modules enhanced learners' motivation and time-on-task. By pre-loading difficult content through rich visual media, holograms lower cognitive load and enable students to enter the class with a baseline level of understanding. It prepares them for higher-order activities, such as problem-solving and peer teaching.

5.2 Hybrid and Remote Learning Models with Holographic Presence

The shift to remote and blended learning has enabled the utilization of holographic avatars or telepresence technology, making it easier for teachers and guest experts to be present in classes in real-time, with the possibility of co-presence perception, regardless of geographical locations. Such arrangements enhance hybrid models where some are present physically while others join virtually (Limbu et al., 2023). Hybrid and online models of learning have transformed the way education is delivered, particularly since the pandemic. The integration of holographic presence, where instructors or learners are represented as 3D figures, enhances virtual interaction to a new extent, aiming to reduce transactional distance and enhance social presence in virtual learning environments (Gudoniene et al., 2025). The model emphasizes cognitive, social, and teaching presence. Holograms enhance social and teaching presence, increasing interaction and reducing feelings of loneliness (Kasuk et al., 2025).

Holographic presence minimizes psychological and communication gaps between students and instructors, improving immediacy and reducing Zoom fatigue (Bailenson, 2021; Limbu et al., 2023). Limbu et al. (2023) proposed a hologram-mediated hybrid learning platform that utilizes depth cameras and mesh rendering to project instructors into classrooms or virtual worlds. It supports synchronous and asynchronous learning modes. Kasuk et al. (2025) proposed the PEPCII model for integrating telepresence robots into blended classrooms, aiming to overcome ethical, cognitive, and instructional design challenges. Holograms enable teachers to engage simultaneously with in-class and online students, maintaining eye contact, using gestures, and demonstrating spatial awareness (Gudoniene et al., 2025). Holographic recordings of lectures provide asynchronous access with greater realism, resulting in improved retention and learner independence (Limbu et al., 2023). Studies show increased flow experience and decreased fatigue compared to traditional video conferencing technology (Limbu et al., 2023). Hybrid systems incorporating holograms are associated with enhanced understanding, increased participation, and improved group learning (Anjum et al., 2024). Kent and Downey (2018) revealed that students found remote holographic instructors more engaging and realistic than video lectures. It was also demonstrated in a pilot program at Imperial College London, where a lecturer taught simultaneously on several campuses using holography, with no measurable difference in performance or satisfaction between on-campus and off-campus students, as presented in Table 3.

5.3 Virtual Labs and Simulations Using 3D Holograms

Lab-based teaching is a pillar of STEM education, but traditional physical labs are manpower-intensive and not viable for every student. Holographic labs and simulations offer an affordable and scalable approach to delivering lab-based learning in fields such as medicine, biology, and engineering. Students build knowledge actively through activities with virtual environments. Holographic simulation enables this by allowing the manipulation of 3D models, which facilitates inquiry-based learning (Sellberg et al., 2024). Physical interaction with holographic objects enhances understanding of abstract scientific concepts, such as protein folding or bacterial morphology (Sypsas et al., 2025). Holograms reduce extraneous load by replacing tedious textual descriptions with easy visualizations, which enhances retention and comprehension (Kefalis et al., 2025). A virtual 3D laboratory of biology was developed by the Hellenic Open Univer, where learners can conduct experiments in microbiology and biotechnology remotely (Sypsas et al., 2025). RGB-D sensor and depth camera technologies facilitate holographic display of dynamic laboratory environments and biological specimens (Fadzli et al., 2023).

Evidence suggests that there is an enhanced understanding of complex systems, greater motivation, and improved performance in STEM areas (Sellberg et al., 2024). Virtual labs deconstruct geographical and physical barriers, allowing risk-free experimentation with harmful substances (Sypsas et al., 2025). Moro et al. (2021) found that students studying anatomy through holographic anatomy models during medical school outperformed learners who learned from 2D images or text illustrations in terms of spatial thinking and procedural memory. Similarly, Zhu et al. (2020) observed improved procedural accuracy among engineering students who learned through holographic circuit assembly simulations, as presented in Table 3.

5.4 Guest Lectures and Holographic Instructor Avatars

Guest lectures offer rich interdisciplinary insights, but practical limitations often limit attendance. Holographic projection enables experts to present themselves as life-sized, interactive avatars in lecture theaters without needing to travel. This technology enhances accessibility and enriches student learning diversity (Mizuho et al., 2023). Holographic avatars provide an enhanced perception of instructor presence, resulting in increased emotional and cognitive engagement (Garcia, 2025). Realistic avatars with human-like movements and facial

expressions enhance learning achievement by mimicking realistic teaching behaviors (Makransky & Petersen, 2021). Avatars that facilitate combined verbal and non-verbal feedback promote dual-channel processing and alleviate cognitive overload (Mayer, 2014). Tools such as Professor Avatar (Luevano et al., 2019) facilitate life-size, real-time projection of off-site lecturers, lowering travel expenses and expanding reach. Mizuho et al. (2023) demonstrated that changing lecturer avatars between sessions enhances memory recall by varying the environmental context. Holographic avatars are used in universities to host foreign experts, allowing students to meet them in real-time (UMA Technology, 2025). Research indicates that avatars that mirror students' cultural or language backgrounds could increase rapport and encouragement (Pan & Steed, 2019). Realistic avatars with expressive behaviors are rated higher in terms of teaching efficacy and trust (Garcia, 2025). Several avatar contexts facilitate recall by encoding variability (Mizuho et al., 2023). Increased attention and student participation are reported when avatars mimic human-like interaction (Daniels & Lee, 2022). A University of Southern California study illustrated that students were more engaged and saw greater relevance when guest speakers appeared as live holograms rather than in pre-recorded videos. Kent and Downey (2018) also observed higher interactivity and Q&A sessions in the sessions with the holographic experts, as indicated in Table 3.

Table 3
Empirical evidence of holographic pedagogical models in higher education

Study / Author(s)	Year	Pedagogical Model	Technology Used	Educational Context	Methodology	Key Findings / Outcomes
Bower et al.	2017	Flipped Classroom with Holograms	Microsoft HoloLens (Mixed Reality)	Undergraduate Biology	Experimental study	Better engagement and conceptual understanding.
Makransky et al.	2019	Simulation-Based Learning	360° VR with Holographic Elements	Medical Training	Randomized controlled trial	Improved motivation, engagement, and retention.
Moro et al.	2021	Visual-Spatial Learning	AR + 3D Holograms	Anatomy Education	Comparative study	Improved spatial awareness and long-term retention.
Zhu et al.	2020	Virtual Labs	Interactive 3D Holograms	Electrical Engineering	Quasi-experimental study	Enhanced accuracy, efficiency, and satisfaction.
Kent & Downey	2018	Guest Lectures via Holographic Avatars	Holographic Telepresence	Business & Marketing	Mixed methods	Higher engagement than video lectures.
Bower & Sturman	2015	Collaborative Design Model	3D Collaborative Holographic Environment	Architecture & Design	Case Study	Improved group communication and creativity.
Cai et al.	2013	Hologram-Supported Science Demonstration	AR and Holographic Science Toolkit	High School Physics	Case Study	Better grasp of abstract phenomena.
Vergel et al.	2022	Hybrid Learning with Holographic Presence	Holographic Projection	Medical Education	Pilot Implementation Study	Reduced cognitive overload, improved presence.

5.5 Frequency of Reported Learning Outcomes in Holographic Pedagogical Studies

The most cited outcomes include engagement, retention, and spatial skill development, reflecting the strong potential of holographic environments to support immersive and interactive learning. Performance accuracy, conceptual understanding, and communication/collaboration were also frequently observed, particularly in STEM and medical education contexts. These results highlight the versatility of 3D holographic technologies in achieving a wide range of pedagogical objectives, as shown in Fig. 5.

5.6 Distribution of Holographic Pedagogical Models in Studies

Flipped classrooms and virtual labs are two of the most widely used formats, especially in engineering and medical education, where spatial visualization and procedural precision are of utmost importance (Moro et al., 2021; Zhu et al., 2020). Simulation-based learning environments and collaborative design spaces, facilitated by holographic tools, enable active learning, peer-to-peer interaction, and reflective thinking (Bower & Sturman, 2015; Makransky et al., 2019). Furthermore, instructor avatars and holographic guest lectures are increasingly used to enhance social presence and engage learners with worldwide experts in real-time (Kent & Downey, 2018; Imperial College London, 2019). This deployment demonstrates the versatility of holography for both content-intensive and practice-oriented learning environments, making it a practical resource for new pedagogical models, as shown in Fig. 6.

5.7 Primary Learning Benefit of Study

Bower et al. and *Kent & Downey* emphasized student engagement, while *Makransky et al.* focused on retention, and *Moro et al.* highlighted spatial skills. This chart provides a clear linkage between individual studies and their dominant educational contributions, helping educators and researchers identify which holographic models align best with their instructional goals, as shown in Fig. 7.

Strategies for Implementation in Higher Education

The successful incorporation of 3D holographic technology in higher education instruction requires crafting thorough approaches that balance both technological capacity and pedagogical purposes. Execution must consider various aspects, including alignment with the curriculum, faculty preparedness, technology availability, cost-effectiveness, and student participation (Luevano et al., 2019). As universities strive to construct immersive, interactive learning spaces, scholars and practitioners have commenced outlining particular approaches that maximize the practicality and efficacy of integrating holography (Cai et al., 2013). Among the building blocks of strategies is situating holographic applications within existing curriculum frameworks. Instead of using holograms as supplements, successful implementations integrate them into course learning objectives and exams (Kent & Downey, 2018). Based on Moro et al. (2021), incorporating 3D holographic visualizations into anatomy and physiology courses has been shown to improve spatial understanding and retention over time. Engineering courses, medical science courses, and design courses have specifically benefited from the integration of holographic simulations into practical laboratory materials, allowing students to interact with intricate systems remotely before undertaking the actual tasks.

Faculty acceptance is instrumental to the viability of any technological innovation. Research highlights the importance of formal faculty training programs with both technical and pedagogical elements. As Bower & Sturman (2015) pointed out, teachers need not only to master the operation of holographic tools but also to understand how to employ them to facilitate active learning, critical thinking, and collaborative engagement. Institutions that have shared successful adaptations, such as those described by Kent & Downey (2018), have invested in repeated workshops, co-teaching interventions, and instructional design assistance for teachers who were piloting holographic content. The deployment of 3D holographic systems requires solid digital infrastructure. It entails fast internet, AR/VR-enabled devices (e.g., Microsoft HoloLens, holographic projectors), and secure content management platforms. Universities need to provide equal access to hardware and software, particularly in hybrid and distance learning environments. Makransky et al. (2019) reported that immersive systems can be enhanced for learning but may collapse if technological flaws or access inequalities persist. Phased deployment—

beginning with limited pilots in a few departments—is often recommended to assess system performance before wider adoption.

Pilot-based approaches enable institutions to pilot holographic pedagogy on a limited scale before mainstreaming its adoption. Pilots commonly incorporate feedback mechanisms, including student surveys, performance monitoring, and teacher interviews (Garcia, 2025). For instance, Vergel et al. (2022) reported on a pilot launch of holographic presence within medical hybrid classrooms, concluding that it enhanced learner attention and social presence but required optimization in delivery scheduling and system calibration. Iterative testing verifies that the technology is both pedagogically and practically responsive. Holographic pedagogy success is spearheaded by interdepartmental collaboration involving education, computer science, instructional design, and discipline-specific faculties. Interdisciplinary teams can create learning material that is both scholarly and technologically viable (Bower et al., 2017). Collaboration between physics educators and AR developers led to the creation of an interactive simulation system that enabled students to grasp abstract scientific concepts more easily. Such interdisciplinary design facilitates scalable and context-dependent implementation (Cai et al., 2013). Students also need to be prepared to interact effectively with holographic spaces. Offering students orientation sessions, practice tutorials, and clear usage guidelines makes them confident and capable of engaging constructively. Inexperienced students in immersive spaces may initially feel overwhelmed (Garcia, 2025). Well-designed onboarding decreases cognitive load and increases user satisfaction.

Furthermore, enhancing digital literacy allows for equal participation, particularly in multicultural student groups (Zhu et al., 2020). To measure the effects of holographic interventions, evaluation methods must be adapted. Standard testing modalities are not suited to measure the procedural and spatial abilities that holography maximizes. Formative testing, performance assessments, and feedback tools are increasingly incorporated into holographic instruction in real-time. Integrating peer-evaluation and reflection assignments into a flipped holographic classroom increased metacognition and learner independence (Bower et al., 2017).

Universities or Institutions Using Holographic Technology

Imperial College London was among the first European universities to introduce holographic telepresence for real-time, interactive classroom sessions. In a pilot conducted in partnership with ARHT Media, medical students participated in live sessions where guest lecturers appeared as full-size 3D holograms (Imperial College London, 2019). The goal was to enhance social presence and reduce the logistical challenges of cross-border faculty collaboration. Evaluations revealed high student satisfaction and perceived realism, especially compared to video conferencing. That model was extended during the COVID-19 pandemic to maintain the continuity of hybrid learning. WesternU in the United States collaborated with Case Western Reserve University and Microsoft to implement the **HoloAnatomy application** using the Microsoft HoloLens. This system replaced cadaver-based dissection labs with 3D anatomical models, allowing students to explore the human body interactively. According to Boning et al. (2018), students using holographic systems achieved comparable or superior scores on practical anatomy tests compared to peers in traditional cadaver labs. The approach also improved **spatial reasoning** and **procedural comprehension**, especially for complex organ systems. The University of South Australia explored the use of holographic avatars and simulated classroom environments to train future educators. A mixed-reality platform was used to replicate classroom management scenarios, with holographic children responding to trainee teachers' instructions in real-time. Bower et al. (2020) noted this model supports experiential learning and reflective practice, enabling pre-service teachers to navigate behavioral challenges without real-world consequences. INSEAD has incorporated holography into its executive education programs, enabling instructors

from remote campuses to appear in lecture halls through holographic projection. This practice, combined with AI-enhanced content delivery, has been used to teach global management and leadership. The institution reported that this format-maintained engagement levels and **eye contact-like interaction**, contributing to higher levels of learner satisfaction and attention retention (INSEAD, 2021).

Discussion

The embedding of 3D holographic technology in tertiary education represents a promising move toward more interactive, immersive, and student-centric pedagogical spaces. Empirical studies included here, across all papers, consistently point to increased student engagement, improved spatial reasoning, enhanced conceptual understanding, and increased motivation as key findings across holographic learning interventions. Of particular interest, these impacts are most substantial where spatial and procedural knowledge are most dominant, including fields such as anatomy, engineering, and architecture. The discussion of pedagogical models—ranging from flipped classrooms and hybrid learning to virtual labs and guest lectures—reveals that holography can be integrated with various teaching models. Each utilizes the strength of holography, whether for creating virtual presence, facilitating hands-on simulations, or encouraging collaborative learning. The contextual variables, however, have a significant impact on the effectiveness of these models, including faculty readiness, course curriculum, students' digital literacy, and access to supporting infrastructure.

The theoretical underpinnings—specifically cognitive load theory, constructivism, and social presence—offer explanatory power for the effectiveness of holographic interactivity. Through the minimization of extraneous cognitive load and embodied interaction, holograms enable learners to construct more effective mental models. Further, the social affordances of holography, including real-time holographic avatars and telepresence, enhance classroom dynamics and interpersonal connectedness in hybrid or remote learning environments. Even with the advantages, there are issues. High costs of implementation, steep technical hurdles, and a high learning curve for students hinder scalability in holographic pedagogy. Additionally, although the existing literature is growing, it remains somewhat fragmented, with most studies focusing on pilot implementations rather than longitudinal or large-scale rollouts. For progress to occur, universities need a multifaceted investment in faculty capacity building, rigorous pilot testing, and equitable research. It should also explore the long-term effects of holographic learning on cognitive development, disciplinary expertise, and learner autonomy.

Implementation Challenges of 3D Holographic Technology in Higher Education

While 3D holographic technology has the potential to revolutionize university pedagogy, its adoption in higher education settings is preceded by several practical, technological, and organizational barriers. These constraints can make large-scale uptake more difficult in resource-poor contexts. It is important to understand and overcome these impediments to enable sustainable, equitable, and pedagogically effective adoption.

9.1 High Cost of Technology and Infrastructure

High equipment and setup costs are one of the primary hurdles to implementing holography. Microsoft HoloLens, holographic projection setups, and spatial computing platforms are often costly, making them sometimes out of reach for public universities or institutions in developing countries (Moro et al., 2021). Moreover, specialized labs

or classrooms might require modification using compatible infrastructure, such as high-performance computing units and 3D content management software.

9.2 Limited Faculty Training and Technological Expertise

Implementation is effective when faculty members have both technical expertise and familiarity with holographic pedagogy. However, faculty members are often not trained or do not feel prepared to plan and deliver holographic learning activities (Bower & Sturman, 2015). The lack of formal professional development programs hinders faculty adoption and may lead to the underutilization or misuse of technology.

9.3 Content Development and Pedagogical Alignment

Producing high-quality holographic learning content is time-consuming and resource-intensive. Institutions often outsource development to third-party developers or partner with tech firms to create interactive content. If not aligned with thoughtful instructional design, holograms can end up as mere superficial graphics instead of instruments of in-depth learning. Maintaining alignment between holographic content and curricular objectives remains an ongoing challenge (Makransky et al., 2019).

9.4 Accessibility and Digital Equity

Holographic learning spaces can inadvertently expand the digital divide. Not all students have the same level of access to compatible hardware or sufficient internet bandwidth, particularly in blended or remote learning environments. This creates issues regarding inclusivity and equity for students who are less privileged or who have physical or cognitive disabilities.

9.5 Technical Limitations and Usability Issues

Existing holographic technology may be plagued by latency issues, device fatigue, limited battery life, or a restricted field of view, which can be detrimental to the learning process. The complexity of the user interface and the occurrence of periodic motion sickness have also been identified, especially during extended sessions or in cognitively demanding simulations (Zhu et al., 2020).

9.6 Institutional Resistance and Change Management

Implementing new technologies typically involves changes to institutional culture, budget redirection, and curriculum revision. Specific academic units may resist adapting or be uncertain about the value of holography, particularly in the face of competing priorities or traditional pedagogical models. Without administrative support and inter-departmental cooperation, efforts to implement may remain isolated or ephemeral.

Future Research Directions

As 3D holographic technology continues to evolve, its integration into higher education from a pedagogical perspective presents a broad spectrum of research opportunities. Although existing research offers optimistic findings concerning participation, spatial awareness, and pedagogical models, the investigation should continue to develop its theoretical, empirical, and practical base. The following are suggested avenues for future research:

10.1 Longitudinal Impact on Learning Outcomes

Most current research measures the short-term effects of holographic learning spaces. Future research should conduct longitudinal studies to assess the prolonged cognitive, behavioral, and emotional effects of holographic teaching over an academic semester or degree program. It would establish the long-term effectiveness of holography in instilling deep learning, knowledge retention, and skill acquisition.

10.2 Cross-Disciplinary and Multi-Context Studies

Current research has focused intensely on medical, engineering, and design education. There is a need for expanded research on holographic integration across a broader range of fields, including the humanities, social sciences, law, and teacher education. Cross-disciplinary comparative studies in different institutional settings can provide more insights into the transferability and scalability of holographic pedagogical designs.

10.3 Inclusive and Accessible Holographic Learning

Future research should investigate digital equity and accessibility in holographic settings for students with disabilities or those with limited technological resources. Studies need to develop inclusive design principles and investigate how adaptive holographic content may assist varied learners in hybrid or distance learning environments.

10.4 Pedagogical Framework Development

While numerous studies cite learning theories such as constructivism and cognitive load theory, there is a lack of comprehensive pedagogical frameworks directly developed for holographic learning. Future research needs to establish instructional design models and evidence-based guidelines for instructors to implement effectively on how holography can be integrated into curriculum design, assessment development, and student-focused pedagogy.

10.5 Faculty Experience and Institutional Adoption Models

In-depth qualitative studies are required to investigate faculty perceptions, barriers, and incentives related to the use of holographic tools. Research can also investigate institutional change management processes, such as models of funding, professional development activities, and administrative support systems that affect successful adoption.

Conclusion

This article has discussed the diverse potential of 3D holographic technology in reshaping university pedagogy. The results confirm that, when holistically implemented, holography can support a range of educational objectives, including enhancing student engagement, expanding students' understanding of abstract concepts, and facilitating collaboration across virtual spaces. Central pedagogical models, such as hologram-amplified flipped classrooms, virtual labs, and hologram-assisted guest lectures, also illustrate the modularity and flexibility of the technology across different fields of study. Research evidence proves the positive learning effect of holography, particularly when paired with constructivist and experiential learning theories. However, successful implementation requires more than a readiness in technology—it takes strategic planning, interdisciplinary

cooperation, and ongoing pedagogical development. Institutions will need to wrestle with issues of cost, access, training, and curriculum alignment to maximize the potential of this revolutionary technology.

As higher education moves towards greater digital transformation, 3D holography represents an edge technology with the ability to span physical and virtual learning, enhance learner experiences, and reshape the process of instructional design. Continued advances and greater availability would place holography at the center of forward-thinking, inclusive, and effective university teaching.

Implications for Educational Practice and Policy

The implications of this review have broader relevance to both educational policymakers and institutional decision-makers. As colleges seek to innovate and improve learning, 3D holographic technology offers an intriguing tool for enhancing student engagement, developing deeper conceptual understanding, and replicating real-world settings across various disciplines. Practically speaking, universities will be able to utilize this evidence to inform investment in educational technology infrastructure, focusing on scalable pilot projects aligned with their curricular objectives. Furthermore, faculty development programs will need to be established to prepare educators to author and deliver holographic materials effectively. At policy levels, they underscore the necessity for strategic funding and frameworks that facilitate accessible access to immersive technologies. National and institutional policies should promote cross-sector coordination, digital inclusion, and the integration of new tools, such as holography, into strategic plans for long-term educational innovation. Ultimately, the growing body of evidence on holographic learning can help institutions make data-informed decisions, create more immersive and inclusive learning experiences, and prepare students for increasingly digital, visual, and interactive professional environments.

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Figures

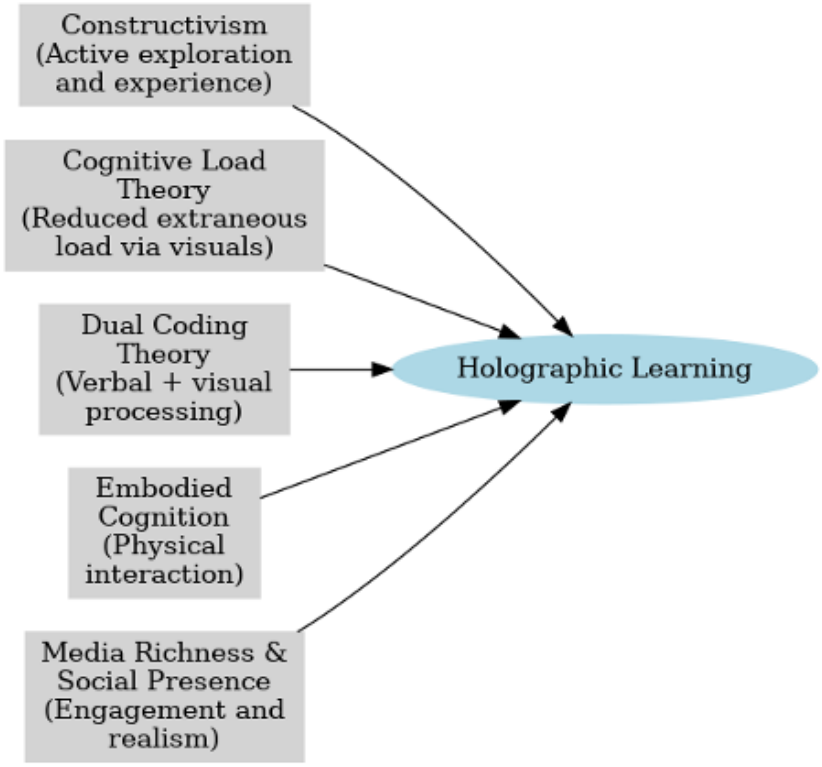


Figure 1

This conceptual diagram illustrates the theoretical foundations that support the use of holograms in education. Each theory Constructivism, Cognitive Load Theory, Dual Coding Theory, Embodied Cognition, and Media Richness & Social Presence—contributes uniquely to the effectiveness of holographic learning. The central node "Holographic Learning" is supported by each theoretical approach, illustrating how they collectively justify the integration of 3D visualization in pedagogy.

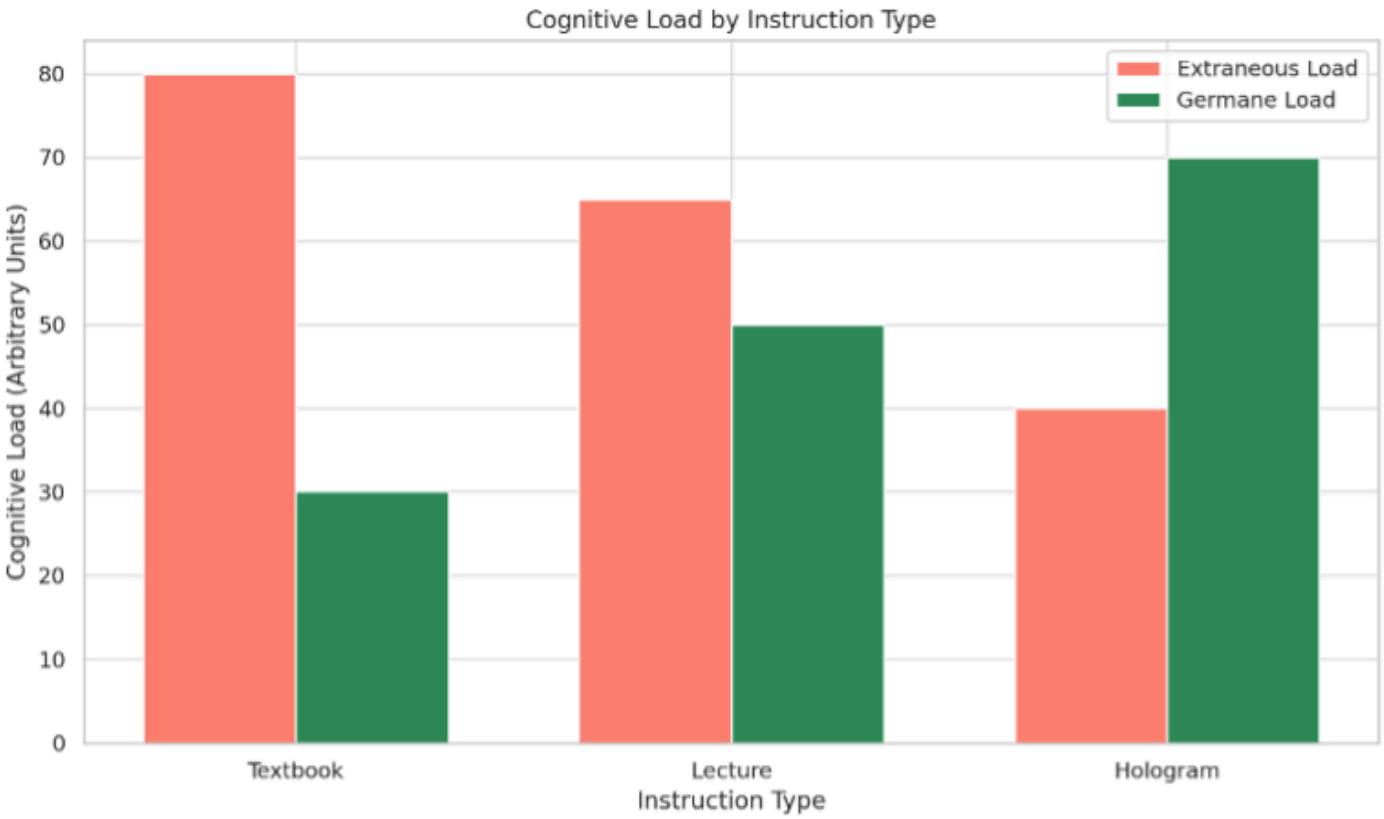


Figure 2

This grouped bar chart illustrates two types of cognitive load **extraneous load** (unnecessary mental effort) and **germane load** (productive learning effort) across three instruction types: textbook-based learning, lectures, and holographic interfaces. As supported by Cognitive Load Theory (Sweller, 1988), holographic learning reduces extraneous cognitive load by visually simplifying complex ideas, while simultaneously increasing germane load through active engagement. The graph emphasizes that well-designed holographic experiences can enhance cognitive efficiency.

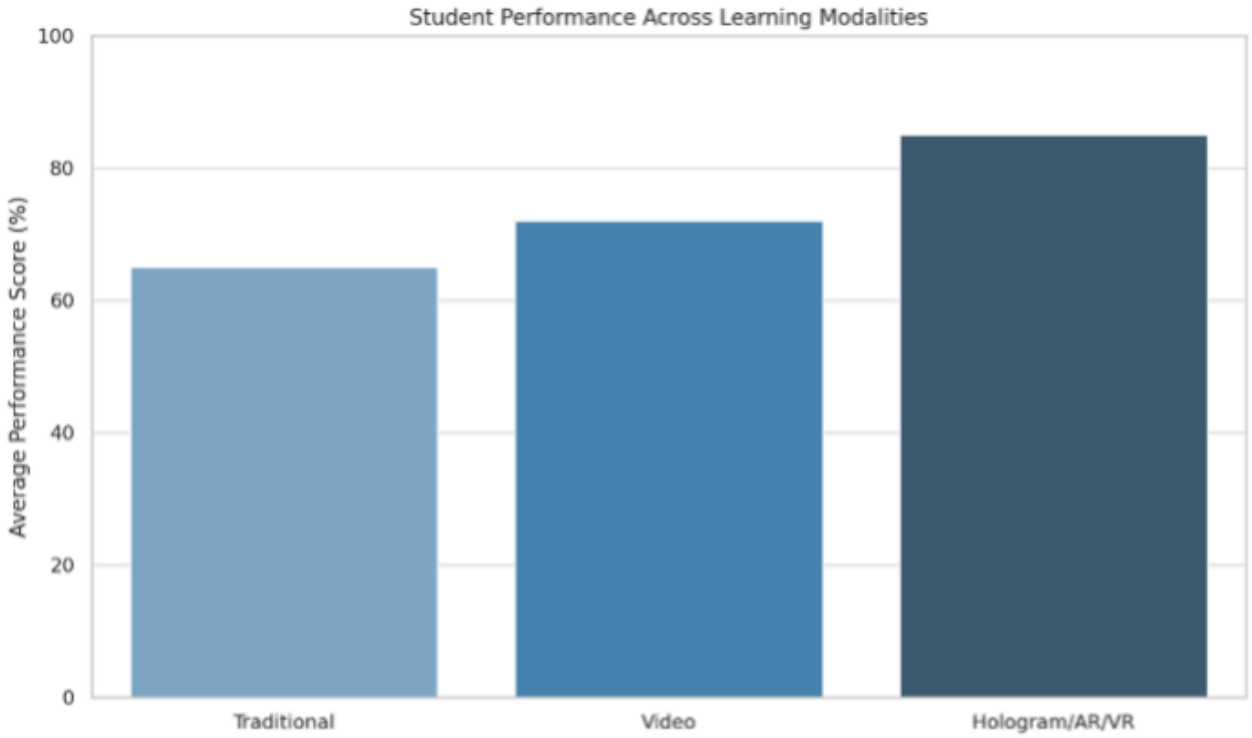


Figure 3

This bar chart compares average student performance across three instructional modalities: traditional methods (e.g., textbook-based lectures), video-based learning, and hologram/AR/VR-enhanced instruction. It supports the theoretical claims of constructivism and dual coding, where immersive and interactive visuals facilitate knowledge retention and enhance conceptual understanding.



Figure 4

This flowchart presents a simplified model explaining how holographic learning enhances educational outcomes.

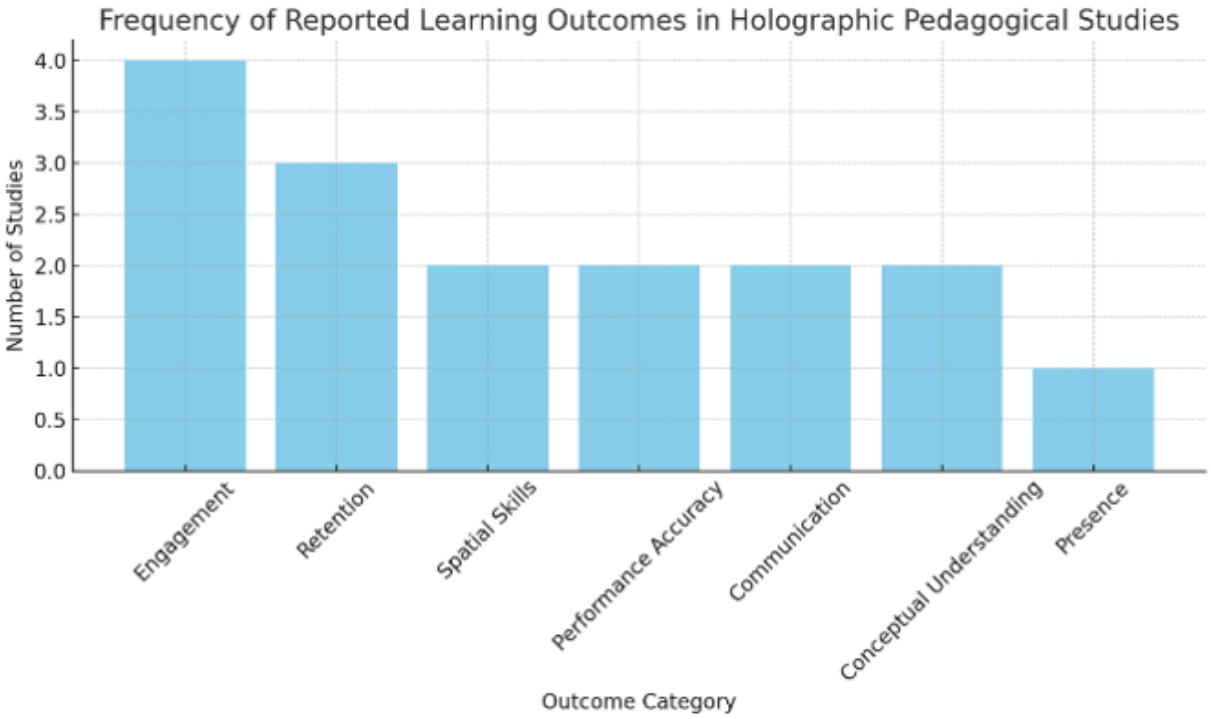


Figure 5

This bar graph illustrates the frequency with which specific learning outcomes were reported across the reviewed empirical studies on holographic pedagogy in higher education.

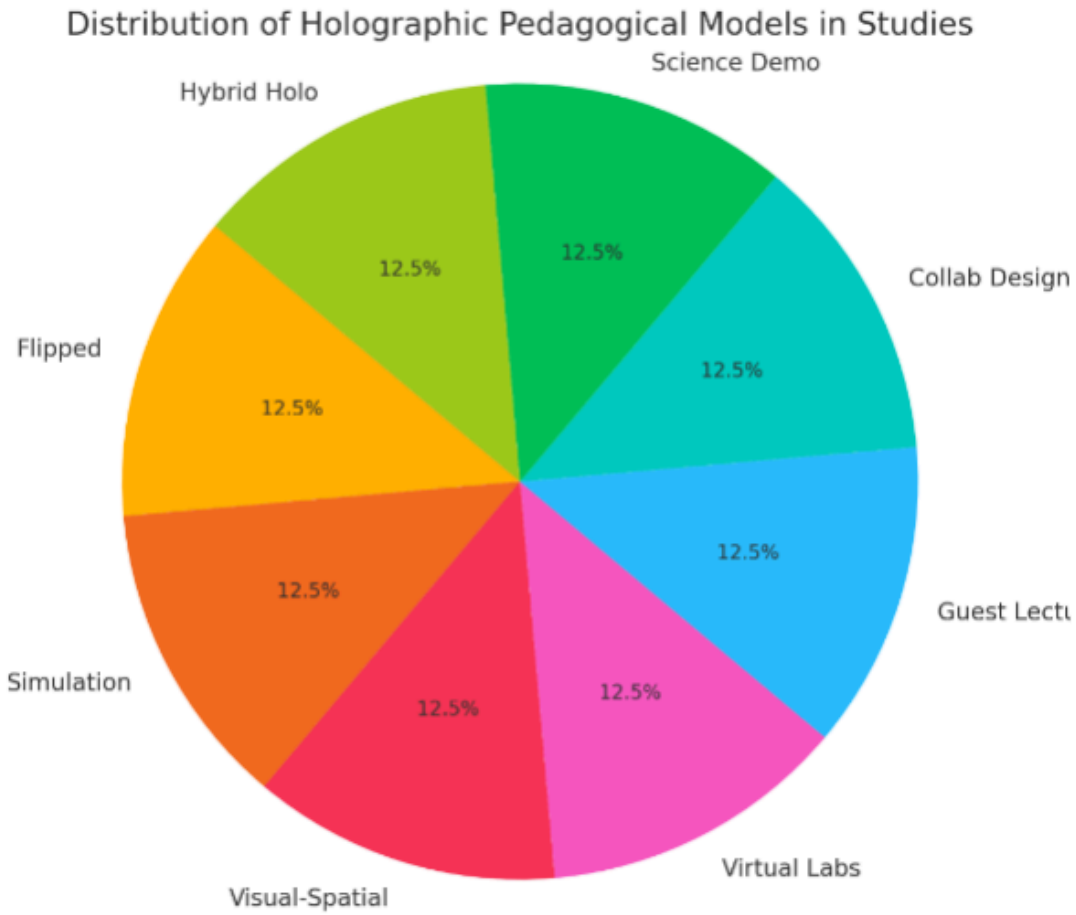


Figure 6

This pie chart illustrates the distribution of various pedagogical models employed in the analyzed empirical studies. Each model **Flipped Classroom, Simulation-Based Learning, Visual-Spatial Instruction, Virtual Labs, Guest Lectures, Collaborative Design, Science Demonstration,** and **Hybrid Holographic Presence** is represented equally in the sample, demonstrating the diverse experimental approaches being tested in higher education settings. This diversity underscores the experimental and exploratory nature of current research in this emerging field.

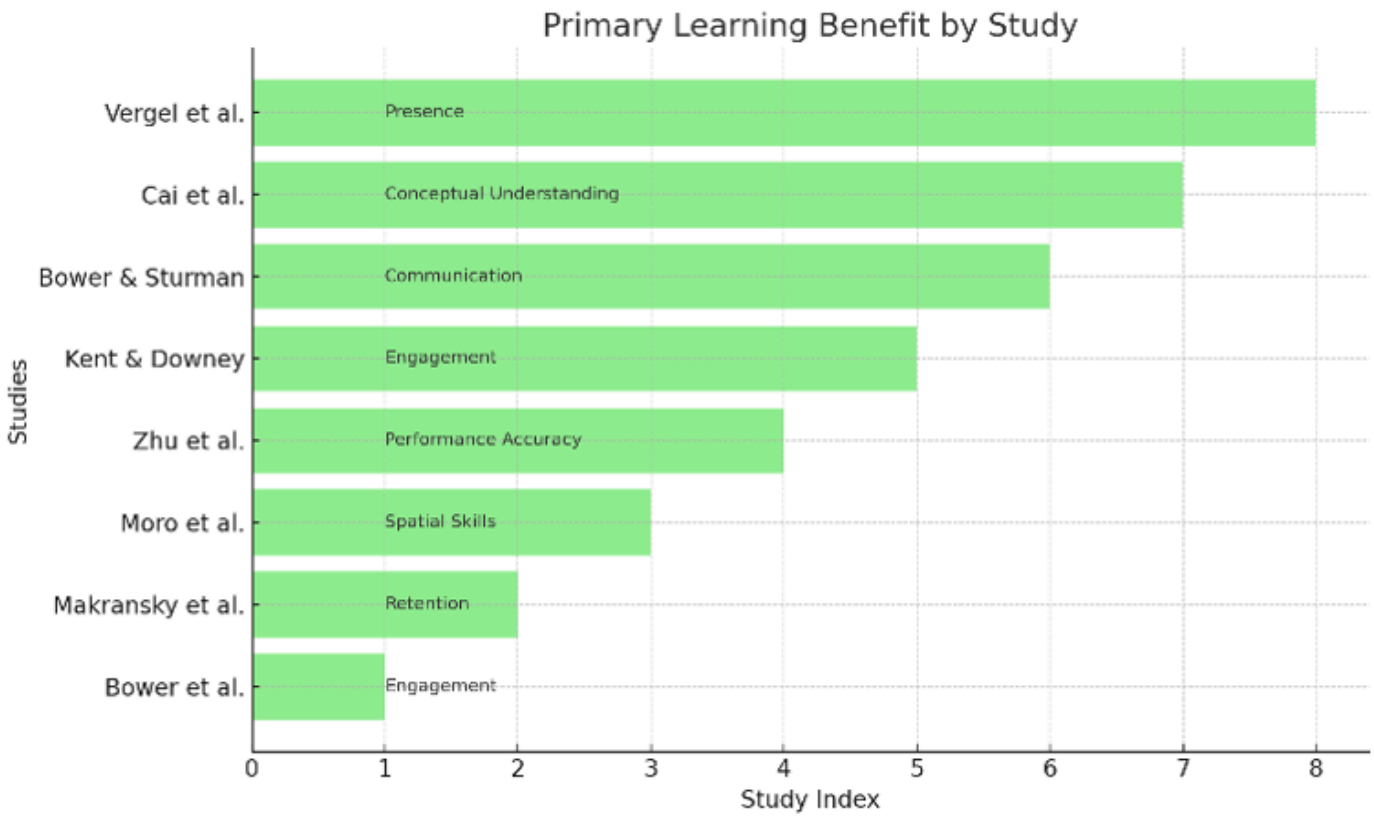


Figure 7

This horizontal bar chart maps each reviewed study to its **primary reported learning benefit**.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- PRISMA2020Checklist.docx