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Impact and Advancements of Using Clinical Laboratories with Extended Reality in Medical Education

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Abstract. Medical education is undergoing a significant transformation thanks to the integration of emerging technologies, especially extended reality (XR). This systematic review guided by the PRISMA methodology has shown that XR, by combining real and virtual environments, not only enhances understanding and retention of knowledge but also transforms the learning experience in clinical laboratories. Through realistic simulations, students can practice technical and communication skills in a controlled environment, allowing them to make critical decisions and learn hands-on. The findings of this study indicate that while the adoption of these technologies presents certain challenges, such as accessibility and resource diversification, the potential of XR to enrich medical education is undeniable. As we move towards a future where the metaverse could be a key tool in professional training, it is essential to address these obstacles to ensure that the benefits of XR are accessible to all students and educators. In summary, this review underscores the importance of XR as a valuable tool in medical education, promising a lasting impact on the training of future health professionals.

Keywords. Clinical laboratories, extended reality, augmented reality, virtual reality, mixed reality, education, medical education.

1 Introduction

Medical education is undergoing a stage of exciting changes and unprecedented advancements, driven by emerging technologies that are revolutionizing the way we train future healthcare professionals. In this landscape of innovation, extended reality (XR)—which includes virtual reality (VR), augmented reality (AR), and mixed reality (MR)—is beginning to play a key role in clinical laboratories, offering new ways to teach and learn. Extended reality combines elements of the real and virtual worlds, creating immersive and interactive experiences that can enhance understanding and knowledge retention. Clinical laboratories, essential in medical training, allow students to apply what they have learned in a practical and controlled environment. These labs simulate real clinical scenarios where students practice procedures, make diagnostic decisions, and develop crucial technical and communication skills for their future professional careers. Traditionally, they have relied on anatomical models, simulators, and, at times, standardized patients. This study explores how these technologies are transforming the medical education field. Through a comprehensive literature review, the efforts, challenges, and future perspectives of using XR in clinical laboratories are analyzed, providing a complete overview of its impact on the training of medical students.

Advances and applications based on various technologies to support the training of clinical and surgical skills, simulating patients and scenarios interactively, have shown an impact on the empirical learning of students by enhancing immediate and personalized feedback. Curran et al. (2023) mentioned that studies highlight how these technologies improve knowledge retention and critical thinking skills by immersing students in realistic environments where they can interact with both virtual and real-world objects simultaneously.

Wang et al. (2024) states that the integration of digital technologies addresses the critical challenges faced by traditional teaching methods, offering immersive, interactive, and experiential learning environments that better prepare students for the complexities of real-world projects.

There are various technologies classified as emerging that are applied in clinical laboratories within the training process for health professionals, such as patient simulations or clinical systems, some based on artificial intelligence, virtual and augmented laboratories that include extended realities through virtual medical simulation platforms, robotics applied in process automation, telemedicine, and e-learning to enable the practice of skills and remote consultations.

On the other hand, it is important to remember that there are mandatory requirements for their integration into medical curricula that address challenges related to finances, technical limitations and didactic aspects as mentioned by Mergen et al. (2024) in their review of the current state of virtual reality integration in medical education.

New educational dynamics, the rise of online or hybrid courses, as well as special situations such as the COVID-19 pandemic, have driven the transformation of medical education, diversifying the application of emerging technologies in various areas of medical training. According to Hadfiz et al. (2021) this is a new challenge for educational institutions, especially in health education, to adapt to all these situations, as teaching and learning activities cannot be conducted merely in an engaging manner but must be carried out boldly.

The clinical laboratory in medical education is relevant both for meeting academic requirements and for the training of medical students. H. L. Phillips et al. (2023) mentioned that in many cases obtaining clinical sites for students enrolled in a medical laboratory academic program, where the students complete their clinical rotations, is a requirement for student graduation.

Extended reality (XR) is a technology that combines the digital world with the real world, creating immersive experiences. It includes technologies such as virtual, augmented, and mixed reality, and is used in various fields like education, entertainment, and training to offer new experiential opportunities.

F. Liarokapis et al. (2024) consider XR technology empowers learners with the ability to a) manipulate visual 3D objects, processes, and procedures and elicit additional information about them, b) access inaccessible views of objects, processes, and procedures, c) combine and compare multiple views, and d) augment their senses.

Clinical laboratories are facilities where tests are conducted on biological samples to diagnose and treat diseases. They are essential both for medical diagnosis and for educating students in practical techniques and skills. Donkin and Gusset (2024) state the role of a Medical Laboratory Scientist employed in a medical pathology service is to provide competent medical testing within a quality control system that determines the cause and nature of diseases.

The training of healthcare professionals is being enriched with new technologies in clinical laboratory environments and procedures, offering students a practical and accessible experience, enhancing their preparation for the real healthcare setting. Han et al. (2019) mention that it can facilitate interactions between students, between students and teachers, and between students and class content.

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Table 1. Search results

Database	Number of studies
Scopus	7
Web of Science	32
Total	39

Note. Results from the search in scientific databases.

The objective of this study is to evaluate the current status and impact of extended reality applications in clinical laboratories for the training and education of health professionals.

Through this systematic review, it aims to identify both the advantages and barriers presented by these technologies, as well as to explore best practices and areas of opportunity for their effective implementation.

Regarding the development of these tools, Moro et al. (2023) conclude these advancements in the educational landscape show great promise for the future and potential improvements in learning outcomes for health profession students.

It is clear that the growing demand for emerging technologies in the training of health professionals has triggered the development of appropriate digital devices and resources, which has undoubtedly influenced the reduction in costs of related products and services.

However, it is somewhat premature to assume that every student will soon have access to these tools, as Tene et al. (2024) mention despite the downward trend in prices, equipping each student with individual VR/AR systems for remote learning remains a complex and costly task.

The impact and expected advancements in the use of extended reality (XR) in clinical laboratories for the training of health professionals are significant. These technologies promise to transform medical education by offering immersive and safe learning environments where future health professionals can practice their skills without the risks associated with treating real patients.

A recent study published by Han et al. (2019) in BMC Medical Education highlights how the integration of advanced technologies, including artificial intelligence and simulation, is revolutionizing the way future doctors are taught. These tools not only enhance students' understanding of complex clinical procedures but also promote a more humanistic approach to patient care.

2 Systematic Review Methodology

Inclusion criteria

To ensure the relevance and quality of the studies included in this systematic review, specific selection criteria were established.

The included studies:

(1) Were in English or Spanish,

(2) Were published between 2020 and 2024,

(3) Classified as articles or reviews,

(4) Contained keywords related to the subject of study like “extended reality”, “virtual reality”, “mixed reality”, “augmented reality”, “education”, “medical”, “laboratory” and

(5) Abstract´s content is related to extended reality in medical education.

Sources of information

It was decided to conduct the search in SCOPUS and Web of Science tools due to their status as the main international academic databases, along with their importance in the production and dissemination of scientific articles.

Search strategy

This systematic literature review is conducted to find relevant studies regarding the development and implementation of technologies considered within extended reality concerning the education and professional training of students in the medical field at an international level. The objectives are to understand: 1) Countries where

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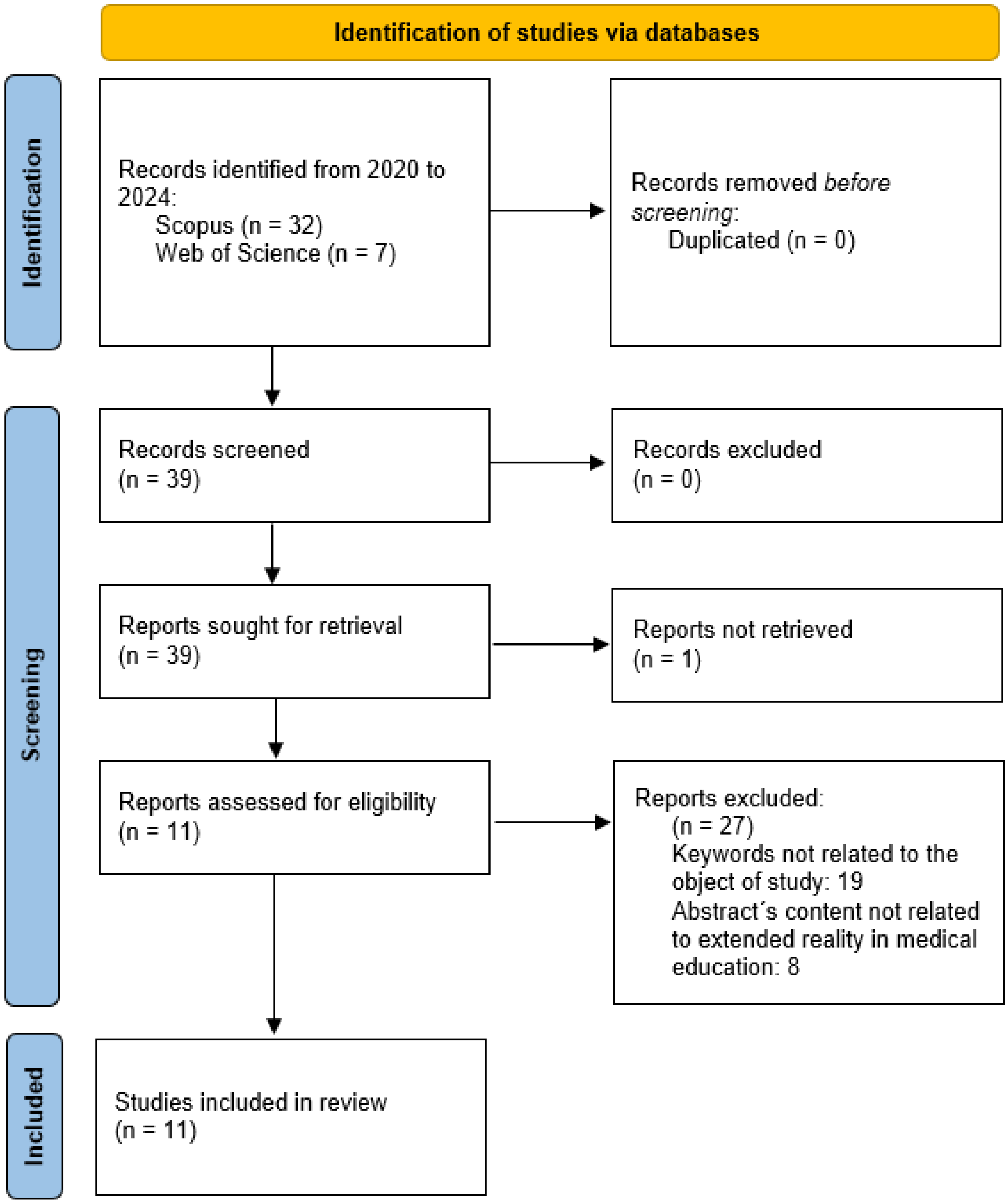
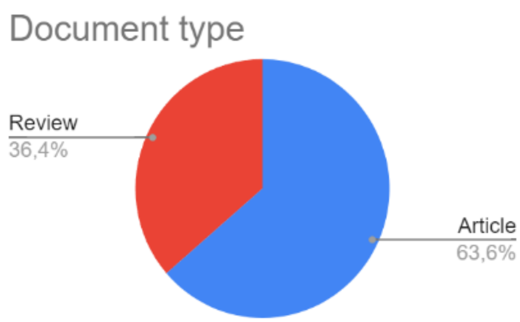
Fig 1. Flow diagram of the systematic literature review



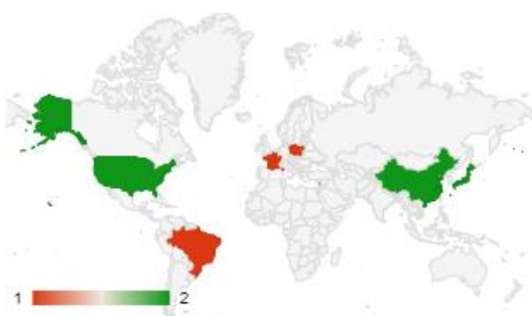
Note. The diagram includes the three main phases for the articles selection.

Fig. 2. Document type



Note. The chart presents stadistical distribution of the articles following the clasification established.

Fig. 3. Articles per country



Note. The map represents the article´s country origin publication

Table 2. Articles per country

Country	Number of publication
Belgium	1
Brazil	1
China	2
France	1
Japan	2
Lebanon	1
Poland	1
USA	2

Note. Total of articles: 11

scientific documentation and dissemination on the topic have been reported, 2) The use of the term "extended reality", 3) The type of research work in conceptual/empirical classification, 4) Obtained results, and 5) Identify future challenges.

For the database search, the primary keywords used were: "medical laboratory", "education", and "extended reality", with main filters indicating language, year of publication, and document type as specified in the previously described criteria.

Table 1 shows the results of the search in specific databases using the defined keywords, including publications in English or Spanish, classified as articles or review articles in document type, from the last 5 years (2020-2024).

Selection process

It was determined to follow the PRISMA (Preferred Reporting Items for Systema-tic Reviews and Meta-Analyses) guidelines for the preparation of this systematic review because it is defined as a widely recognized and utilized set of guidelines to improve aspects such as transparency and quality in the development and reporting of systematic reviews and meta-analyses.

Additionally, it meets comparability criteria, which facilitates comparison between systematic reviews due to its standardized format and structure, making it highly useful for researchers and reviewers, thus becoming an advantageous criterion regarding acceptance and credibility in scientific publication and dissemination.

In the PRISMA statement Page et al. (2021) provide a template for the flow diagram is provided, which can be modified depending on whether the systematic review is original or updated.

Once the records from both databases were obtained, an Excel file was generated to merge both lists and carry out the identification process, during which no duplicate records were detected. Subsequently, the review was conducted, during which one of the articles could not be retrieved.

As part of the process indicated in the flow diagram presented in Figure 1 provided by the PRISMA statement (Page et al.), the selection phase continues using the criteria, excluding a total of 27 records.

ISSN 2007-9737

Data collection process

Once the final database with the included works for the review is defined, the process continues with the extraction of information relevant to the study, guided by its objectives and the research questions posed.

Data elements

The data elements collected and analyzed in this systematic review included important information about each selected study. These elements comprise: (1) bibliographic data, such as the author, year of publication, and source of publication; (2) study characteristics, including the type of study; (3) details about the content, such as the type of extended reality used (AR, VR, MR), and whether the development or appropriation of resources or technologies is addressed; (4) main related results; and (5) future challenges and limitations. The collection of these elements allowed for a systematic and thorough comparison of the reported im-pacts and advancements in the use of clinical laboratories with extended reality in medical education.

Assessment of risk of bias of studies

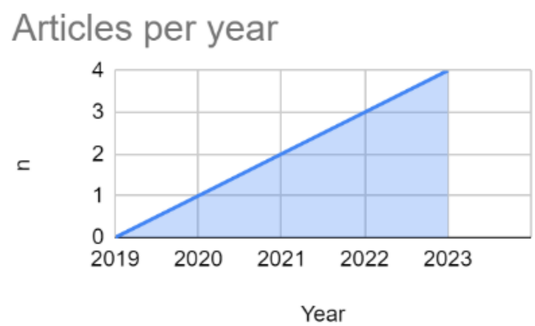
To assess the risk of bias in the included articles, several specific evaluation criteria were applied: (1) the study design and whether it was aligned with the research objectives, (2) transparency in describing the data collection methods, (3) clarity in defining and measuring the variables and outcomes, (4) details about the sample and selection procedures, and (5) objectivity in the presentation and analysis of the data. Each study was examined to identify potential sources of bias in these areas. This evaluation ensured the quality and reliability of the findings and conclusions of the review.

Research questions

Based on the defined research objective and subject of study, the following re-search questions are established:

1) How many articles use 'Extended Reality' as keywords? 2) What technologies included within extended realities are used? 3) How many articles refer to the appropriation or implementation of technologies or applications? 4) How many articles refer to the development of applications or re-sources? 5) How many articles are conceptual research works? 6) How many articles are empirical research works? 7) What research method is used? 8) What are the obtained results

Fig. 4. Articles per year



Note. The chart represents the increment in publications.

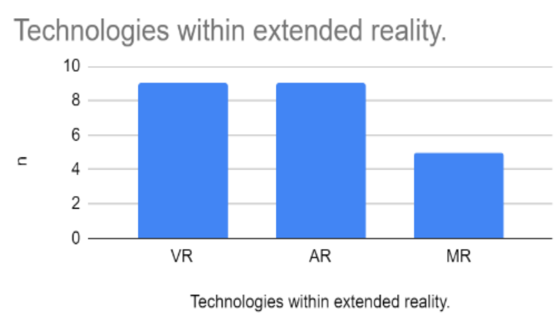
Table 3.

Use of the term 'Extended reality'

Use of the term "Extended Reality"	Amount
Yes	11
No	0

Note. Most of the articles use the term "extended reality"

Fig. 5. Technologies within extended reality



Note. Most of the articles mention VR and AR.

Table 4. Appropriation or implementation of technologies

Article	How many articles refer to the appropriation or implementation of technologies or applications?
Gruson et al. (2023)	Not applicable
Bashir et al. (2023)	Not aplicable
Pregowska et al. (2022)	Yes
Shao et al. (2023)	Not aplicable
Herur-Raman et al. (2021)	Not aplicable
Jacquesson et al. (2020)	Yes
Santos et al. (2022)	Not aplicable
Jim et al. (2023)	Not aplicable
Venkatesan et al. (2021)	Not aplicable
Li et al. (2024)	Yes
Morimoto et al. (2022)	Not aplicable

Note. Most of the articles doesn´t apply successfully to the question.

Table 5. Technological development / applications

Article	Technological development / applications
Gruson et al. (2023)	Not applicable.
Bashir et al. (2023)	Not applicable.
Pregowska et al. (2022)	Yes
Shao et al. (2023)	Not applicable.
Herur-Raman et al. (2021)	Not applicable.
Jacquesson et al. (2020)	Not applicable.
Santos et al. (2022)	Not applicable.
Jim et al. (2023)	Not applicable.
Venkatesan et al. (2021)	Not applicable.
Li et al. (2024)	Not applicable.
Morimoto et al. (2022)	Not applicable.

Note. Just one article mentioned technological development.

3. Results

Regarding the results obtained upon concluding the systematic review of the accepted articles, it can be mentioned that 4 were found in Scopus and 7 in Web of Science, with the majority classified as articles (7) and the rest as reviews (see Figure 2). Figure 3 shows the countries of origin of the publications, and Table 2 lists the quantity of publications by country.

On the other hand, the number of articles published per year, shown in Figure 4, exhibits an increasing trend, indicating potential for conducting systematic reviews in the future with a greater number of results.

Answer per research question

1. How many articles use "Extended Reality" as keywords?

Regarding the use of the term 'extended reality,' we can see in Table 3 that only 3 implement the concept, with the majority classified as conceptual works (see Figure 6).

2. What technologies included within extended realities are used?

The articles mention the technologies included within extended reality, primarily virtual reality and augmented reality (see Figure 5), with mixed reality being the least mentioned. This may be due to it being relatively new and costly technology in terms of development and execution devices.

3. How many articles refer to the appropriation or implementation of technologies or applications?

Three articles indicate the appropriation or implementation of resources (Table 4) using one of the technologies of XR.

4. How many articles refer to the development of applications or resources?

Only one article mentions technological or application development. (Table 5)

Two works mention the development of solutions. (Table 6)

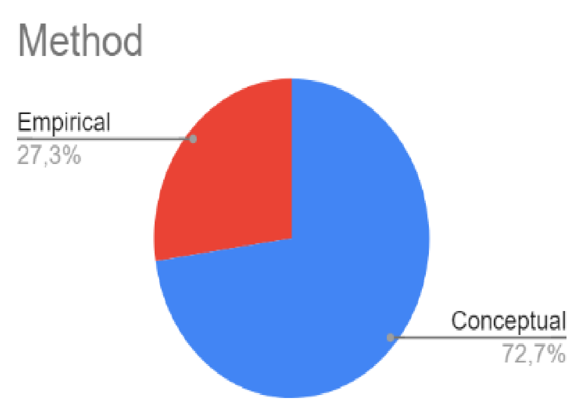
5. How many articles are conceptual research works?

Table 6. Development of applications or resources

Article	How many articles refer to the development of applications or resources?
Gruson et al. (2023)	Not applicable.
Bashir et al. (2023)	Not applicable.
Pregowska et al. (2022)	yes
Shao et al. (2023)	Not applicable.
Herur-Raman et al. (2021)	Not applicable.
Jacquesson et al. (2020)	Yes
Santos et al. (2022)	Not applicable.
Jim et al. (2023)	Not applicable.
Venkatesan et al. (2021)	Not applicable.
Li et al. (2024)	Not applicable.
Morimoto et al. (2022)	Not applicable.

Note. Most of the articles doesn´t refer development of applications or resources.

Fig. 6. Method implemented in the articles



Note. Most of the articles implemented a conceptual method of research.

Table 6. Development of applications or resources

Article	Type	Results obtained
Gruson et al. (2023)	Literature Review	The metaverse is revolutionizing laboratory medicine by integrating new technologies that make services more efficient, personalized, and immersive, enhancing the user experience and transforming healthcare.
Bashir et al. (2023)	Literature Review	A detailed survey was conducted on the use of Federated Learning (FL) in the healthcare metaverse, explaining its fundamentals and reviewing its main applications in smart healthcare.
Pregowska et al. (2022)	Implementation of MR	Proposal of ICT-based systems designed to operate on Microsoft HoloLens 2 MR glasses, which can be successfully applied in medical and pharmacy courses.
Shao et al. (2023)	Literature Review	In the medical field, healthcare personnel can utilize the metaverse to achieve efficient diagnostics, education, and treatments
Herur-Raman et al. (2021)	Literature Review	Extended reality (XR) applications in education include teaching macroscopic anatomy through 3D visualizations, training in communication and empathy through simulations of clinical interactions and practicing surgical techniques and procedures in virtual environments.
Jacquesson et al. (2020)	Proof of concept	A stereoscopic 3D anatomy class was taught, which left all students satisfied. The majority improved their understanding and believed that the class will benefit their clinical practice. The class was rated 8.9/10, outperforming traditional 2D classes.
Santos et al. (2022)	Literature Review	The analysis indicates that, among all technologies, those related to the internet and 3D printing are the most applicable in terms of student learning and economic cost for their structural implementation
Jim et al. (2023)	Literature Review	A VR and AR-assisted microscope system, a virtual anatomy lab in VR, and a virtual environment for practical learning were developed, highlighting the opportunities of the metaverse in laboratory medicine, such as MetaLabs.
Venkatesan et al. (2021)	Literature Review	This work examines how XR technologies, especially virtual reality, enhance the learning of biological and anatomical concepts by allowing the visualization of 3D models, from molecular to anatomical structures.
Li et al. (2024)	Proof of concept	The WeMed program is well-received, with most students finding it useful and easy to use. After 6 months, students who used WeMed achieved better results in knowledge tests than those in the traditional training group. However, these results should be taken with caution due to the lack of a pre-test.
Morimoto et al. (2022)	Literature Review	The factors that have driven the advancement of XR technology in spinal surgery were discussed, such as digital transformation, the COVID-19 pandemic, and minimally invasive surgery (MISS). In spinal medicine, XR has been integrated into education, diagnosis, surgery, and rehabilitation, showing outstanding results

Among the reviewed works, 8 are classified with a conceptual method (see Figure 6). Conceptual articles focus on theoretical development and the formulation of new concepts, theoretical frameworks, or models. These articles do not necessarily rely on empirical data but are based on logical reasoning, literature review, and idea synthesis.

6. How many articles are empirical research works?

Among the articles, 3 are identified with an empirical method as shown in Figure 6. Empirical articles are based on the collection and analysis of observable or measurable data. These articles aim to test hypotheses or answer research questions through the use of quantitative or qualitative data.

7. What research method do they use?

In the study conducted on the research methods used, it was observed that the majority of the analyzed articles employed a conceptual approach. With 72.7% of the articles using conceptual methods, there is a notable trend towards theoretical development and literature review. In comparison, the remaining 27.3% of the articles followed an empirical approach, focused on the collection and analysis of quantitative and qualitative data. These results suggest a significant preference for theoretical construction and idea synthesis, as well as potential documentation for conducting proof-of-concept tests and reporting on technological development.

8. What are the results obtained?

The results identified in each work are referenced in Table 6.

4 Future Challenges and Limitations

Future challenges and limitations are mentioned in Table 7.

5 Discussion

Advancements in the integration of extended reality technologies in educational clinical laboratories are on the rise, driven by the opportunities they offer to develop technological solutions that enhance learning. Projects involving virtual, augmented, and mixed reality are beginning to address specific needs and enrich educational experiences.

This systematic review not only provides a detailed assessment of the impact of XR technologies on clinical laboratories and medical education but also fits within the broader digital transformation in higher education. The analysis offers deep insights into how the integration of these technologies is changing teaching and learning methods in health sciences.

Furthermore, the review aligns with the United Nations Sustainable Development Goals (SDGs), particularly with Goal 4, which promotes quality, inclusive, and equitable education. At the national level, the research connects with the National Strategic Programs (Pronaces) of the National Council of Science and Technology (CONACYT) in Mexico, which aim to foster innovation and the application of new technologies in key sectors, including education. This combination of global and local efforts highlights the importance and transformative potential of clinical laboratories with extended reality to significantly and sustainably advance medical education.

6 Conclusion

The conclusions of this systematic review highlight the success of various projects and research that have incorporated XR technologies into clinical laboratories, demonstrating their capacity to enhance medical education. The integration of new technologies and tools in the educational field is being driven by key factors such as accessibility, the adoption of new teaching models, and the improvement of student experiences.

These advancements are transforming the way teaching and learning occur, paving the way for a future where the metaverse could play an important role in education and professional practice.

Extended realities are establishing themselves as valuable tools that can be integrated into clinical laboratories to provide more immersive and effective learning experiences.

Table 7. Challenges and limitations

Article	Future challenges
Gruson et al. (2023)	Laboratory medicine specialists must prepare to integrate the metaverse and metametric laboratories, educate professionals about their benefits, and establish guidelines to optimize their use and mitigate negative effects.
Bashir et al. (2023)	Federated Learning (FL) and the Metaverse have great potential to revolutionize healthcare. This work aims to increase interest in their research and promote innovative ideas on how the metaverse, driven by FL, can trans-form medical services
Pregowska et al. (2022)	It is planned to develop guidelines for Mixed Reality in medical education, create adaptive training systems that monitor and enhance performance, and develop automated anatomical segmentation tools using Machine Learning and Deep Learning, validated by experts in anatomy and radiology
Shao et al. (2023)	The medical metaverse faces challenges such as managing large volumes of data, issues with interaction devices, concerns about data privacy, high technological costs, and balancing reality with virtualization.
Herur-Raman et al. (2021)	Adopting new technologies in medical education should be done in phases, ensuring that XR anatomy modules are aligned with the curriculum and understanding aspects such as funding, policies, and attitudes toward change.
Jacquesson et al. (2020)	Los estudiantes disfrutan de la anatomía en 3D estereoscópica, pero su implementación es costosa. Se necesita una evaluación objetiva de su impacto en las competencias clínicas para considerar su expansión a otras áreas.
Santos et al. (2022)	Research in educational technologies for anatomy should focus on identifying which technologies are most suitable for each teaching scenario, beyond just evaluating improvements in student grades
Jim et al. (2023)	The metaverse presents opportunities but faces challenges in privacy, digital identity, and interoperability between virtual worlds.
Venkatesan et al. (2021)	The use of XR in biomedicine is on the rise, but it faces challenges in software, hardware, and user experience. Improving affordability and technical knowledge are key to its widespread adoption.
Li et al. (2024)	It is essential to apply continuous improvement to the program and conduct a long-term follow-up study to assess the lasting impact of WeMed.
Morimoto et al. (2022)	XR technology in spinal medicine will bring disruptive changes in education, diagnostics, communication, treatment, and rehabilitation, accelerating the development of the medical field.

Note. The table shows fute challenges identificated on each article

However, significant challenges still exist, such as the need to diversify hardware and software resources and make them more accessible for all students and educators.

Overcoming these obstacles will be crucial to ensure that the benefits of these innovative technologies are distributed equitably and universally.

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