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Immersive technologies for engineering teaching: an approach applied to higher education

Tecnologias imersivas para o ensino de engenharia: uma abordagem aplicada ao ensino superior

Tecnologías inmersivas para la enseñanza de la ingeniería: un enfoque aplicado a la educación superior

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ABSTRACT

The evolution of the educational environment requires constant adaptation to emerging technological trends. Within this transformation, conventional teaching tools, such as traditional whiteboards, are gradually being replaced by digital resources like projectors and interactive whiteboards, which enhance student engagement and interaction with learning materials. This paper explores the integration of Augmented Reality (AR) as an instructional resource in the context of Mechanical Engineering education. The study addresses a common challenge faced by students: the difficulty in comprehending three-dimensional structures when presented in two-dimensional formats. To investigate this, a bibliographic review of academic literature was conducted to map current findings and approaches in this field. The review highlights that incorporating AR into the classroom is feasible and beneficial, provided that educators receive adequate training to effectively facilitate its use. The findings suggest that AR can enrich the learning experience in Mechanical Engineering by fostering deeper conceptual understanding and offering a practical, applicable solution for enhancing education through immersive technology.

Palavras-chave: *Mechanical Engineering; Teaching-learning; Augmented reality; Technology.*

RESUMO

A evolução do ambiente educacional exige constante adaptação às tendências tecnológicas emergentes. Nessa transformação, ferramentas convencionais de ensino, como quadros brancos tradicionais, estão sendo gradualmente substituídas por recursos digitais como projetores e quadros brancos interativos, que aumentam o engajamento e a interação dos alunos com os materiais de aprendizagem. Este artigo explora a integração da Realidade Aumentada (RA) como recurso instrucional no contexto do ensino de Engenharia Mecânica. O estudo aborda um desafio comum enfrentado pelos alunos: a dificuldade em compreender estruturas tridimensionais quando apresentadas em formatos bidimensionais. Para investigar isso, foi realizada uma revisão bibliográfica da literatura acadêmica para mapear as descobertas e abordagens atuais nessa área. A

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revisão destaca que a incorporação da RA em sala de aula é viável e benéfica, desde que os educadores recebam treinamento adequado para facilitar efetivamente seu uso. Os resultados sugerem que a RA pode enriquecer a experiência de aprendizagem em Engenharia Mecânica, promovendo uma compreensão conceitual mais profunda e oferecendo uma solução prática e aplicável para aprimorar a educação por meio da tecnologia imersiva.

Keywords: *Engenharia Mecânica; Ensino-aprendizagem; Realidade aumentada; Tecnologia.*

RESUMEN

La evolución del entorno educativo exige una adaptación constante a las nuevas tendencias tecnológicas. En esta transformación, las herramientas de enseñanza convencionales, como las pizarras tradicionales, están siendo sustituidas gradualmente por recursos digitales como proyectores y pizarras interactivas, que mejoran la participación e interacción del alumnado con los materiales de aprendizaje. Este artículo explora la integración de la Realidad Aumentada (RA) como recurso didáctico en el contexto de la formación en Ingeniería Mecánica. El estudio aborda un reto común al que se enfrentan los estudiantes: la dificultad para comprender estructuras tridimensionales cuando se presentan en formatos bidimensionales. Para investigar esto, se realizó una revisión bibliográfica de la literatura académica para identificar los hallazgos y enfoques actuales en este campo. La revisión destaca que la incorporación de la RA en el aula es viable y beneficiosa, siempre que los docentes reciban la formación adecuada para facilitar su uso de forma eficaz. Los hallazgos sugieren que la RA puede enriquecer la experiencia de aprendizaje en Ingeniería Mecánica al fomentar una comprensión conceptual más profunda y ofrecer una solución práctica y aplicable para mejorar la educación mediante tecnología inmersiva.

Palabras clave: *Ingeniería Mecánica; Enseñanza-aprendizaje; Realidad aumentada; Tecnología.*

1. INTRODUCTION

Augmented Reality (AR) is a technological tool that enhances interactivity with projected elements. Through internet-connected mobile devices, both educators and students can access AR features, which contributes to better comprehension of the content addressed in class. As noted by Mekni and Lemieux (2014), the widespread accessibility of smartphones, particularly after 2010, enabled the expansion of interactive AR tools within academic settings. In this context, Moran (2004) highlights that one of the most common complaints from university students concerns the traditional manner in which subjects are taught, pointing to the need for pedagogical innovations that incorporate technology into the teaching-learning process.

Although AR is not a new technology—with its development dating back to the 1960s—its use in educational environments remains limited. A key barrier to its adoption is the lack of adequate teacher training. Various studies explore the benefits of AR in project-based education, such as the research by Fernández, Raposo, and Costa (2007), which analyzes the reduction of construction errors in architectural planning using AR tools. Furthermore, Lopes, Vidotto, Pozzebon, and Ferenhof (2019) mention its application in interior design and building restoration processes.

The advancement of this technology has stimulated discussions about its integration into educational practices. Mechanical engineering programs aim to train professionals who are capable of addressing the challenges of the labor market. In this context, computational modeling emerges as a valuable strategy, enhancing the assimilation of key concepts and the development of new knowledge.

Modern mechanical engineers must not only develop technically sound solutions, but also understand the broader context of problems, including their causes and multidimensional consequences.

According to the Ministry of Education (2010), failure to train professionals with this comprehensive skill set may hinder technological development.

Therefore, among the various possible applications of AR in subjects related to Mechanical Engineering, its capacity to enhance learning stands out. The objective of this study is to conduct a literature review on AR and its applications in the teaching of Mechanical Engineering subjects. The analysis confirms the value of this technological tool in academic settings, improving the learning process of both theoretical and practical mechanical concepts.

2. MATERIALS AND METHODS

This research organizes its materials and methods based on the following thematic axes:

2.1: Augmented Reality (AR);

2.2: Teaching of Mechanical Engineering;

2.3: Applications of AR in the instruction of Mechanical Engineering-related subjects.

Following the literature review on the aforementioned topics, a spreadsheet was created to compile the data from the selected publications, allowing for the identification of common points and patterns among the studies.

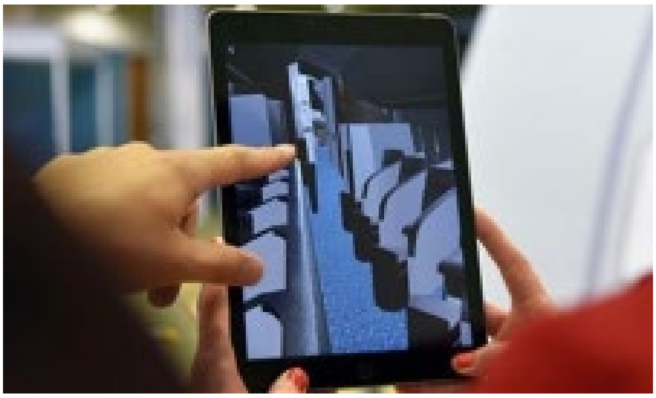
2.1. Augmented reality (AR)

Augmented Reality plays a key role in enhancing learning across various disciplines. It offers educators a user-friendly and accessible technology that enables content exploration through active learning methodologies, in which students are positioned as the primary agents in constructing their own knowledge, supported by the teacher.

As defined by Azuma (1997), AR is a system that overlays virtual elements onto the physical world, enabling real-time interaction between virtual and real components, with emphasis on tangible objects. Thornton, Ernst, and Clark (2012) support this definition, emphasizing AR's potential as a powerful tool in technology-based educational curricula. Unlike Virtual Reality (VR), which immerses users entirely in a simulated environment, AR builds upon the real world by integrating complementary digital elements, as noted by Romero and Hounsell (2018).

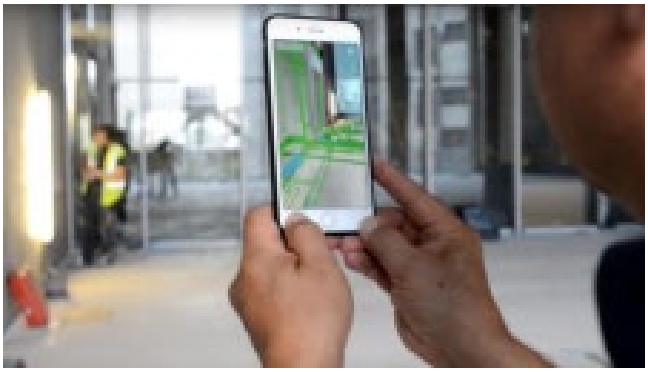
According to Azuma (1997), the development of AR began in the 1960s. In addition to improving educational practices, it is applied in fields such as equipment assembly and maintenance, as discussed by Justimiano, Gomes, Motta, and Sementille (2021). Other applications include aviation training (Figure 1), visualization of hydrosanitary systems (Figure 2), and understanding architectural and engineering components (Figure 3), among others.

Figure 1 - Training through Augmented Reality (AR) aimed at aviation professionals.



Source: Scielo (2012).

Figure 2 - Exploration of hydrosanitary installations through Augmented Reality (AR).



Source: Archdaily (2015).

Figure 3 - AR visualization of a home, with AR projection

Source: Own authorship (2025).

Beyond its various implementations, Augmented Reality (AR) contributes significantly to the instructional process within the Topography subject area, as noted by Moreira and Ruschel (2015). This methodology incorporates a sandbox system integrated with motion detection sensors, a digital projector, and dedicated software. In the context of geography education, numerous investigations have examined the utility of AR technologies. Herpich *et al.* (2015), for example, highlighted how AR can support the development of case-based activities and problem-solving exercises with students.

In light of these educational advancements, the impact of this Information and Communication Technology (ICT) tool on the teaching-learning dynamic becomes increasingly apparent, as emphasized by Lopes *et al.* (2019). Leite (2020) explains that access to AR content typically requires

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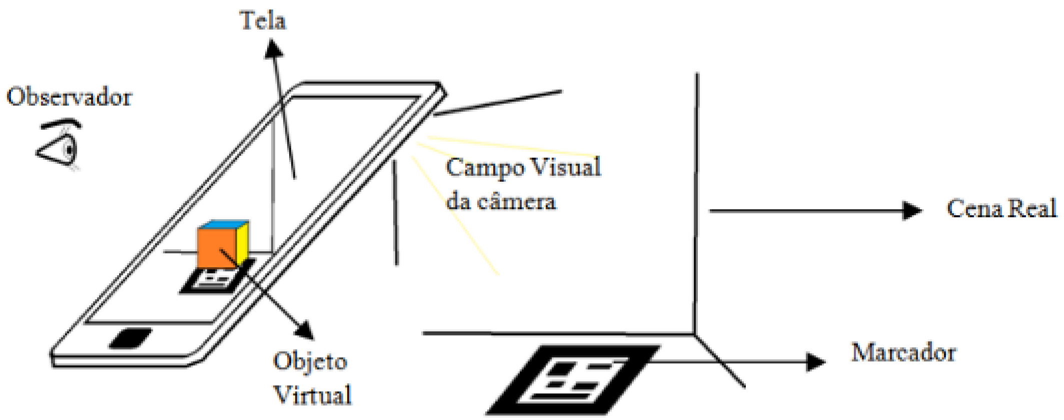
the presence of a visual marker (illustrated in Figure 4). When a mobile device identifies this marker through its camera, it renders a 3D model on the screen, enabling users to observe and engage with the augmented content.

It is essential to differentiate between AR and Virtual Reality (VR): while VR immerses users fully within a simulated digital space, AR retains users in their real-world context while overlaying virtual components into that environment via digital devices such as smartphones or tablets.

In essence, AR involves the integration of digitally generated virtual elements—commonly in three dimensions—into the user's physical surroundings using technological means. One notable advantage of AR for education is its capacity to deliver immersive 3D visualizations and its compatibility with widely available Android smartphones, making it particularly accessible to students.

Figure 4 - Representation of an AR system using a smartphone



Source: Kirner and Tori (2006).

As highlighted by Herpich (2020), the extensive range of information provided through Augmented Reality (AR) significantly contributes to increased student motivation, particularly when seamlessly integrated with other Information and Communication Technologies (ICT) commonly applied in educational contexts. Furthermore, AR's inclusion in the production of textbooks and instructional resources introduces an additional layer of interactivity, enabling the incorporation of dynamic learning elements. This enhances conceptual understanding, fosters deeper student engagement, elevates enthusiasm for learning, and ultimately enriches the overall educational experience.

Moreover, Pedrosa and Guimarães (2019) emphasize that the dissemination and application of so-called "emerging technologies" have been central themes in social and educational policy discussions. Devices such as televisions, digital projectors, interactive whiteboards, tablets, and audio systems are increasingly available in schools and universities, often promoted alongside narratives that advocate for the integration of digital tools and platforms as a means to elevate instructional quality and drive pedagogical innovation.

In educational environments, as noted by Lima (2020), AR is gaining prominence due to its adaptability and compatibility with a range of emerging educational technologies, including mobile devices and gamified learning tools. It presents a valuable enhancement to traditional teaching strategies, allowing educators to incorporate virtual objects—often three-dimensional and to scale—

into lessons, thereby enriching digital learning applications with interactive and immersive experiences.

Table 1 presents the compilation of academic publications examined in this study that focus on the use of AR in education:

Table 1 - List of publications studied on AR

Title	Type	Year	Authors	Publication
Augmented reality as a visual and spatial learning tool in technology education	article	2012	T. Thornton, J. V. Ernst, A. C. Clark	Technology & Engineering Teacher
Introduction to Virtual and Augmented Reality	Book	2018	T. Romero and M. da S. Hounsell	Publishing Company SBC
Augmented Reality System for Teaching and Training People in the Execution of Assembly and Maintenance Services	article	2021	A. C. Justimiano, C. Gomes, E. S. Motta and A. C. Sementille	Revista Iberoamericana de Tecnología en Educación y Educación en Tecnología
Augmented Reality in the Visualization of Architectural Design Solutions	article	2015	L. C. de Sousa Moreira and R. C. Ruschel	Revista Sociedade Ibero-americana de Gráfica Digital
Augmented Reality in Geography: An Orientation Activity in Elementary Education	article	2017	F. Herpich, F. B. Nunes, G. B. Voss, P. Sindeaux, L. M. R. Tarouco and J. V. de Lima	Revista Novas Tecnologias na Educação
Educational Innovations with the Use of Augmented Reality: A Systematic Review	article	2019	L. M. D. Lopes, K. N. Sartor Vidotto, E. Pozzebon and H. A. Ferenhof	Educação em Revista
Virtual and Augmented Reality Applications for Teaching Chemistry	article	2020	B.S. Leite	Revista de Estudos e Pesquisas sobre Ensino Tecnológico
Educational Activity Using Augmented Reality for Teaching Physics in Higher Education	article	2020	F. Herpich, W. V. C. Lima, F. B. Nunes, C. O. Lobo, L. M. R. Tarouco	Revista Iberoamericana de Tecnología en Educación y Educación en Tecnología
Virtual and Augmented Reality: Reflecting on Uses and Benefits in Education	article	2019	S. M. P. A. Pedrosa, M. A. Z. Guimarães	Revista Educação e Cultura Contemporânea
A Systematic Literature Review on Augmented Reality Educational Activities in Science Education	article	2020	W. V.C. Lima, F. B. Nunes, F. Herpich, C. O. Lobo	Revista Iberoamericana de Tecnología en Educación y Educación en Tecnología

Source: Own authorship (2025).

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Given its versatility, it is entirely possible to develop numerous Augmented Reality (AR) applications to support a wide range of knowledge domains. Specifically, in the context of this study, which focuses on assessing the potential of AR to enhance the teaching of Mechanical Engineering, this technology stands out as a highly effective educational tool.

2.2. Teaching in the field of mechanical engineering

Educating future Mechanical Engineers is an inherently intricate process. The curriculum spans a broad spectrum of scientific and technological domains, shaping the professional competencies required throughout the course. Over time, instructional practices have evolved, influenced by the cultural and technological transformations occurring in society. Such changes have been essential, as the mechanical engineering profession demands a comprehensive foundation across multiple disciplines to perform effectively. As Correa and Bazzo (2017) explain, teaching—as a professional activity—has been confronted with numerous challenges, largely stemming from ongoing changes within the professional and societal landscape.

In the classroom, for instance, topics such as gear design necessitate foundational knowledge in subjects like Solid Mechanics, alongside a prior understanding of Machine Elements. The learning process is structured into multiple stages and requires handling complex mathematical formulations, performing unit conversions, and considering various factors that influence outcomes. Due to this complexity, solving even a single case can require significant time and cognitive effort from the student, both inside and outside the classroom.

According to Rocha (2019), greater emphasis should be placed on the teaching of machining within Mechanical Engineering programs, particularly through the sustainable creation of instructional tools. By replacing conventional cutting tools with alternatives made from miriti (a type of palm), instructors can promote cost-reduction strategies while maintaining tool functionality, thus enhancing educational accessibility.

When it comes to using concept maps in Mechanical Engineering courses, Krummenauer and Darroz (2019) observed noticeable improvements in students' meaningful learning through structured exploration and assimilation of content. Their research highlights the effectiveness of concept maps in fostering innovative approaches to understanding complex topics.

In terms of assessment, Freitas, Fontana, and Zatti (2021) conducted a study proposing a formative, continuous, and diagnostic evaluation model tailored to higher education in Mechanical Engineering. They argue that conventional assessment methods limit students' ability to monitor their own progress, often failing to accommodate varied learning speeds. The model introduced by the authors integrates active learning strategies, positioning students at the center of their educational journey while redefining the instructor's role as a facilitator.

Table 2 presents the compilation of studies considered in this research concerning the teaching of Mechanical Engineering:

Table 2 - list of publications addressed on the teaching of Mechanical Engineering

Title	Type	Year	Authors	Publication
Sustainable Use of the Miriti Palm as Raw Material and Teaching Tool in the Learning Process of the Materials Machining Discipline in Mechanical Engineering	article	2019	T. O.S. Rocha, I. S. Gomes, D. S. Silva, J. S. Andrade, F. X. L. Silva, E. S. Vilhena, L. C.O. Pereira, R. T. Fujiyama	Brazilian Applied Science Review
Assessment Through Concept Maps in a Physics Course in Mechanical Engineering	article	2019	W. L. Krummenauer, L. M. Darroz	Revista Experiências em Ensino de Ciências
Concept Maps as Assessment Tools in Youth and Adult Education	article	2009	W. L. Krummenauer, S.S.C. Costa	Revista Experiências em Ensino de Ciências
Relationships Between Active Methodology, Formative Assessment, and Student Learning in Mechanical Engineering	article	2021	R. E. P. Freitas, M. I. Fontana, A. H. Zatti	Revista Cadernos Unifoa

Source: Own authorship (2025).

Consequently, when teaching Mechanical Engineering—a field centered on the conceptualization, construction, and upkeep of machinery and mechanical systems—it is essential for educators to go beyond traditional theoretical and practical knowledge. Instructors must also adopt innovative pedagogical approaches that empower students to develop more meaningful and lasting learning outcomes. Integrating emerging technologies becomes a crucial step in streamlining and enriching this educational process. Building on this perspective, the subsequent section will explore how Augmented Reality (AR) is currently being utilized within the realm of Mechanical Engineering.

2.3. Utilization of ar in mechanical engineering education

Due to its versatility and wide-ranging applicability across numerous academic disciplines, Augmented Reality (AR) is particularly well-suited for integration into subjects aligned with Mechanical Engineering. Its capacity for fostering interactivity and enabling spatial, three-dimensional visualization equips students with a deeper understanding of mechanical components and how these systems function in unison. This section aims to highlight key instances of AR application within the domain, underscoring its potential to enhance student learning experiences.

As noted by Araújo and Schorn (2017), educational discourse increasingly includes topics such as public policy, curricular development, and the integration of digital technologies—emphasizing their relevance in modern academic environments.

In relation to Technical Drawing courses, Aliev *et al.* (2017) suggest that learning becomes more intuitive when three-dimensional visual tools are incorporated, supplementing traditional methods like orthographic projections and perspective drawings. For students of Mechanical Engineering, platforms

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such as Unity and Vuforia offer dynamic opportunities to engage with instructional content through interactive experiences. Figure 5 provides a visual representation of one such application:

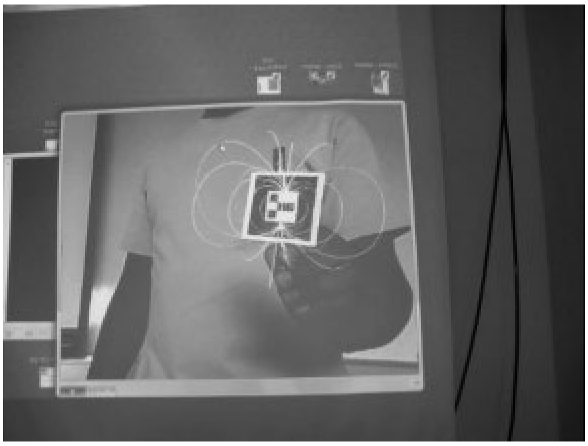
Figure 5 - Three-dimensional AR projection of a Technical Drawing element

Source: Archdaily (2012).

Furthermore, the research conducted by Gutierrez and Fernández (2014) focused on the creation and implementation of an augmented reality-enhanced textbook. The findings revealed that students enrolled in Mechanical Engineering who utilized the AR-supported material showed increased engagement and achieved better academic outcomes compared to their peers who relied solely on traditional resources. By using AR markers, students were able to access augmented content, allowing them to both visualize and interact with the presented material.

Macedo, Biazus, and Fernandes (2021) explored the representation of a magnetic field using AR, specifically in the form of a bar-shaped model. Their study involved five Mechanical Engineering students who engaged with the three-dimensional virtual representation of the magnetic field. The results demonstrated that the incorporation of AR significantly enriched both the teaching and learning processes for the subject matter. Figure 6 illustrates the application used in their study:

Figure 6 - Environment in Augmented Reality created in the classroom showing the magnetic field



Source: Tecmundo (2021).

Diniz (2012) conducted a study focused on robotic systems integrated with augmented reality (AR) interfaces. In this research, a robotic arm was developed using Computer Graphics techniques, enabling it to operate within an AR environment in a natural and intuitive manner. This innovation marks a significant step forward in Mechanical Engineering education, as it enhances the comprehension of mechanical systems in conjunction with robotics. Table 3 summarizes the publications discussed in this section.

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Table 3 - Survey of publications addressed in section 2.3

Title	Type	Year	Authors	Publication
3D Augmented Reality Software Solution for Mechanical Engineering Education	article	2017	Y. Aliev, V. Kozov, G. Ivanova, A. Ivanov	ACM International Conference Proceeding Series
Applying Augmented Reality in engineering education to improve academic performance & student motivation	article	2014	J. M. Gutierrez, M. D. M. Fernandéz	International Journal of Engineering Education
Teaching the Magnetic Field of a Bar Magnet Using Augmented Reality Resources	article	2021	S. H. Macedo, M. C. V. Biazus, F. A	Revista Informática na Educação: Teoria e prática
Control of Robotic Devices Through Natural Interface in Augmented Reality	Master's Dissertation	2012	W. F. S. Diniz	State University of Campinas

Source: Own authorship (2025).

When examining the applications of Augmented Reality (AR) in the context of Mechanical Engineering—particularly within educational settings—it becomes clear that this technology holds considerable promise for enhancing student engagement and understanding in subject areas related to the field. For this potential to be fully realized, educators must be equipped and prepared to integrate AR into their teaching practices throughout the curriculum. This approach enables students to develop a deeper grasp of concepts through interactive experiences.

3. RESULTS AND DISCUSSIONS

The literature review reveals significant opportunities for implementing AR in the instruction of Mechanical Engineering-related disciplines. As part of the broader metaverse framework—which bridges physical and digital realities—AR provides partial immersion, enabling dynamic interaction between virtual elements and the real world. Based on the studies analyzed in the previous section, AR emerges as a practical alternative to traditional lab infrastructure, offering cost-effective solutions for educational institutions.

Mechanical Engineering educators can leverage AR to explore the structure and functionality of machinery components in a three-dimensional format alongside their students. As noted in the reviewed sources, a simple internet-connected smartphone is sufficient to access AR content, transforming the device from a classroom distraction into a valuable learning companion. The growing discourse around mobile phone use in education underscores the potential of AR as a powerful instructional tool capable of improving the delivery of technical content.

Given the complex nature of Mechanical Engineering education, it becomes evident—from the literature reviewed—that student development must go beyond technical training. It should also include cultural awareness and environmental responsibility. Overcoming outdated pedagogical models, where the teacher is seen as the sole source of knowledge and students as passive recipients, is critical. Instead, incorporating active learning methodologies is essential for cultivating learners who take responsibility for constructing their own knowledge.

To support this pedagogical shift, the review highlights AR as a feasible educational tool in Mechanical Engineering courses. One notable example is its application in the Technical Drawing subject, where AR enhanced students' comprehension of visual perspectives and spatial views, leading to improved understanding of the course material. Overall, the research points to AR as a highly adaptable and affordable resource with considerable potential for reshaping Mechanical Engineering education.

4. CONCLUSIONS

The systematic review of publications concerning AR, its role in Mechanical Engineering education, and its specific applications in course-related subjects confirms the value and usability of this technology in academic contexts. AR offers various practical uses that support student-centered knowledge construction, positioning the educator as a facilitator who bridges the gap between theoretical content and practical understanding.

Considering the broad range of subjects included in Mechanical Engineering programs, students often face challenges due to reliance on conventional teaching approaches, which typically involve chalkboard lectures and textbook-based instruction. This traditional framework tends to limit students to passive roles, reducing opportunities for critical engagement and hindering both academic and professional development.

In response to these challenges, this study aimed to highlight the diversity of content in Mechanical Engineering programs and proposed AR as a strategic alternative to address learning difficulties in core subjects. Furthermore, it advocated for the educational use of mobile devices in the classroom, allowing students to interact with complex content in three dimensions and in real time. This interactive learning process not only reinforces conceptual understanding but also simulates professional scenarios encountered in real-world engineering practice.

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