

Augmented Reality in Collaborative Learning: A systematic Review on Motivation, Interdisciplinary Understanding, and Team Performance

Realidad aumentada en el aprendizaje colaborativo: Una revisión sistemática sobre motivación, comprensión interdisciplinar y desempeño en equipo

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Abstract:

Augmented Reality (AR) is emerging as an increasingly significant pedagogical tool in higher education. Due to its immersive and interactive qualities, AR is promising tool for enhancing the learning process across a variety of disciplines. However, teamwork is an area that needs further inquiry as in this context the potential of AR remains inconclusive, and due to ARs' ability to create new opportunities to strengthen student motivation, foster interdisciplinary understanding, and improve the overall effectiveness of group work. Recent findings further indicate that immersive technologies such as AR and VR can play a central role in stimulating students' creativity, particularly in entrepreneurial and project-based contexts. While AI emerged as the strongest predictor of innovation, AR/VR was also shown to significantly support students' ability to generate business ideas, underlining its growing relevance for higher education. This systematic review synthesizes the current state of knowledge on the use of AR in collaborative projects in higher education, focusing on key dimensions such as responsibility, group cohesion, and students' confidence in contributing to collective outcomes. The review also considers research on foreign language learning, in which collaboration and interaction constitute core pedagogical components. The purpose of this article is to assess the extent to which AR can be regarded as a tool for promoting engagement, self-assessment, and teamwork outcomes in academic education, and to outline future directions for research in this domain.

Keywords:

Augmented Reality; Collaborative learning; Higher education; Interdisciplinary; Student motivation; Teamwork.

Resumen:

La Realidad Aumentada (RA) se está consolidando como una herramienta pedagógica cada vez más importante en la educación superior. Gracias a sus cualidades inmersivas e interactivas, la RA se perfila como una herramienta prometedora para mejorar el proceso de aprendizaje en diversas disciplinas. Sin embargo, el trabajo en equipo es un área que requiere mayor investigación, ya que en este contexto el potencial de la RA aún no está del todo claro, y se destaca su capacidad para crear nuevas oportunidades que fortalezcan la motivación estudiantil, fomenten la comprensión interdisciplinaria y mejoren la eficacia general del trabajo en grupo. Hallazgos recientes indican, además, que las tecnologías inmersivas como la RA y la RV pueden desempeñar un papel fundamental en el estímulo de la creatividad estudiantil, especialmente en contextos emprendedores y basados en proyectos. Si bien la IA se ha consolidado como la innovación más potente, la RA/RV también ha demostrado ser un apoyo significativo para la capacidad de los estudiantes de generar ideas de negocio, lo que subraya su creciente relevancia predictiva en la educación superior. Esta revisión sistemática sintetiza el estado actual del conocimiento sobre el uso de la RA en proyectos colaborativos en la educación superior, centrándose en dimensiones clave como la responsabilidad, la cohesión grupal y la confianza del alumnado en su contribución a los resultados colectivos. La revisión también considera la investigación sobre el aprendizaje de lenguas extranjeras, donde la colaboración y la interacción constituyen componentes pedagógicos fundamentales. El propósito de este artículo es evaluar en qué medida la RA puede considerarse una herramienta para promover la participación, la autoevaluación y el trabajo en equipo en la educación académica, y esbozar futuras líneas de investigación en este campo.

Palabras claves:

Educación superior; motivación estudiantil; interdisciplinariedad; realidad aumentada; trabajo en equipo.

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1. Introduction

The ability to collaborate effectively constitutes one of the cornerstones of university education, with group projects often employed to develop social and interdisciplinary competencies (Smith & MacGregor, 1992; Yang, 2023). Collaboration not only prepares students for professional teamwork, but also supports the development of transversal skills such as communication, negotiation, and self-regulation. In practice, however, teamwork is frequently reduced to a simple division of tasks, which limits interactions and diminishes student engagement, and undermines the potential for co-construction of knowledge (Roschelle & Teasley, 1995; Oxford, 1997).

Extended Reality (XR), which includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has become a powerful tool in teaching applied sciences. A recent review shows that XR can improve motivation, learning efficiency, and short-term knowledge acquisition, and may also help to improve retention and confidence in longer-term applications (Huang & Tseng, 2025). AR is a technology that integrates digital elements with the real world to create interactive and immersive learning experiences, combining physical and virtual settings in real time. It is gaining more attention for its use in education (Azuma, 1997; Moreno et al., 2001; Yilmaz & Göktaş, 2018). While studies show AR can boost student engagement and improve its cognitive skills and learning outcomes, there is less research on how it can help with teamwork in higher education, especially in collaboration (Ali et al., 2017). Recent reviews also emphasize that AR is the most studied immersive technology in education, with consistent evidence that it improves both engagement and academic performance. Moreover, AR can also help students work together by creating shared and interactive learning environments (Tene et al., 2024).

AR has the ability to simulate real team situations by encouraging responsibility, building group relationships, and enhancing students' confidence. It can also make student feel more connected and part of a group, and when guided properly, it can support effective teamwork (Bower et al., 2017; Choi-Lundberg et al., 2023; Gil Ortega & Falconer, 2015). New research also shows that AR can reduce learning stress and help students apply abstract ideas to real-world situations, showing its value in group learning settings (Yu et al., 2022).

Another area where AR can support teamwork is in learning foreign languages, where interaction and group activities are key elements (Belda-Medina, 2022, 2025; Cai et al., 2022). Considering this context helps us better understand how AR can improve real communication and student collaboration. New findings also show that AR can greatly improve vocabulary learning in English as a foreign language, increasing motivation and student engagement, which highlights its potential as an interactive and collaborative learning tool (Khan et al., 2023).

The aim of this review is to collect and evaluate available evidence about how AR helps with teamwork in higher education. It covers a broad range of disciplines and focuses especially on how AR affects motivation, self-esteem, interdisciplinary understanding, and the results of teamwork. The analysis also includes studies on using AR in language learning to identify how these findings might apply to other areas and to provide a more comprehensive picture of AR's applications.

Research Questions:

- RQ1: How is AR utilized in higher education in the context of group projects and collaborative learning?
- RQ2: What are the documented effects of AR on the motivation and engagement of students participating in teamwork?
- RQ3: Does the use of AR in group projects support students' self-esteem and increase their confidence in their contributions to the team?
- RQ4: What evidence exists that AR promotes interdisciplinary understanding and the development of collaboration skills in academic settings?
- RQ5: To what extent do studies on AR in foreign language learning indicate the potential for using this technology to support authentic communication and teamwork?

2. Theoretical Framework

2.1. Augmented Reality as an Educational Technology

AR overlays digital information to the real world, letting users interact with 3D models and simulations in real time (Azuma, 1997; Moreno et al., 2001; Yilmaz & Göktaş, 2018). This hybrid nature makes learning more real and context-based, helping students grasp difficult or abstract ideas in many different fields of studies. Other research shows that whether AR works well depends on several factors like how immersive it feels, the quality of the technology, perceived usefulness and ease of its use, social influence and the learners' own attitudes. These factors together decide if AR can be successfully used in education (Ghobadi et al., 2022). Recent systematic reviews emphasize that AR is becoming a valuable tool in higher education, enhancing students' engagement and learning outcomes by combining real and virtual elements (Elnaqlah et al., 2023). These reviews also point out that AR is being used more in language learning, where it helps with motivation, involvement, and vocabulary, but there are still challenges because of how tasks are designed and how they are assessed (Christou et al., 2023).

In addition to helping with visualization, AR shows important features of new technologies in higher education, like personalization, ubiquitous learning, collaboration, and authenticity (Isaías, 2018). Research has shown that AR supports learning by creating active and student-centered environments, which increases students' satisfaction and involvement (Martínez Pérez & Fernández Robles, 2018). By enabling shared interactions with digital objects in real spaces, AR supports learning methods that focus on active participation and engagement, learning through experience, and inquiry-based exploration.

2.2. Collaborative Learning and Social Constructivism

Collaborative learning is crucial part of higher education, emphasizing teamwork, shared knowledge construction, and collective problem-solving (Yang, 2023). Based on social constructivist theories, Vygotsky (1978) emphasized the role of social interaction in cognitive development, while Bandura's (1977) social theory discussed how personal, behavior, and envi-

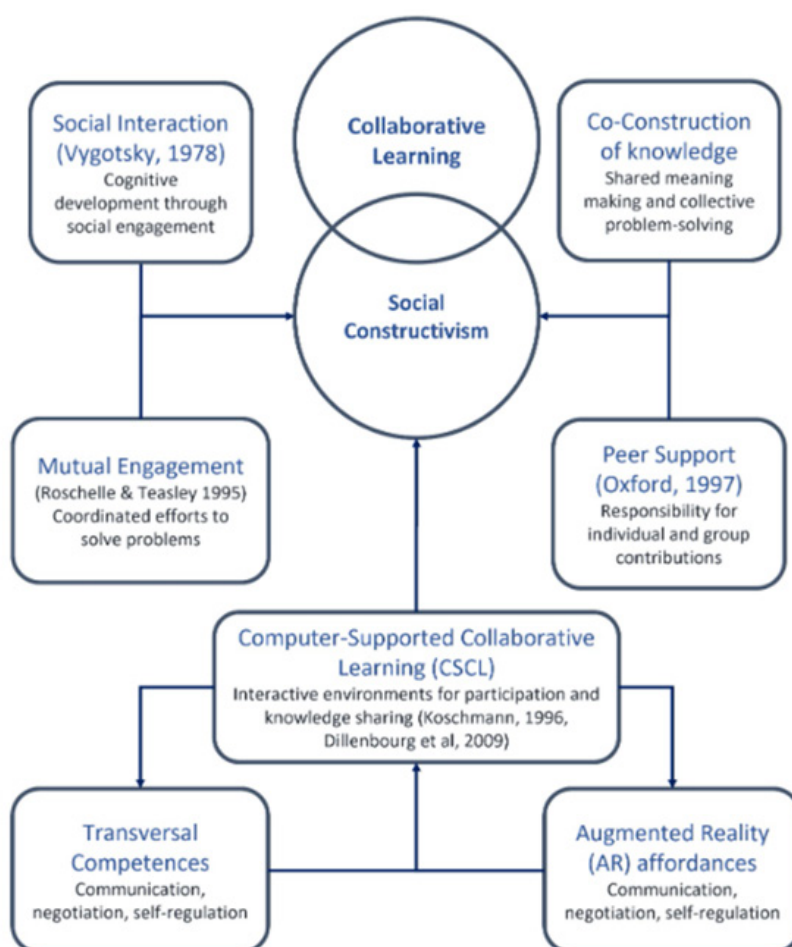
ronmental factors influence each other. Within this framework, learning occurs when students work together, learn from each other, and build understanding as a group.

Scholars explain collaboration as mutual engagement in coordinated efforts to solve problems (Roschelle & Teasley, 1995). In this process, learners are not only responsible for their own work, but also for supporting peers (Oxford, 1997). Such group-based approaches encourage motivation, accountability, and the development of transversal competencies, including communication, negotiation, and self-regulation.

The growth of Computer-Supported Collaborative Learning (CSCL) has further changed how we think about collaborative pedagogy. CSCL brings digital tools into the classroom to help students work together better. It creates environments where students can share ideas, learn from each other, and build shared understanding (Koschmann, 1996; Dillenbourg et al., 2009). AR, as part of this digital learning system, offers new affordances for co-presence, multimodal communication, and work together on learning materials. The key concepts and connections of the collaborative learning and social constructivism is represented in Figure 1.

Figure 1

Collaborative Learning and Social Constructivism: Key Concepts and Connections



Source: own elaboration.

2.3. Interdisciplinarity and Knowledge Integration

In higher education, complex problem-solving increasingly requires integration across disciplines. Interdisciplinary learning involves synthesizing knowledge, perspectives, and methods from multiple fields, fostering cognitive flexibility and deeper understanding (Mansilla et al., 2000). Effective pedagogy for interdisciplinarity engages students in tasks that demand cross-disciplinary reflection and collaboration (Graybill et al., 2006; Lattuca et al., 2004). According to Marín-Rodríguez et al. (2023), AR is useful across many disciplines such as sciences, medicine, architecture, and languages, this shows how AR can be adapted to diverse educational needs and knowledge domains.

This approach enhances critical thinking and prepares students for real-world challenges (National Research Council, 2012). Furthermore, AR fosters inclusivity and adaptability, offering opportunities to approach abstract and complex topics while supporting collaborative methodologies and constructivist approaches. Studies have shown that using AR can improve learning materials, save time, students' memory retention and motivation (Martínez Pérez et al., 2021).

AR can help in this process by creating interactive spaces where students can access knowledge from different disciplines. For instance, students can collaborate to explore molecular structures, historical events, or engineering designs, combining scientific, technical, and social knowledge in real-world situations. A complementary approach is the integration of Living Lab methodologies, which, when combined with problem-based learning, provide authentic, collaborative environments for applied problem-solving and knowledge transfer (Arenas Crespo et al., 2023).

2.4. Motivation, Engagement, and Self-Determination Theory

Motivation is a critical determinant of effective teamwork and academic success. According to Self-Determined Theory (SDT), people need to feel competent, have control over their actions, and feel connected to others in order to be motivated and happy (Wang et al., 2024). AR applications, through interactive and immersive tasks, can directly address these needs:

Self-Determination Theory (SDT) posits those three psychological needs, competence, autonomy, and relatedness, must be satisfied to foster intrinsic motivation and well-being (Wang et al., 2024). AR applications, through interactive and immersive tasks, can directly address these needs. They can enhance competence through mastery of challenging content, supporting autonomy by giving control and letting their users to explore on their own, and fostering relatedness by helping to feel connected and allowing to work with others. This alignment with SDT principles promotes deeper learning and persistence in educational settings (Ryan & Deci, 2020). A study with students showed that using AR objects made learning process more enjoyable and engaging, which positively influenced motivation and positive attitude towards learning (Martínez Pérez & Fernández Robles, 2018).

Beyond supporting motivation, AR/VR environments have been shown to foster creative risk-taking and innovation. They allow learners to experiment in immersive and low-risk settings—skills that are directly tied to entrepreneurship and teamwork (Prabowo et al., 2025). Emotional design plays an additional role in sustaining engagement. Features such as intuitive interaction with 3D models, scalable objects, and clear instructional cues can elicit positive emotions such

as trust, curiosity, or professional motivation (Redzuan et al., 2019). These affective responses contribute to group cohesion and a sense of belonging, which are vital in collaborative learning environments. Empirical evidence also shows that AR can significantly boost motivation, creativity, and enthusiasm, with students describing AR-supported lessons as more attractive and engaging than traditional methods (Sáez-López et al., 2020).

2.5. Cognitive Theories and Multimedia Learning

From a cognitive perspective, Mayer's theory of multimedia learning underscores how the integration of words and pictures can enhance understanding when aligned with cognitive load principles (Mayer, 2005). AR extends this model by introducing spatially and contextually integrated visualizations that reduce abstraction and support dual-channel processing. However, without careful design, AR may increase extraneous cognitive load, particularly when students must simultaneously navigate complex interfaces and content (Yılmaz & Göktaş, 2018). Thus, AR-based teamwork requires balancing cognitive demands with pedagogical scaffolds to optimize learning outcomes. Collaborative learning environments foster deeper understanding when guided by structured pedagogical strategies (Johnson & Johnson, 2009).

2.6. Positioning AR within Higher Education Teamwork

Bringing together these theoretical perspectives, AR can be understood as both a technological affordance and a pedagogical tool. By supporting collaborative learning (through shared interactions), social constructivist principles (through co-construction of knowledge), interdisciplinary integration (through multimodal simulations), and motivational frameworks such as SDT, AR provides a multidimensional framework for enhancing teamwork in higher education. At the same time, alignment with cognitive theories of multimedia learning ensures that the potential benefits are not undermined by overload or poor design. Teacher facilitation is essential to guide collaborative AR experiences and ensure meaningful learning outcomes (Laurillard, 2012).

In this way, AR holds promise as a mediating technology that not only visualizes content but also fosters motivation, confidence, and collaboration, key competencies for academic and professional contexts in the era of Education 4.0.

3. Methods

To examine the key benefits and challenges of implementing Augmented Reality (AR) in teamwork within higher education, this study employed a systematic literature review (SLR) guided by the PRISMA 2020 framework (Page et al., 2021). The PRISMA methodology ensures a rigorous and transparent review process by clearly defining research objectives, formulating precise research questions, identifying relevant search terms, and establishing explicit inclusion and exclusion criteria. This review aims to explore how AR can enhance collaborative learning, student motivation, self-esteem, interdisciplinary understanding, and overall team performance in higher education contexts.

The literature search focused on peer-reviewed articles and review papers indexed in major academic databases, including Web of Science and Scopus. Recognizing the importance of

collaborative interaction in language learning, the review also incorporated studies examining AR applications in foreign language education.

The methodological approach was designed to systematically gather and synthesize current evidence regarding the role of AR in facilitating effective teamwork and collaborative learning. By providing a comprehensive overview of the benefits, limitations, and research gaps, this review offers valuable insights for educators and identifies directions for future research and practical implementation in higher education settings.

Table 1

Research Criteria

Database	WOS / SCOPUS
Search fields	Title of the work, abstract, keywords
Search terms	Augmented Reality, Immersive Learning, Higher Education, University, Project-Based Learning, Collaborative Learning, Technology Acceptance, Education, Engagement, Motivation, Self-Esteem, Self-Efficacy, Perceived Learning, Critical Thinking, Problem Solving, Collaboration Efficacy,
Boolean operators	and
Period	Limited: 10 years

Source: own elaboration

As a result of applying the predefined selection criteria at the outset of this systematic literature review, a total of 18,777 records were initially identified across the selected databases. The article selection process began with filtering these results to include only publications from the last decade. The search was conducted using carefully chosen keywords in the Web of Science and Scopus databases, employing Boolean operators to combine terms specifically aimed at identifying studies on the use of AR in collaborative learning within higher education.

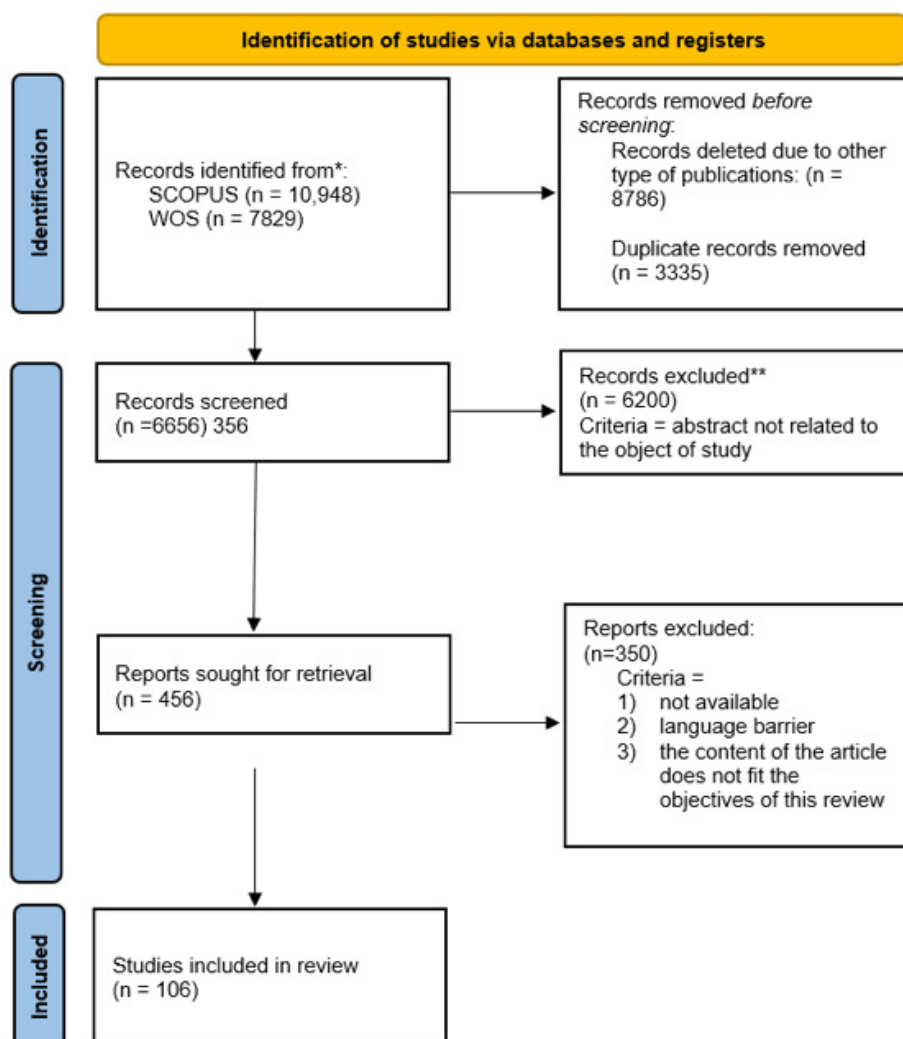
These criteria were designed to capture current trends while also reflecting broader developments in the field over the past ten years. Publications other than peer-reviewed journal articles and systematic reviews, such as book chapters, dissertations, or conference proceedings, were excluded from the analysis. Duplicate records retrieved from multiple searches were removed to ensure accuracy.

Next, the abstracts of the initially qualified articles were screened to identify studies explicitly focused on collaborative learning and AR implementation in higher education. Articles addressing other educational levels or different AR applications were excluded. Additionally, publications in languages other than English and Spanish, as well as articles inaccessible in full text, were removed. The final stage of selection involved a full-text review, during which publications were excluded if they did not provide relevant information regarding AR use in higher education collaborative learning contexts.

Factors such as study design, methodology, participant language proficiency, gender, or socio-economic background were not used as exclusion criteria. The systematic review ultimately included all sources meeting the predefined criteria, thereby providing a comprehensive overview of diverse perspectives, applications, and research findings on AR-supported collaborative learning in higher education.

Figure 2

Review Flow Process



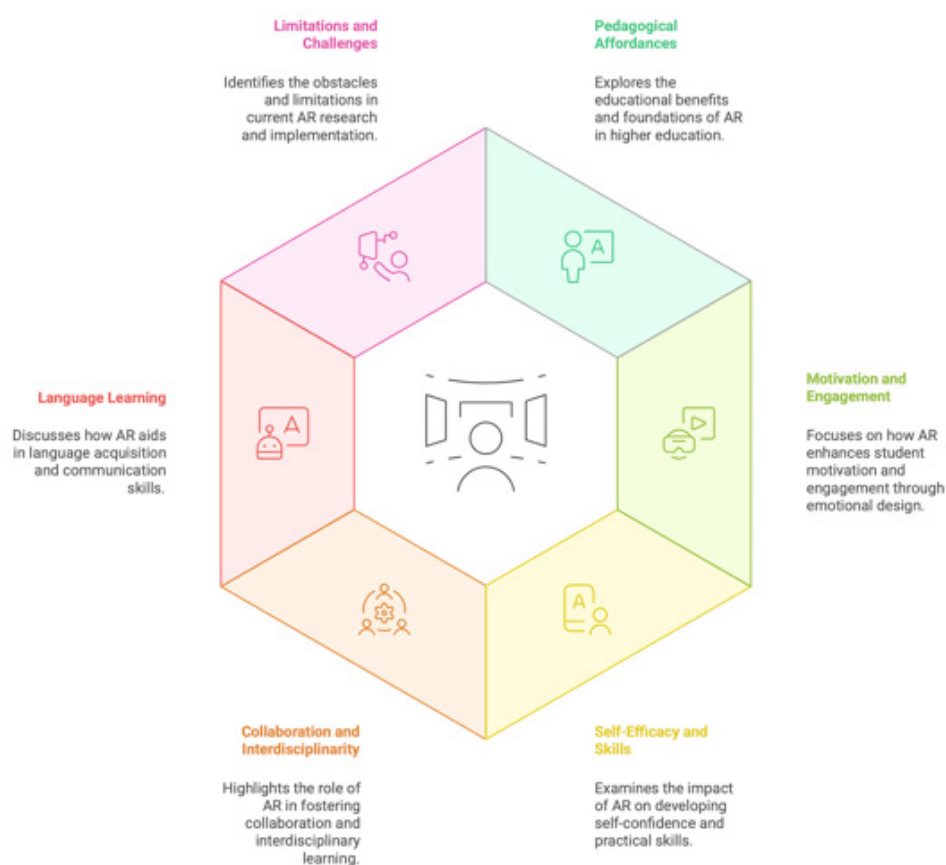
Source: own elaboration

4. Results

The following section presents the main findings derived from the systematic review, organized into six thematic areas that reflect the dominant trends in the literature as shown in Figure 3. These subsections examine: (1) the pedagogical affordances and foundations of augmented reality (AR) in higher education; (2) its impact on motivation, engagement, and emotional design; (3) effects on self-efficacy and skills development; (4) the role of collaboration, peer interaction, and interdisciplinarity; (5) contributions to language learning and communication skills; and (6) the limitations and challenges identified in current research. Together, these themes provide a comprehensive overview of how AR technologies are being integrated into higher education and the factors influencing their effectiveness.

Figure 3

Thematical classification of the defined areas.



Source: own elaboration

4.1. Affordances and Pedagogical Foundations

AR enriches higher education by enabling the visualization of invisible phenomena, the simulation of hazardous scenarios, and the concretization of abstract concepts, thereby supporting inquiry-driven and collaborative learning (Wojciechowski & Cellary, 2013; Walczak et al., 2006). Applications span STEM, engineering, health sciences, the humanities, and language education, where AR enhances comprehension, retention, and collaborative learning (Choi-Lundberg et al., 2023; Marín-Rodríguez et al., 2023). In molecular chemistry, for example, AR clarifies structures and processes otherwise invisible to the naked eye, reducing misconceptions and strengthening spatial skills (Wojciechowski & Cellary, 2013; Saidin et al., 2024). Multimodal frameworks that combine touch and gestures further improve outcomes and engagement (Asiri et al., 2022).

Beyond STEM, AR has been successfully integrated into literary education through immersive literary environments (ILEs), which merge physical supports with AR activators to create multi-sensory and playful experiences that foster reading motivation and literary competence (Neira-Piñeiro & del-Moral-Pérez, 2021). In geometry and science, it facilitates collaborative manipulation and experiential visualization (Redzuan et al., 2019), while in museums and history, it

enables context-rich, interactive engagement. More broadly, AR consistently supports attention, motivation, problem-solving, and authentic situational learning (Yilmaz & Göktaş, 2018).

Recent studies demonstrate that technology alone does not guarantee engagement: narrative-driven AR games only achieve strong results when aligned with problem-based learning principles (Lee, 2022). Indeed, students using an AR mobile game reported greater immersion and motivation when adopting problem-solving roles such as investigators compared to traditional formats (Lee, 2022). Similarly, experimental research confirms that AR significantly improves conceptual understanding and knowledge application, with higher post-test performance in experimental groups (Kuanbayeva et al., 2024).

In collaborative contexts, multi-user AR applications allow learners to visualize abstract concepts, coordinate tasks in real time, and achieve stronger outcomes than in traditional formats (Masneri et al., 2022). Mapping studies confirm that AR remains the most widely applied mixed-reality technology in education, though systematic evaluation of its collaborative features is still underdeveloped (Ali et al., 2017). At the same time, AR embodies the five hallmarks of emerging technologies—personalization, ubiquitous learning, collaboration, lifelong learning, and authenticity—while reshaping learning spaces (Isaías, 2018).

Language learning has also benefited from immersive technologies. Systematic reviews show that XR applications create multimodal, interactive, and authentic contexts for communication that align with constructivist and experiential learning principles (Luo et al., 2024). Evidence further indicates that gamified AR and VR prioritize interactivity as their main affordance for vocabulary learning, with AR offering additional advantages through collaboration and visualization (Lin & Wei, 2024). More broadly, AR, VR, and MR have been highlighted as transformative tools capable of reshaping traditional educational paradigms by providing immersive, interactive, and authentic environments for experiential learning (Crogman et al., 2021).

4.2. Motivation, Engagement, and Emotional Design

AR-supported learning consistently enhances engagement, social presence, and belonging (Choi-Lundberg et al., 2023; Bower et al., 2017; Gil Ortega & Falconer, 2015). Beyond AR, studies on three-dimensional virtual worlds (3DVWs) in higher education show that factors such as ease of use, usefulness, enjoyment, and visual attractiveness shape user acceptance and engagement (Ghanbarzadeh & Ghapanchi, 2020). Similarly, scaffolded and game-based tasks reduce anxiety and sustain motivation (Lin & Hou, 2022; Soltis et al., 2020; Upadhyay et al., 2024). Students generally report AR-enhanced classes as more engaging than traditional formats in fields including chemical engineering, health sciences, physical education, arts, and the humanities (Rebello et al., 2024; Soriano-Sánchez & Jiménez-Vázquez, 2025), with meta-analyses confirming significant gains in attention, confidence, and satisfaction (Soriano-Sánchez & Jiménez-Vázquez, 2025). In computer science education, combining AR with gamification and serious games significantly improved motivation and self-efficacy (Lampropoulos et al., 2023). Anatomy applications such as Anatomy 4D also boosted attention and confidence, though lecturers reported technical challenges and the need for staff support (Khan et al., 2019).

Motivational outcomes vary across learner groups. In collaborative AR interventions, women and younger learners reported higher motivation and satisfaction (Peralta-Jaén, 2025), while older participants highlighted stronger improvements in teamwork perception. Project-based and XR-supported learning further enhanced emotional engagement and facilitation (Hamida-

ni et al., 2025), and flipped or gamified AR models promoted positive attitudes, ease of use, and participation (Lu et al., 2021; Criollo-C et al., 2024; Marcial et al., 2022). Although cohort studies confirm higher motivation and engagement, improvements do not always translate into better grades (Sviridova et al., 2023). At the same time, participants across institutions emphasized that AR motivates students, enriches classroom engagement, and fosters inclusive learning opportunities (Huertas-Abril et al., 2021).

In subject-specific contexts, AR shows strong benefits. In literary education, augmented books and interactive environments stimulated curiosity, sustained attention, and enhanced enjoyment (Neira-Piñeiro & del-Moral-Pérez, 2021). Language learning studies reveal that gamified AR strengthens curiosity and collaboration (Wang & Khambari, 2020), while QR codes improve motivation, comprehension, and retention in reading (Kuru Gönen & Zeybek, 2021). Bibliometric analyses confirm positive attitudes in AR language learning but note persistent challenges of cognitive load and technical barriers (Min & Yu, 2023; Huang et al., 2021). Cooperative gamification strategies in AR-GBL reduce cognitive load and foster cultural literacy more effectively than competitive ones (Zhan et al., 2025), findings reinforced by evidence that collaborative AR settings yield more positive experiences than individual competition (Zhan et al., 2025). Similarly, recent work shows AR-based lessons in secondary schools improved satisfaction, interest, and perceived usefulness compared to traditional methods (Marrahi-Gomez & Belda-Medina, 2024).

Across educational levels, AR also enhances motivation and creativity in vocational education, while reducing cognitive load and supporting self-efficacy (Liu, Zhan, & Zhao, 2023). Students report higher satisfaction, interactivity, and willingness to integrate AR into other courses, reinforcing its role in sustaining motivation and positive learning attitudes (Kuanbayeva et al., 2024). At the design level, affective features such as scalable 3D objects, icon-based instructions, and typography intentionally elicit trust, challenge, and professional motivation (Redzuan et al., 2019). Still, research cautions that the motivational impact of AR cannot be assumed universally; effectiveness depends on alignment between design, content relevance, and learners' prior experiences (Iqbal et al., 2022). Likewise, superficial use of immersive environments offers limited benefits, whereas deep cognitive involvement is essential for satisfaction, retention, and learning outcomes (Ghanbarzadeh & Ghapanchi, 2020). Overall, AR enhances student motivation by creating interactive, collaborative, and creative learning scenarios, supporting a more open and dynamic educational paradigm (Dorta Pina & Barrientos Núñez, 2021).

4.3. Self-Efficacy, Confidence, and Skills Development

Safe, simulated AR environments enhance self-efficacy and readiness for practice, particularly in clinical and health education (Choi-Lundberg et al., 2023). Effective cognitive strategies, usability, and supportive classroom contexts further strengthen task value, confidence, and students' willingness to reuse AR (O'Connor & Mahony, 2023). In STEM courses, collaborative peer modeling has been linked to gains in self-efficacy and performance (Lee et al., 2022), while AR has also been shown to mitigate learning anxiety by supporting the transfer of abstract concepts (Yu et al., 2022). Evidence from VAR-based classrooms reinforces these findings, showing that students' self-efficacy and academic performance significantly improved after weeks of immersive lessons, with collaboration enhancing both confidence and subject mastery (Lee et al., 2023).

Integration with artificial intelligence and big data analytics expands these benefits by enabling adaptive feedback, realistic simulations, and interprofessional collaboration in health care (Guraya, 2024; Asoodar et al., 2024). In professional education, adoption depends heavily on design quality and motivational affordances, with gender and role differences moderating acceptance (Ghobadi et al., 2022). Broader studies confirm that technology competence in AR/VR and AI predicts motivation and engagement (Zhang & Miao, 2025). Similarly, AR combined with collaborative project-based learning improves academic performance, critical thinking, and teamwork (Adi et al., 2025), while also strengthening transversal skills such as communication, teamwork, and problem-solving (Slyusarenko et al., 2024). These outcomes align with findings by Lampropoulos et al. (2023), who showed that AR supports comprehension, fosters computational thinking, and builds learner confidence. From an experiential learning perspective, immersive technologies are particularly effective in enhancing active experimentation and reflective observation (Kee et al., 2024).

Nonetheless, as Iqbal et al. (2022) caution, the positive effects of AR on self-efficacy cannot be assumed universally. Inconsistencies in instructional design and a lack of robust evaluation frameworks make it difficult to generalize results across disciplines.

4.4. Collaboration, Peer Interaction, Knowledge Integration and Interdisciplinarity.

AR enhances collaboration by enabling joint manipulation of content, synchronous observation, and shared problem-solving (Upadhyay et al., 2024; Kumar et al., 2022). In classroom practice, it has been shown to foster communication, cooperation, and innovative thinking as students actively contribute ideas and engage in group projects (Sáez-López et al., 2020). High-achieving teams transition more quickly to complex tasks and converge on shared understandings, whereas lower-achieving groups often display fragmented coordination (Kang et al., 2024). Shared holographic environments in professional training provide real-time facilitation and objective teamwork assessment (Wilkins et al., 2024). Similarly, Marín-Rodríguez et al. (2023) underline that AR promotes participatory and collaborative learning, while broader reviews confirm its potential for collaborative exploration and problem-solving across domains (Scavarelli et al., 2021).

Disciplinary studies further illustrate these effects. In-service TEFL teachers engaged in collaborative AR learning outperformed lecture-based controls and reported stronger technology beliefs (Nikimaleki & Rahimi, 2022). In chemistry, group familiarity proved critical, with self-selected groups collaborating more effectively than randomly assigned ones (Ahmed & Lataifeh, 2023), while in geometry, participants using AR demonstrated greater efficiency and richer collaborative strategies than individuals (Sarkar et al., 2020). Literary education projects using AR-supported immersive environments strengthened pre-service teachers' collaborative skills by integrating creative, didactic, and technological elements (Neira-Piñeiro & del-Moral-Pérez, 2021). Large-scale evaluations of multi-user AR platforms likewise confirm that peer interaction predicts engagement, though teachers emphasize the need for content customization and LMS integration (Masneri et al., 2024). Importantly, Masneri et al. (2022) caution that many AR tools promote interactivity but only a subset enable genuine collaboration, underscoring the importance of multi-user design.

Evidence also shows that AR integration can extend beyond traditional academic contexts. In higher education, it has been linked not only to collaboration but also to entrepreneurial crea-

tivity and innovative problem-solving, with clear implications for business ideation (Prabowo et al., 2025). Health science reviews highlight benefits such as clinical reasoning, spatial understanding, retention, and reduced cognitive load (Rodríguez-Abad et al., 2021), while interdisciplinary applications include molecular visualization, safety training, and transport phenomena (Rebello et al., 2024). Integration with computational tools further supports analytical reasoning in line with Education 4.0 (Betancourt Arango et al., 2024). Creative collaboration can also be scaffolded through progressive transitions from 2D to 3D to AR (Sanabria & Arámburo-Lizárraga, 2017), while mobile AR conversations reveal emergent multimodal coordination patterns (Hellermann & Thorne, 2022).

From a design perspective, immersive classrooms also shape collaboration. For example, VAR classrooms in which small groups shared a headset encouraged peer discussion and boosted confidence and teamwork skills (Lee et al., 2023). In ripple tank practicum modules, AR explicitly fostered collaborative problem-solving (Indrasari et al., 2019). Likewise, Peralta-Jaén (2025) shows that AR/VR integration in teacher training supports teamwork and motivation, particularly when paired with collaborative strategies. More broadly, Dorta Pina and Barrientos Núñez (2021) demonstrate that AR strengthens attention, memory, and teamwork by immersing students in shared learning contexts.

Finally, collaboration emerged as a defining affordance of AR-based activities, with learners reporting that teamwork allowed them to notice details they would have overlooked individually, increasing enjoyment and meaningful engagement (Lee, 2022). Students further described AR experiences as more authentic and immersive than print-based tasks, confirming its potential to foster real-world collaboration (Lee, 2022). Yet, as Iqbal et al. (2022) note, collaborative affordances of AR remain underexplored, with many implementations failing to fully leverage interaction and co-construction of knowledge—an important direction for future research.

4.5. Language Learning and Communication Skills

Meta-analyses indicate strong effects of AR on vocabulary and reading, with smaller but consistent gains in motivation (Cai et al., 2022). Studies across schools and universities report improvements in vocabulary, listening, writing, and speaking, with learners highlighting higher engagement and satisfaction (Belda-Medina, 2022, 2025; Khan et al., 2023; Parlar & Sütçü, 2025; Elnaqlah et al., 2023). Experimental interventions confirm these outcomes: AR with QR codes enhanced comprehension in technical EFL (Dukalskaya & Tabueva, 2022), AR-based writing classes improved performance (Elnaqlah et al., 2023), and AR-supported CLIL boosted both vocabulary and content knowledge (Belda-Medina, 2025). Saudi EFL students using AR outperformed controls in vocabulary post-tests (Khan et al., 2023), while collaborative AR projects strengthened motivation and interdisciplinary skills among pre-service teachers, despite challenges in content authoring (Belda-Medina, 2022).

Additional studies show that AR improves vocabulary, fluency, and creativity (Hung & Yeh, 2023; Petrovych et al., 2023), supports listening and anxiety reduction in primary contexts (Parlar & Sütçü, 2025), and maintains engagement through narrative-driven games (Lee, 2022). QR codes further scaffold cultural or linguistic content, enhancing comprehension, motivation, and long-term retention (Kuru Gönen & Zeybek, 2021). In Ecuadorian distance education, Assemblr Edu was found to sustain attention and improve writing performance, with measurable gains in organization, grammar, vocabulary, and punctuation (Carrión-Robles et al., 2023).

Reviews and bibliometric analyses provide broader insights. Research outputs in AR language learning are increasing worldwide, with positive attitudes from both teachers and learners, particularly in vocabulary and oral skills, though challenges such as overload, cost, and technical barriers remain (Min & Yu, 2023; Huang et al., 2021). Systematic reviews of XR confirm that immersive technologies foster authentic communication, multimodal literacy, and reflective practice (Christou et al., 2025; Luo et al., 2024), as well as curiosity, immersion, and willingness to participate—though novelty effects and learning preferences may moderate outcomes (Luo et al., 2024). XR-based interventions have also been shown to promote vocabulary, speaking confidence, and cultural literacy, while shifting learners' focus from linguistic form to meaningful communicative use (Lee, 2022).

Quantitative syntheses further demonstrate that gamified AR and VR significantly improve vocabulary knowledge, particularly form and meaning, with AR supporting productive use through collaborative activities and multimodal input and VR enabling immersive, self-paced learning (Lin & Wei, 2024). Complementary work highlights that combining AR with concept mapping enhances vocabulary gains and retention without increasing cognitive load (Liu et al., 2025), while AR in Spanish language instruction has been linked to curiosity, collaboration, and improved vocabulary retention (Huang et al., 2025). More generally, systematic reviews confirm that XR/AR interventions reliably foster positive emotions such as curiosity and enjoyment, although extended use can lead to fatigue (Gómez-Ríos et al., 2023).

Finally, although AR consistently supports motivation and linguistic gains, not all skills benefit equally: grammar learning performance showed no statistically significant differences between AR-based and control groups, despite the clear motivational advantages (Marrahi-Gomez & Belda-Medina, 2024).

4.6. Limitations and Challenges of using AR in higher education

Institutional implementations illustrate both promise and limitations. For example, a dedicated VR lab at the University of Sydney hosted thousands of visits but reached only a small proportion of courses, reflecting early diffusion stages (Marks & Thomas, 2022). Broader syntheses classify AR/VR as disruptive technologies that generally enhance motivation and spatial intelligence, though effects on academic achievement remain mixed (Cabero & Robles, 2018; Huang & Tseng, 2025; Tene et al., 2024). Successful adoption requires not only access to devices and infrastructure but also careful pedagogical design and adequate teacher training (Marín-Rodríguez et al., 2023).

Common barriers include system instability, hardware/software failures, sensitivity to environmental conditions, multi-device dependence, and high cognitive load, particularly when students must simultaneously master content and interfaces (Upadhyay et al., 2024; Yilmaz & Göktaş, 2018). Effective teamwork relies on structured instructional design with clear roles and objectives (Choi-Lundberg et al., 2023), while poor preparation risks distraction and inefficient use of class time (Sáez-López et al., 2020). Surveys confirm teacher reluctance, limited preparedness, and insufficient digital resources as major obstacles (Marrahi-Gomez & Belda-Medina, 2024; Huertas-Abril et al., 2021).

In health sciences, realism and engagement are balanced by challenges such as limited haptic feedback, eye strain, high costs, and shortages of skilled developers (Rodríguez-Abad et al., 2021). In e-learning, barriers include resistance, insufficient training, and device limitations,

highlighting the importance of professional development and scaffolding (Alzahrani, 2020). Teachers also cite costs, lack of quality content, and a need for programming skills, recommending training and collaborative planning (Perifanou et al., 2023). Generational divides show younger teachers more open to AR/VR (Koreneva et al., 2023), while schools find AR easier to integrate than VR, particularly for student-created content (Lytvynova & Soroko, 2023). Inclusive frameworks emphasize Universal Design for Learning but highlight persistent gaps in adaptations for learners with disabilities (Poggianti et al., 2025). Accessibility concerns also remain for learners with visual impairments (Martínez Pérez et al., 2021).

At the design level, many AR applications still follow transmissive “delivery” models rather than collaborative or inquiry-based pedagogies, with effectiveness varying by subject (Li et al., 2025). Gamified AR can enhance motivation and performance in blended contexts but risks overemphasizing extrinsic motivation (Guaña-Moya et al., 2024). Bibliometric reviews confirm rapid growth in AI+XR publications, concentrated in China, the US, and Canada, revealing global disparities (Lampropoulos, 2025; Burke et al., 2025). In health education, most studies focus on VR, with only a minority explicitly applying instructional design principles (Asoodar et al., 2024). Cognitive load profiles further reveal differentiated effects of AR on self-efficacy and collaboration (Lin et al., 2024). Teacher surveys show low actual adoption of AR apps and highlight misalignment with pedagogy, underscoring that novelty does not guarantee long-term learning gains (Mirza et al., 2025). Technical barriers such as latency and replicability challenges remain in MR environments (Ali et al., 2017).

In vocational education, AR consistently supports safe skill practice, motivation, blended learning, and inclusive access, but high-quality content and structured design are essential (Indarta et al., 2025). Emerging trajectories include AI-driven tutoring systems and adaptive analytics, which enhance personalization but raise ethical concerns around privacy, surveillance, and autonomy (Lampropoulos, 2025; Raman et al., 2025). At the same time, students often struggle with AR during design and implementation of digital objects, underlining the importance of pedagogical and technological training and continuous teacher support.

Collaboration-specific challenges also persist. Most AR applications lack robust multi-user features, with Masneri et al. (2022) finding that the majority did not support remote participation—an omission underscored during the COVID-19 pandemic. Nevertheless, multi-user systems that did exist demonstrated clear benefits for joint problem-solving and teamwork. Classroom studies similarly noted that while AR improved attention and collaboration, results were constrained by small samples, scheduling issues, and unfamiliarity with VAR systems (Lee et al., 2023).

Overall, although AR is widely recognized for enhancing engagement and motivation, its effectiveness depends on thoughtful pedagogical integration, technical stability, accessibility, and continuous teacher training to overcome persistent barriers and ensure equitable, sustainable adoption. This is summarized in Table 2.

5. Discussion

This review demonstrates that AR holds considerable potential to transform higher education by enriching visualization, fostering experiential practice, and enhancing collaboration. At the same time, the evidence highlights that AR's effectiveness depends heavily on careful pedagogical design, technical infrastructure, and institutional support. Findings from student perceptions further confirm that AR can be seen as a user-friendly technology that supports the learning process, al-

Table 2
Results' summary

Affordances and Pedagogical Foundations	AR enhances higher education by making abstract or invisible concepts visible, fostering inquiry-based, collaborative, and experiential learning across disciplines. It supports engagement, comprehension, and problem-solving when pedagogically aligned, though its collaborative and evaluative dimensions need further research.	- Walczak et al., 2006. - Choi-Lundberg et al., 2023 - Marín-Rodríguez et al., 2023. - Wojciechowski & Cellary, 2013 - Saidin et al., 2024. - Asiri et al., 2022. - Neira-Piñero & del-Moral-Pérez, 2021. - Redzuan et al., 2019.	- Yilmaz & Gökaş, 2018. - Lee, 2022. - Kuanbayeva et al., 2024. - Masneri et al., 2022. - Ali et al., 2017. - Isaías, 2018. - Luo, Zou, & Kohnke, 2024. - Lin & Wei, 2024. - Crogman et al., 2021.
Motivation, Engagement, and Emotional Design	AR consistently increases motivation, engagement, and enjoyment through interactive, gamified, and collaborative experiences. However, motivational effects depend on thoughtful design, content relevance, and learner context, as superficial use or poor alignment limits impact.	- Choi-Lundberg et al., 2023 - Bower et al., 2017 - Gil Ortega & Falconer, 2015 - Ghanbarzadeh & Ghapanchi, 2020. - Lin & Hou, 2022 - Soltis et al., 2020; - Upadhyay et al., 2024. - Rebello et al., 2024 - Soriano-Sánchez & Jiménez-Vázquez, 2025 - Lampropoulos, Keramopoulos, Diamantaras, & Evangelidis, 2023. - Khan et al., 2019. - Peralta-Jaén, 2025 - Hamidani et al., 2025 - Lu et al., 2021 - Criollo-C et al., 2024. - Marcial et al., 2022. - Sviridova et al., 2023	- Huertas-Abril et al., 2021. - Neira-Piñero & del-Moral-Pérez, 2021. - Wang & Khambari, 2020. - Kuru Gönen & Zeybek, 2021. - Min & Yu, 2023. - Huang et al., 2021. - Zhan et al., 2025. - Marrahi-Gomez & Belda-Medina, 2024. - Liu, Zhan, & Zhao, 2023. - Kuanbayeva et al., 2024. - Redzuan et al., 2019. - Iqbal, Mangina, & Campbell, 2022. - Ghanbarzadeh & Ghapanchi, 2020. - Dorta Pina & Barrientos Núñez, 2021.
Self-Efficacy, Confidence, and Skills Development	AR environments improve students' self-efficacy, confidence, and practical skills—especially in STEM and health fields—by offering safe, immersive simulations and collaborative tasks. Still, inconsistent design and limited evaluation frameworks prevent universal generalization of these benefits.	- Choi-Lundberg et al., 2023. - O'Connor & Mahony, 2023. - Lee et al., 2022. - Yu et al., 2022. - Lee et al., 2023. - Guraya, 2024; Asoodar et al., 2024. - Ghobadi et al., 2022.	- Zhang & Miao, 2025. - Adi et al., 2025. - Slyusarenko et al., 2024. - Lampropoulos et al. 2023. - Kee et al., 2024. - Iqbal et al. 2022.

Collaboration, Peer Interaction, Knowledge Integration and Interdisciplinarity	AR strengthens collaboration and teamwork by enabling shared visualization, joint problem-solving, and creative participation across disciplines. Yet, many AR tools still emphasize interactivity over true collaboration, highlighting the need for robust multi-user and co-constructive designs.	- Upadhyay et al., 2024. - Kumar et al., 2022. - Sáez-López et al., 2020. - Kang et al., 2024. - Wilkins et al., 2024. - Marín-Rodríguez et al., 2023. - Scavarelli et al., 2021. - Nikimaleki & Rahimi, 2022. - Ahmed & Lataifeh, 2023. - Sarkar et al., 2020. - Neira-Piñero & del-Moral-Pérez, 2021. - Masneri et al., 2024. - Masneri et al., 2022. - Prabowo et al., 2025. - Rodríguez-Abad et al., 2021. - Cai et al., 2022.	- Rebello et al., 2024. - Betancourt Arango et al., 2024. - Sanabria & Arámburo-Lizárraga, 2017. - Hellermann & Thorne, 2022. - Lee et al., 2023. - Indrasari, Budi, & Ambarwulan, 2019. - Peralta-Jaén, 2025. - Dorta Pina and Barrientos Núñez, 2021. - Lee, 2022. - Iqbal et al., 2022.
Language Learning and Communication Skills	In language education, AR significantly improves vocabulary, comprehension, and communicative confidence through interactive, multimodal, and authentic contexts. While learners show high motivation, challenges such as cognitive load and uneven effects across language skills persist.	- Belda-Medina, 2022, 2025. - Khan et al., 2023. - Parlar & Sütçü, 2025. - Elnaqlah et al., 2023. - Dukalskaya & Tabueva, 2022. - Elnaqlah et al., 2023. - Hung & Yeh, 2023. - Petrovych et al., 2023. - Parlar & Sütçü, 2025. - Kuru Gönen & Zeybek, 2021. - Min & Yu, 2023.	- Carrión-Robles, Espinoza-Celi, & Vargas-Sarritama, 2023. - Huang et al., 2021. - Christou, Parmaxi, & Christoforou, 2025. - Luo, Zou, & Kohnke, 2024. - Lin & Wei, 2024. - Huang et al., 2025. - Gómez-Ríos et al., 2023. - Marrahi-Gomez & Belda-Medina, 2024.
Limitations and Challenges of using AR in higher education	Despite its motivational and pedagogical potential, AR adoption faces barriers like technical instability, high costs, lack of teacher training, and limited pedagogical integration. Sustainable, inclusive, and pedagogically grounded implementation remains essential for long-term impact.	- Marks & Thomas, 2022. - Cabero & Robles, 2018. - Huang & Tseng, 2025. - Tene et al., 2024. - Marín-Rodríguez et al., 2023. - Upadhyay et al., 2024. - Yilmaz & Göktas, 2018. - Choi-Lundberg et al., 2023. - Sáez-López et al., 2020. - Marrahi-Gomez & Belda-Medina, 2024. - Huertas-Abril et al., 2021. - Rodríguez-Abad et al., 2021. - Alzahrani, 2020. - Perifanou et al., 2023. - Koreneva et al., 2023. - Lytvynova & Soroko, 2023.	- Poggianti et al., 2025. - Martínez Pérez et al., 2021. - Li et al., 2025. - Guaña-Moya et al., 2024. - Lampropoulos, 2025. - Burke et al., 2025. - Asoodar et al., 2024. - Lin et al., 2024. - Mirza et al., 2025. - Ali et al., 2017. - Indarta et al., 2025. - Lampropoulos, 2025. - Raman et al., 2025. - Masneri et al., 2022. - Lee et al., 2023.

Source: own elaboration

though teacher support remains essential to address students' initial uncertainty when adopting it (Martínez Pérez & Fernández Robles, 2018).

Across disciplines, AR affords opportunities to concretize abstract concepts, enable authentic simulations, and create interactive environments that align with constructivist and inquiry-based learning principles (Wojciechowski & Cellary, 2013; Walczak et al., 2006). These affordances have been widely adopted in fields such as engineering, health sciences, computer science, and language education, reflecting the versatility of immersive learning environments (Choi-Lundberg et al., 2023).

One of the most consistent findings concerns AR's ability to promote positive affective responses. Studies across contexts report increased enjoyment, curiosity, and enthusiasm, which in turn strengthen motivation and engagement (Gómez-Ríos et al., 2023; Soriano-Sánchez & Jiménez-Vázquez, 2025). These outcomes are particularly strong when AR is integrated into scaffolded or game-based learning environments, where visualization, interactivity, and self-paced participation sustain motivation and reduce anxiety (Hung & Yeh, 2023; Soltis et al., 2020). Meta-analyses confirm substantial effects on attention, confidence, and satisfaction (Cai et al. 2022; Chang et al., 2022). Importantly, AR's motivational impact can be intentionally shaped by design. Kansei Engineering research shows that features such as scalable 3D objects and intuitive visual instructions evoke emotions of trust, challenge, and professional motivation, underscoring the importance of emotional design in fostering engagement (Redzuan et al., 2019). Likewise, tailoring AR activities to different learning styles enhances comprehension and personalization, strengthening learners' sense of control and ownership (Titchiev et al., 2023).

Beyond affective outcomes, AR significantly enhances self-efficacy and confidence by providing safe, simulated environments for practice, especially in health and engineering education (Rebello et al., 2024). Controlled studies demonstrate that students' cognitive strategies and perceptions of usability strongly influence adoption, willingness to reuse AR, and perceived task value (O'Connor & Mahony, 2023). Moreover, AR supports higher-order thinking, particularly when combined with structured argumentation tasks. By making abstract phenomena tangible, AR scaffolds evidence-based reasoning, enabling students to justify claims, consider counterarguments, and reflect critically on their reasoning processes (Demircioglu & Ucar). These outcomes suggest that AR can play a critical role in fostering critical thinking and argumentation skills, particularly in socioscientific contexts where complex reasoning is required.

Collaboration emerges as another key strength of AR. Interactive environments enable joint manipulation of digital content, synchronous observation, and collaborative problem-solving, all of which enhance teamwork and peer interaction (Upadhyay et al., 2024; Choi-Lundberg et al., 2023). Fine-grained analyses show that high-achieving groups transition more quickly to complex tasks, effectively coordinate attention, and converge on shared conceptual understandings, while lower-achieving groups display fragmented collaboration, highlighting the need for instructional scaffolding (Kang et al., 2024). Evidence from professional training further demonstrates that AR supports teamwork in high-stakes contexts such as crime scene investigation, where shared holographic environments enable collective analysis and provide opportunities for real-time facilitation and objective assessment (Wilkins et al., 2024). Importantly, demographic variables moderate these collaborative outcomes: older learners often report greater improvements in teamwork, while younger women consistently report the highest levels of motivation and satisfaction (Peralta-Jaén, 2025). These findings highlight the interaction between technological affordances and learner characteristics in shaping collaborative engagement.

In language education, AR has proven particularly effective in supporting vocabulary, reading, writing, and oral performance across learner levels and languages (Cai et al. 2022; Elnaqlah et al., 2023). Game-based and project-oriented AR environments foster creativity, divergent thinking, and collaborative problem-solving, thereby integrating language acquisition with higher-order thinking skills (Hung & Yeh, 2023; Petrovych et al., 2023). Collaborative projects in EFL contexts transform students from passive recipients to active designers, strengthening interdisciplinary competencies and motivation (Belda-Medina, 2022; Dukalskaya & Tabueva, 2022). In CLIL settings, AR enhances both content and language retention, while increasing engagement and enjoyment, though some students continue to favor traditional methods, suggesting that blended approaches may be most effective (Belda-Medina, 2025).

The potential of AR also extends to inclusivity and accessibility. Evidence indicates that AR can benefit students with intellectual disabilities or autism spectrum disorders by supporting practical skills, social interaction, and motivation (Jdaitawi & Kan'an, 2022). Similarly, AR facilitates collaborative and creative learning in multicultural and diverse classrooms, although accessibility barriers remain for learners with visual impairments or limited digital skills (Marín-Díaz, 2017). Compared with VR, AR is generally more accessible due to its reliance on mobile devices, but disparities in infrastructure, content availability, and developer expertise still restrict adoption in many higher education contexts (Rodríguez-Abad et al., 2021).

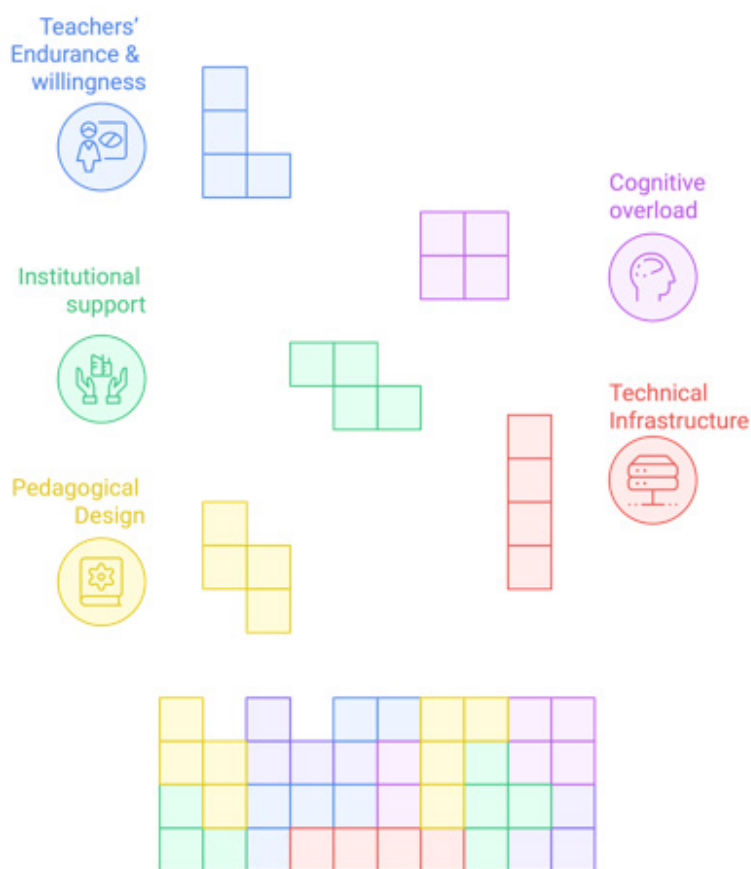
Despite these benefits, challenges persist. Technical instability, usability issues, and hardware malfunctions can undermine engagement, as shown in large-scale institutional implementations such as the University of Sydney's VR lab (Marks & Thomas, 2022). Moreover, while students frequently perceive AR as a technology of the future, its actual presence in academic practice remains limited, highlighting a gap between potential and implementation (Sáez-López et al., 2020). Cognitive overload is another concern, as students may struggle to simultaneously master AR interfaces and complex content (Yilmaz & Göktaş, 2018). Teachers also face barriers including resistance to innovation, limited training, and lack of co-design opportunities, which inhibit sustainable adoption (De Lima et al., 2022). Moreover, the evidence on learning performance remains mixed, with strong effects on motivation and engagement but less consistent gains in academic achievement (Cabero & Robles, 2018).

Taken together, the findings suggest that AR is not a replacement for traditional teaching but a supplementary tool that can enhance motivation, collaboration, and higher-order thinking when thoughtfully integrated. However, there are also challenges related to the adoption of augmented reality in higher education. These are described below in Figure 4

To move beyond novelty-driven adoption, universities must invest in teacher training, institutional infrastructure, and content co-design, while embedding AR into pedagogical frameworks that support scaffolding, collaboration, and interdisciplinary learning. Longitudinal, multicenter studies are also needed to examine retention, inclusivity, and transfer of skills to professional practice. If these challenges are addressed, AR has the potential to shift from isolated pilot projects to a systemic component of higher education, advancing the goals of Education 4.0 by combining technological interactivity with pedagogical depth.

Figure 4

Challenges in the adoption of augmented reality in higher education.



Source: own elaboration

6. Conclusions

This review has synthesized a wide range of studies exploring the role of augmented reality in higher education, focusing on its potential to enhance motivation, engagement, collaboration, and learning outcomes. The findings reveal both substantial opportunities and persistent challenges, offering a nuanced understanding of AR's pedagogical value and limitations. Taken together, the evidence positions AR as a promising, though not yet fully realized, educational technology whose effectiveness depends on thoughtful integration, adequate support, and careful instructional design.

Answering the first research question, AR has been shown to positively influence student motivation, engagement, and learning outcomes. Its immersive and interactive affordances stimulate curiosity and enjoyment, increase attention, and create opportunities for deeper involvement in tasks. While the strongest effects are observed in short-term interventions and in specific domains such as language learning, health sciences, and STEM, the evidence also points to improvements in higher-order skills, including self-efficacy and creative thinking. Nevertheless, performance gains are not universal, underscoring the importance of aligning AR activities with pedagogical objectives and minimizing novelty-driven effects.

In relation to the second question, AR effectively supports collaborative learning and the development of transversal competencies. By allowing students to jointly manipulate virtual objects, engage in shared problem-solving, and co-construct knowledge, AR fosters teamwork, communication, and creativity. Collaborative applications in particular highlight AR's potential to cultivate critical thinking and interdisciplinary understanding, as students negotiate perspectives and integrate knowledge across domains. These benefits are strongest when supported by structured task design, clear role allocation, and opportunities for reflection, indicating that pedagogy plays a decisive role in realizing AR's collaborative value.

Addressing the third question, several challenges continue to hinder the widespread adoption of AR in higher education. Technical issues—including unstable hardware, software malfunctions, and usability barriers—can compromise student experiences. Cognitive overload remains a concern when learners must simultaneously master both the content and AR interface. On the pedagogical side, gaps in teacher training, resistance to change, and lack of co-design processes limit integration. Institutional barriers such as cost, resource inequality, and insufficient high-quality content also restrict scalability. Together, these challenges underscore the need for systemic solutions that extend beyond student outcomes to encompass teachers, curricula, and infrastructure.

Finally, considering the fourth question, the findings hold important implications for future practice and research. For educators, AR should be viewed as a complementary tool embedded within pedagogical frameworks that emphasize scaffolding, inclusivity, and interdisciplinarity. Teacher preparation, emotional and cognitive design, and institutional support are essential to ensure sustainable use. For researchers, future work should move toward longitudinal and large-scale studies, investigate diverse populations and disciplines, and explore the interplay between AR, motivation, and collaborative skill development. Expanding attention to ethical, cultural, and accessibility considerations will also be crucial for ensuring that AR contributes meaningfully to equitable and transformative higher education.

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Authors contribution

- AIC: Conceptualization; Data curation; Data collection; cleaning, and organization; Formal analysis; Investigation; Resources; Supervision; Validation; Writing - original draft; Writing - review & editing
- JAHT: Conceptualization; Data curation; Data collection; Formal analysis; Investigation; Resources; Software; Visualization; Writing - original draft

JFAJ: Conceptualization; Data collection; cleaning, and organization; Investigation; Resources; Software; Visualization; Writing – original draft.

MSAA: Conceptualization; Data collection; cleaning, and organization; Formal analysis; Funding acquisition; Investigation; Project administration; Project supervision and coordination; Supervision; Validation; Writing – review & editing.