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Influence of Technological Tools in the Teaching of Morphology in Medical Education: A Systematic Review.

Influencia de las Herramientas Tecnológicas en la Enseñanza de la Morfología en la Educación Médica: Una Revisión Sistemática.

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Abstract: Background: The integration of technology in medical education has significantly transformed the teaching of morphology, a fundamental discipline in health sciences. The aim of this systematic review is to discover the technological tools reported in the literature for teaching morphology in medical education and to assess their influence on students. **Methods:** A systematic review was conducted following the PRISMA 2020 guidelines. Searches were performed in the Web of Science and SCOPUS databases, focusing on studies published between 2009 and 2024. Articles were included that examined the use of technology in teaching morphology and that provided quantitative or qualitative results comparing the use of technology with traditional methods. **Results:** A total of 87 articles were identified, of which 12 studies were included in the final analysis. The use of digital and virtual microscopes, 3D models, interactive platforms, and online resources showed a significant improvement in student academic performance and satisfaction. Furthermore, these technologies improved technical and spatial skills, promoting active participation and student autonomy. However, two studies reported no significant differences in academic outcomes. **Conclusions:** The literature reports a positive influence on morphology learning, improving aspects such as academic performance and student engagement. Future research should focus on long-term impacts and personalized approaches to optimize the use of technology in medical education.

Keywords: Medical Education; Morphology; Technological Tools; Educational Technology.

Resumen: Antecedentes: La integración de la tecnología en la educación médica ha transformado significativamente la enseñanza de la morfología, una disciplina fundamental en las ciencias de la salud. El objetivo de esta revisión sistemática es descubrir las herramientas tecnológicas que se reportan en la literatura para la enseñanza de la morfología en la educación médica y evaluar su influencia en los estudiantes. **Métodos:** Se llevó a cabo una revisión sistemática siguiendo las directrices PRISMA 2020. Las búsquedas se realizaron en las bases de datos Web of Science y SCOPUS, enfocándose en estudios publicados entre 2009 y 2024. Se incluyeron artículos que examinaran el uso de la tecnología en la enseñanza de la morfología y que proporcionaran resultados cuantitativos o cualitativos comparando el uso de tecnología con métodos tradicionales. **Resultados:** Se identificaron un total de 87 artículos, de los cuales 12 estudios fueron incluidos en el análisis final. El uso de microscopios digitales y virtuales, modelos 3D, plataformas interactivas y recursos en línea mostró una mejora significativa en el rendimiento académico y la satisfacción de los estudiantes. Además, estas tecnologías mejoraron las habilidades técnicas y espaciales, promoviendo la participación activa y la autonomía estudiantil. Sin embargo, dos estudios no reportaron diferencias significativas en los resultados académicos. **Conclusiones:** La literatura reporta una influencia positiva en el aprendizaje de la morfología, mejorando aspectos como rendimiento académico y la participación estudiantil. Las futuras investigaciones deberían enfocarse en los impactos a largo plazo y en enfoques personalizados para optimizar el uso de la tecnología en la educación médica.

Palabras clave: Educación Médica; Morfología; Herramientas Tecnológicas; Tecnología Educativa.

1. Introduction

In the field of training of health professionals in Chile, the teaching of anatomy, histology and embryology are grouped in the course called "Human Morphology", constituting one of the basic sciences fundamental for the correct development of the professional. This The course addresses the comprehensive study of the human being, including its form and the transformations it experiences throughout life (1). Traditionally, anatomy has been taught through the dissection of cadavers, complemented with atlases and anatomical models, while Histoembryology has been taught using optical microscopes and histological preparations (2-3).

However, the teaching of morphology has undergone a significant transformation with the incorporation of advanced technologies. This responds to the need to adapt to the new generations of students, called “digital natives” and “digital immigrants”, better known as Generation Z and Millennials respectively, who have grown up in a technologically rich environment or in its exponential development (4). New methodologies include virtual dissection tables, digital image processing, artificial intelligence, and the use of global databases and mobile devices, representing a revolutionary change in the pedagogy of this discipline (5). However, the adoption of these technologies has not been uniform, and their effectiveness and acceptance within medical education are not yet completely clear, given that many institutions have only recently begun to incorporate these resources.

Therefore, this work aims to discover the technological tools reported in the literature for teaching morphology in medical education and to evaluate their influence on students. This analysis will be carried out through a systematic review following the PRISMA 2020 protocol for systematic reviews and meta-analyses.

2. Methods

Review protocol

A systematic review was carried out using the guidelines of the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISMA 2020) protocol (6) (Figure 1).

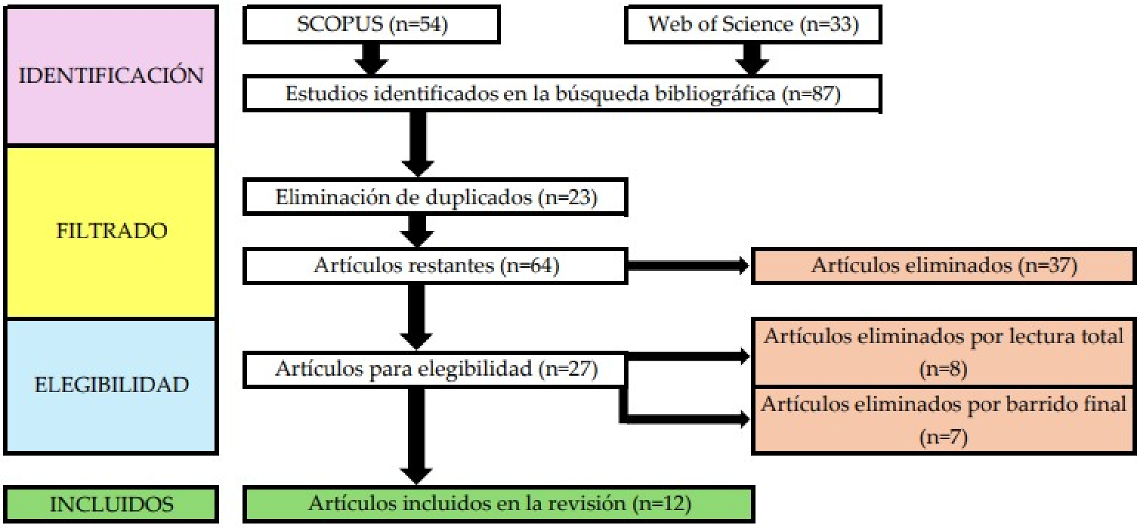

Figure 1. Flowchart of the search, review and selection of articles

Search strategy

One of the authors performed the search in two databases, Web of Science and SCOPUS. The search was performed only in these two databases since they include the journals with the greatest impact, and since they have similar search algorithms, the results obtained would be directed to the same objective. The topic "articles" and a range of 15 years, from 2009 to 2024, with articles in English and Spanish, were applied as filters. The range of years was determined by an initial search in Web of Science, where articles appeared between those years, and determined the range for the SCOPUS database. The language was determined by the languages spoken by the authors. Finally, the results of the search in both databases were entered into the same Excel file that was shared among all the authors, to discard duplicate articles. Table 1 details the search formula, the filters applied, and the results obtained in number of articles. This search was performed on May 2, 2024.

Inclusion and exclusion criteria

The articles had to base their research on the use of various types of technology as a teaching method for morphology within the context of medical education. The types of technology considered were digital and virtual microscopes, digital dissection tables, 3D modeling and printing, use of online games, AI-based platforms, multimedia resources, interactive resources, and online learning. Studies that were comparative for groups of students who will use the technologies and another group that will implement traditional learning of the taught discipline were considered. Failing that, studies that were follow-up were also considered, that is, that compared the before and after intervention of the use of technology. Studies that considered a third group as blended learning were not ruled out. Finally, the studies had to contain both quantitative and qualitative results; regarding quantitative results, evaluations that measured and achieved a comparison between the use and non-use of technology, and multiple-choice perception surveys were considered as such; As for the qualitative results, the results of open-ended perception surveys were considered. Articles that did not have quantitative results that could be used to compare the effectiveness of technological methods were excluded. Articles whose study was not focused on medical education, but on determining new diagnostic methods, or whose study was focused on an area that was complemented by morphology, but was not such, were also excluded. All inclusion and exclusion criteria are presented in Table 2.

Table 1. Database search.

Ecuación de búsqueda	Filtros	Base de datos	Resultados	
(TITLE-ABS-KEY("technology" OR "technological" OR "digital" OR "online") AND TITLE-ABS-KEY("learning" OR "education") AND TITLE-ABS-KEY("morphology") AND TITLE-ABS-KEY("medical students" OR "medical education"))	Artículos Años: 2009-2024	Scopus	54	
(TS=("technology" OR "technological" OR "digital" OR "online") AND TS=("learning" OR "education") AND TS=("morphology") AND TS=("medical students" OR "medical education"))	Artículos **aparecían del 2009 al 2024*	Web of Science	33	
			87	Total
			23	Duplicados
			37	Descartados
			27	Total después del filtro inicial
			8	Descartados luego de la revisión completa
			7	Descartados luego del barrido final
			12	**Total después del filtro final**

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Study context: Research focused on medical education in morphology.	**Outside the context of medical education in morphology:** Studies that focus on the use of technology in diagnosis or in areas complementary to morphology, but not centered on it.
Intervention: Use of technologies as a teaching method for morphology, including digital and virtual microscopes, digital dissection tables, 3D modeling and printing, online games, AI platforms, multimedia and interactive resources, and online learning.	**Absence of technological intervention in teaching:** Articles without use of technologies or that do not use them as a teaching method in morphology.
Study design: Comparative studies between a group using technology and another using traditional methods, or follow-up studies (before and after the technological intervention). Studies with a third group using blended learning are allowed.	**Inadequate design for comparative evaluation:** Studies without comparison between technology groups and traditional methods, or without follow-up design.
Quantitative and qualitative results: Studies that include quantitative results (benchmarking, multiple-choice perception surveys) and qualitative results (open-ended perception surveys).	**Lack of quantitative results:** Articles without useful quantitative results to compare the effectiveness of technology in learning morphology (discarded in the final scan).
Type of study: Studies that contain results that	**Absence of relevant comparative results:**

allow evaluating the effectiveness of the use of technology in learning morphology for medical students.	Studies that do not have quantitative or qualitative results of interest to evaluate the effectiveness of technology in teaching morphology in medical education.
Publication period: Articles published between 2009 and 2024.	**Publication year outside the established range:** Articles published before 2009 or after 2024.

Pre-selection process

Once the articles that were duplicates were eliminated, each author independently and individually reviewed a series of studies that were numbered from 1 to 87 and distributed equally. The title and abstract of the 87 articles were reviewed. This information was organized in a joint Excel file, so that all team members could manage the information. Those articles that did meet the previously agreed inclusion criteria were selected, and then, discrepancies were reviewed in meetings with all authors. At the end of this selection process, the author with the most experience reviewed each selection, to avoid making mistakes and manage discrepancies.

Selection process and data collection

The 27 articles that were accepted after the initial review were distributed equally for thorough review among all authors. Each author independently read each text completely, recovering titles, names of authors, year and country in which the study was conducted, objective, design, participants, instruments, and results that were relevant to answer the research question. All of this data was compiled in another joint Excel, and each author selected those articles that made reference to and answered our research question. Again, a meeting was held to increase the knowledge of all authors about why some articles were selected and others were not, and then the author with the most experience read all of the selected articles completely, also reviewing what was compiled in the Excel, and correcting sections or eliminating selected articles if necessary. The 7 articles that were discarded in the final sweep did not have quantitative results, only qualitative ones through perception surveys, so they did not meet all of the inclusion criteria. The selection process for the articles is shown in Figure 1. Finally, those results that referred to similar experiences were grouped under common names, jointly by all the authors. The development of the selected studies is shown in Table 3. An artificial intelligence tool was used to synthesize the reviewed articles.

Analysis process: Classification of experiences

The experiences were then classified into four relevant categories: i) Academic performance; ii) Student satisfaction and perception; iii) Active and autonomous participation; iv) Development of technical and special skills.

Table 3. Selected studies.

Author (Country, Year), Ref.	Objective of the study	Study design	Participants	Tools	Findings
Alzahrani et al. (Saudi Arabia, 2019) (11)	To examine the effectiveness of SODAR training in improving the quality of dental carving skills and knowledge among Saudi male preclinical students in Saudi Arabia.	Randomized, double-blind, parallel-arm clinical trial.	30 male dental hygiene undergraduate students from Albaha University, Saudi Arabia. They were divided into two groups: Experimental group (n=15): 12 hours of SODAR training. Control group (n=15): Did not receive SODAR training.	Assessment of dental carving quality by two double-blind examiners, on a scale of 0 to 10 points. A theoretical questionnaire with 10 questions to evaluate before and after the use of the SODAR intervention, where the questions focused on identifying different shapes, locations, configurations, characteristics, parts and tissues of deciduous and permanent teeth, anatomy of the oral cavity and the alveolar process, and the tooth numbering and coding system.	The SODAR group obtained a slightly higher average score in the theoretical knowledge assessment, with an average score of 7.4 compared to 7.1 in the control group. However, no statistically significant differences were observed in the frequency of correct answers for each of the theoretical questions, with a percentage of correct answers of 82% for the SODAR group and 80% for the control group.
Becerra et al. (Chile, 2018) (12)	Evaluate students' academic performance and perception using optical microscopy and virtual microscopy based on a web application.	Experimental study.	92 first-year dentistry students, who attended the histology course, who enrolled in 2017 and are taking the course for the first time, from the Universidad de los Andes, Santiago, Chile. They were separated into 2 groups: Optical microscopy: n=46 Digital microscopy: n=46	Optical and digital microscopy. Cognitive test. Perception survey.	In the cognitive test, the optical microscopy group obtained an average of 5.4, while the digital microscopy group obtained an average of 5.7, on a scale of 1 to 7. The T-test analysis showed a tendency towards better results for the digital microscopy group (t = 0.77). In addition, 73.24% of the students considered the digital microscopy assessment to be fairer than the optical one.
Becerra et al.	To compare the	Experimental	95 first-year dentistry students,	Optical and digital	Regarding the correct

(Chile, 2015) (7)	academic performance and perception of students using three learning methods: digital system, microscopy and microscopy plus digital system, in the muscle tissue unit of the first-year morphology course in Dentistry at the Universidad de los Andes.	study.	studying histology and enrolled in 2012, at the Universidad de los Andes, Santiago, Chile. They were divided into 3 groups: Group 1 (n=32): individual optical microscope. Group 2 (n=34): Digital systems. Group 3 (n=29): microscopy plus digital systems.	microscopy. Cognitive test. Perception survey.	identification of tissues and structures, Group 1 had an average of 5.03, Group 2 had an average of 4.5, and Group 3 had the highest average with 5.45. The differences between the scores of the groups were statistically significant, with a p value of 0.0023, indicating that the group that used both methods obtained superior results compared to the groups that used only one of the methods. In addition, 69% of Group 1 reported feeling motivated, versus 51% of Group 2.
Donkin et al. (Australia, 2019) (9)	To determine whether students enrolled in a medical laboratory science program show greater engagement with the subject matter and achieve better academic outcomes when using video feedback and online resources.	Experimental with a mixed approach.	28 first-year students enrolled in the histology course of the medical laboratory sciences program in 2017. Two groups were separated: Video group (n=14). Control group (n=14).	Videos recorded by experts demonstrating histological techniques. Video group recorded their procedures, in first person using GoPro, and in third person using iPhones, which were then evaluated and given feedback by an instructor. Online learning portfolio with supporting information. Practical evaluation of histological techniques and morphological identification. Perception survey.	In the MLS121 histology course, practical attendance was high in both groups: 87.5% in the control group and 97.7% in the video group. Tutorial attendance was 95.1% in the video group and 64.0% in the control group. Students in the video group showed significant improvement in final grade, with a mean of 75.6% (SD 12.74), compared with the control group, which had a mean of 55.6% (SD 24.46; P = 0.01).
Felszegh et al. (Finland, 2019) (13)	To investigate whether students in a medical and dental histology course would obtain better grades using the Kahoot® gaming	Quasi-experimental study.	215 first-year students of medicine and dentistry at the University of Eastern Finland (UEF). The students were randomly divided into five equal groups:	Kahoot gamification platform. Cloud-based histological full-image platform. Perception survey. Assessment of academic performance through final	Correct scores on the tests were significantly higher when students completed the tests in team mode (69%) versus individually (58%; p < 0.05) at the beginning, and the same at the end (group=87%;

	software and whether gamification affects student learning and satisfaction.		Group 1 (G1): Kahoot® at the start of the session as individual players. Group 2 (G2): Kahoot® at the start of the team session. Group 3 (G3): Kahoot® at the end of the session as individual players. Group 4 (G4): Kahoot® at the end of the team session. Group 5 (G5): Kahoot® at the beginning and end of the team session.	histology exams.	individual=82%; $p < 0.05$). Participation in the Kahoot® quizzes was 93% of the student population.
Hsiao et al. (Taiwan, 2016) (8)	To compare the use of interactive multimedia eBooks (IME) with the use of traditional PowerPoint (TPP) to teach blood and bone marrow cell morphology.	Prospective randomized study.	51 interns from three medical schools in Taiwan, who were in training with a single teacher in the Department of Pediatric Hematology at Chang Gung Memorial Hospital, Kaohsiung, Taiwan. They were separated into 2 groups: Traditional PowerPoint Group (TPP): 25 inmates. Interactive multimedia eBook group (IME): 26 inmates.	Interactive multimedia eBook (IME), including interactive features such as game quizzes, cell type identification, simulated clinical diagnoses, image labeling, and drag-and-drop learning modules. PowerPoint presentation (TPP). CellAtlas CellQuiz app for pre- and post-learning assessment. A perception questionnaire on interest, motivation, and effectiveness.	Interns who used the interactive multimedia eBook achieved significantly better scores on the post-test compared to those who used the PowerPoint atlas, with a mean of 103.2 (SD 13.6) versus 70.6 (SD 13.7), respectively ($p < 0.001$). In addition, the IME group reported a higher level of interest, motivation, and effectiveness with their study material (92.3%), compared to the PPT group (36%).
Odeh et al. (Jordan, 2022) (14)	To evaluate the effectiveness of using the Poll Everywhere (PollEV) audience response system (ARS) in online practical teaching of histology during the COVID-19	Randomized controlled crossover trial.	140 first-year students from the Faculty of Medicine, Al-Balqa Applied University (BAU), Al-Salt, Jordan. They were randomly divided into two equal groups: Group A (n=70): Bone histology without PollEv, muscle histology	Microsoft TeamsTM and MoodleTM as virtual classroom platforms. Poll Everywhere (PollEV) Audience Response System software for the interactive practical histology sessions; used to create interactive	Group B had a significantly higher mean score on the bone histology quiz (16.46 ± 2.77) compared to group A (13.71 ± 4.51; $p = 0.000$). On the other hand, group A had better results on the muscle histology quiz (17.66 ± 1.98) compared to group B (15.80 ± 4.38;

	pandemic lockdown and its impact on student preferences and performance.		with PollEv. Group B (n=70): Bone histology with PollEv, muscle histology without PollEv.	questions (multiple choice, word cloud, clickable image, rank order) that were embedded in PowerPoint presentations. PowerPoint presentations. Performance assessments at the end of each week of learning, on the topics covered that week, consisting of 20 questions. Perception surveys.	p = 0.002). 91% indicated that PollEV increased their attention in class, 92% that it increased their enjoyment of the sessions, and 78.3% that it improved their skills in practical histology.
Rinaldi et al. (United States, 2017) (18)	To evaluate the use of a cloud-based interactive classroom response system (CRS) to identify misconceptions on the fly, minimize misinterpretation due to contradictory or confusing informal feedback, and achieve a more inclusive teaching atmosphere.	Prospective study.	Undergraduate and graduate students enrolled in the 2015 histology course at Cornell University (n=39).	The Pearson Learning Catalytics CRS, in its 2015 version; interactive review sessions (IRS) with question modules during them; surveys before starting and at the end of the IRS; surveys and exams at the end of the complete intervention, in students who have used and not used the CRS, and in teachers who taught with CRS.	The interactive response system (IRS) did not significantly improve final exam scores over currently employed feedback methods (P = 0.11). The overall perception of the interactive review sessions was positive, with an average score of 4.2 on a 5-point Likert scale.
Schoenherr et al. (United States, 2022) (15)	To develop, implement, and evaluate a concise, self-paced learning tool, utilizing widely-recognized survey software, to improve the integration of histology and anatomic pathology at Oakland University William Beaumont School of Medicine (OUWB).	Quasi-experimental study.	79 first-year medical students from Oakland University William Beaumony School of Medicine (invited=119, participated in some element of the research=106, participated in the module=79).	Online learning module developed in the "Qualtrics XM" survey software. Pre- and post-module questionnaires, with 10 multiple choice questions. Four short videos with the content to be learned. Three categorization activities for identification. Post-activity feedback. Validation by expert histologists external to	Post-module test scores were significantly higher (6.8 ± 1.9) compared to pre-module scores (5.9 ± 1.7; $t(58) = 3.70$, $p < 0.001$). Module users showed higher pathology self-efficacy compared to non-users ($p = 0.02$).

				the University. Self-efficacy survey on respiratory pathology.	
Ullah et al. (Pakistan, 2021) (16)	To evaluate student satisfaction and educational outcomes in a dental anatomy course delivered via blended learning (BL) compared to a dental anatomy course delivered in a traditional/face-to-face (F2F) manner.	Comparative and intervention study.	98 first year students of dental anatomy. They were divided into 2 groups: F2F Group: 48 in conventional face-to-face learning BL Group: 50 in the blended learning group.	Multiple choice questionnaires (MCQs), to assess pre- and post-learning, with 40 questions. Dundee Ready Education Environment Measure (DREEM), used as a perception survey. Online learning platform (LMS) for the BL group; it contained multimedia lectures, demonstration videos, questionnaires, discussion forums and announcements, and was also available for personal computers, mobile phones and tablets. For both BL and F2F, 26 face-to-face sessions; F2F: 90 minutes each, with multimedia presentations and demonstrations of dental anatomy models. BL: 60 minutes each, complemented by the LMS platform.	Post-test scores were significantly higher in the Web-Based Learning (BL) group (31.5 ± 4.5) compared to the face-to-face (F2F) group (27.2 ± 4.8). DREEM scores were higher in the BL group (147.3 ± 15.5) compared to the F2F group (134.5 ± 15.1; $p < 0.002$).
Zhang, Chen (China, 2020) (10)	To evaluate the impact of computer-assisted animation technology in the teaching of hematologic medicine and its effectiveness in improving students' understanding of cell	Quasi-experimental study.	492 clinical undergraduate students in the Department of Hematology, Gulou Hospital, Nanjing University. Experimental group: 235 students who used the teaching method with computer-assisted 3D animation technology to	3D animation software to create animated models of immune cell morphology, to illustrate morphological changes in the process of cellular immune regulation. Traditional clinical teaching methods, such as the use of	The theoretical and practical skills assessments in the experimental group were significantly better compared to the control group ($P < 0.001$). Students in the experimental group also showed a higher ability to handle 3D animation technology compared

	morphology and interest in learning.		learn about "Morphological changes in the process of cellular immune regulation". Control group: 257 students who used traditional clinical teaching methods.	whiteboard drawings, two-dimensional slide graphics, and static representations of cells and tissues. Theoretical exams to assess understanding of cell morphology, and practical assessments to measure recognition skills. Perception surveys.	to students in the control group.
Zoia et al. (Ukraine, 2023) (17)	To establish the peculiarities of the impact of the COVID-19 pandemic on the academic process in higher medical institutions and to develop an optimal model of organization and teaching methodology under quarantine conditions for students of the specialty "Nursing".	Comparative study.	90 second-year students of the "Nursing" specialty of the National Medical University of Ukraine.	Sociological surveys, to assess students' perceptions and preferences regarding teaching principles implemented during quarantine. Skyscape and Virtual Practice for Doctors, applications used to provide detailed medical information and to facilitate virtual practical learning, which included topics such as human anatomy, diseases, and practical recommendations for patient management. Tests of practical and theoretical knowledge, 4 months after virtual classes began.	Most students achieved high levels of both theoretical and practical knowledge. 57.0% of students achieved a high level of practical knowledge, with an average score of 0.91, while 39.0% demonstrated a sufficient level of practical knowledge, with an average score of 0.83. Only 4.0% of students showed a low level of practical knowledge, with an average score of 0.52. In terms of theoretical knowledge, 63.0% of students achieved a high level, with an average score of 0.93, and 35.0% achieved a sufficient level, with an average score of 0.80. Only 2.0% of students showed a low level of theoretical knowledge, with an average score of 0.57.

3. Results

Selection of studies

The systematic review identified a total of 87 articles from different databases. Of these, 33 articles were found in Web of Science (WOS) and 54 in Scopus. After removal of duplicate articles, 64 unique articles were selected for further review. Of these, 27 articles were accepted based on their title and abstract, while 37 were discarded. During the full-text review of the 27 initially accepted articles, 8 articles were discarded for not meeting the inclusion criteria. In the final sweep performed by the most experienced author, 7 additional articles were eliminated. Finally, 12 studies met all inclusion criteria and were selected to be part of this systematic review. A summary of each of these articles, as reviewed and retrieved by the authors, is found in Table 3.

Characteristics of the studies

The selected studies were published between 2015 and 2023, with a notable increase in interest in this area of research starting in 2018. Regarding the geographical distribution of the studies, most were concentrated in two main countries: the United States (2 studies) and Chile (2 studies). This indicates a particular interest in these regions to research and improve medical education in relation to the topics addressed in the selected studies. The predominant language of the articles was English, which facilitates their accessibility and dissemination in the international scientific community.

Common themes found in the studies

Of the 12 selected studies, various influences of technologies on the teaching of morphology were identified. These influences were classified into four main categories: i) Academic performance, ii) Student satisfaction and perception, iii) Development of technical and spatial skills, and iv) Active participation and autonomy. A summary of these is presented in Table 4. In addition, a categorization according to the types of technologies used in the studies was carried out (Table 5), based on this first categorization of results. These categories and the relevant themes found in each of them are presented below.

I. Academic performance

The first category addresses the academic performance of students who used technologies compared to those who did not. Two main subthemes were identified within this category.

I.1. Better academic performance of students who used technologies compared to students who did not use them

Ten studies reported that students who used technologies showed better academic performance compared to those who did not use them. These studies highlighted significant improvements in grades and understanding of study materials. For example, the combined use of digital and traditional microscopes was found to result in better scores in tissue and structure identification, compared to using only one of the methods (7). Furthermore, interns who used an interactive multimedia eBook scored significantly better on the post-test compared to those who used a PowerPoint atlas (8). Also, students in the video group in a histology course showed a significant improvement in the final grade compared to the control group (9). Likewise, students in an experimental group who used 3D animation technology were found to have significantly better theoretical and practical assessments compared to the control group (10). Other studies also supported these findings, showing improvements in final grades and increased self-efficacy among students who used technologies (12-17).

Table 4. Categorization of results according to the influence on the student.

I. Academic performance (12) *I.1.* Better academic performance of students who used technologies compared to students who did not use them (10) *I.2.* No improvements or setbacks were observed in the academic performance of students who used technologies compared to students who did not use them (2)
II. Student satisfaction and perception (7) *II.1.* Students positively value the various technologies used in their learning (7) *II.2.* High academic motivation of students who used technologies in their learning (3)
III. Active participation and autonomy (6) *III.1.* Impact of Technology on Student Participation (5) *III.2.* Impact of digital learning tools on student autonomy (3)
IV. Development of technical and spatial skills (1) *IV.1.* How technologies help develop critical technical and spatial skills for the study of morphology (1) *IV.2.* Technologies such as 3D models and animations significantly improve the spatial understanding of complex anatomical structures (1)

Table 5. Categorization of results according to the technology used.

I. Multimedia and interactive resources (6) Positive Impact on Academic Performance (6) Student satisfaction and perception (2) Active participation and autonomy (1)
II. Blended and online learning (4) Positive Impact on Academic Performance (3) Student satisfaction and perception (3) Active participation and autonomy (2)
III. Digital and virtual microscopy (3) Positive Impact on Academic Performance (3) Active participation and autonomy (3) Student satisfaction and perception (2)
IV. 3D models and simulations (1) Student satisfaction and perception (1) Positive Impact on Academic Performance (1) Active participation and autonomy (1) Development of technical and spatial skills (1)
V. Gamification and game-based learning (1) Positive Impact on Academic Performance (1) Student satisfaction and perception (1) Active participation and autonomy (1)

I.2. No improvements or setbacks were observed in the academic performance of students who used technologies compared to students who did not use them.

Two studies reported that there were no significant differences in academic performance between students who used technologies and those who did not. For example, it was concluded that the SODAR intervention had no significant effect on theoretical knowledge assessments, as no statistically significant differences were observed in the frequency of correct answers for each of the theoretical questions (11). Furthermore, it was found that the interactive response system (IRS) did not significantly improve final exam scores compared to currently employed feedback methods (18).

II. Student satisfaction and perception

The second category focuses on students' satisfaction and perception regarding the use of technologies in their learning.

II.1. Students positively value the various technologies used in their learning

Seven studies found that students positively valued the technologies used in their learning. These studies reported that students considered technologies as useful educational tools that enhanced their understanding and motivation. For example, students considered that the use of 3D animations aroused their desire to learn, and facilitated the understanding of the concepts seen (10). Furthermore, participation in Kahoot quizzes was 93% of the student population, indicating a general positive perception of these technologies (5). Other studies also found positive perceptions about the technologies used, highlighting their usefulness and effectiveness in the learning process (12, 15-18).

II.2. High academic motivation of students who used technologies in their learning

Three studies reported high academic motivation among students who used technologies. These studies highlighted that the use of technologies fostered increased interest and participation in academic activities. For example, participation in Kahoot quizzes showed that students were highly motivated and engaged in their learning (13). The overall perception of interactive review sessions was also positive, with a high average score on a Likert scale indicating elevated motivation (18). Furthermore, students who used web-based learning were found to have higher scores and greater satisfaction with their learning environment (16).

III. Active participation and autonomy

The third category examines the impact of digital learning tools on student autonomy and active student participation.

III.1. Impact of technology on student participation

Five studies highlighted that technology has a significant impact on student engagement. These studies found that the use of technology fostered greater student participation and engagement in academic activities. For example, high participation in Kahoot quizzes demonstrated that students were highly motivated and engaged in their learning (5). Other studies also found that technology enhanced students’ active participation in the learning process (7, 10, 16, 18).

III.2. Impact of digital learning tools on student autonomy

Three studies indicated that digital learning tools have a positive impact on student autonomy. These studies found that the use of technologies allowed students to have greater control over their learning process and fostered their independence. For example, it was reported that students who used both digital and traditional systems performed better compared to those who used only one of the methods, suggesting greater autonomy in their learning (7).

IV. Development of technical and spatial skills

The fourth category refers to the development of technical and spatial skills critical to the study of morphology through the use of technologies.

IV.1. Technologies help develop technical and spatial skills critical for the study of morphology

One study indicated that technologies help develop technical and spatial skills. This study highlights that the use of 3D models and other advanced technologies significantly improved students' ability to visualize and understand complex anatomical structures. For example, it was found that students in an experimental group showed an increased ability to handle 3D animation technology (10).

IV.2. Technologies such as 3D models and animations significantly improve the spatial understanding of complex anatomical structures.

One study highlighted that the use of technologies such as 3D models and animations improve spatial understanding. It was reported that the use of these models not only improved students' spatial understanding but also facilitated the formulation of operational plans in practical contexts (10).

4. Discussion

The results contain different conclusions that were drawn from each article. In general, no results were found that described a negative effect of the application of technology in the teaching of health sciences students. Instead, the results show how these technologies could be neutral, either at an academic level or at a more emotional level, or as was the case in most cases, these technologies would become a significant contribution to the way students approach and learn morphology. Given this, we can say that the results we selected do answer the research question, since the articles we have reviewed provide us with a lot of information about the influence that technology had on the learning of morphology, which for a better understanding we classified as: academic performance, student satisfaction and perception, active participation and autonomy, and finally, development of technical and spatial skills.

Academic performance was mentioned in 100% of the articles. Certainly, after the review, it has become clear that it is important to keep up to date in the classrooms to deliver the content in the best possible way. Articles mentioned that students with a comprehensive study of both new and old learning methodologies had managed to have the best grades (7).

Student satisfaction and perception was mentioned in 58.3% of the articles. This point is relevant because it shows us that not only can the implementation of technology in teaching improve grades, it also has an important role in improving the attitude of students. The introduction of more didactic games and activities such as quizzes in Kahoot generated a positive perception in students (13). Other works that address student perception, such as that of Halalsheh R. et al (19) in the teaching of physiology, highlight that, for complex subjects and difficult-to-understand concepts, it is when a series of tools are most needed that allow a practical and visual connection of the theoretical contents that are addressed in class, which makes these tools not only more effective in the learning process, but also a support to the learning process that teachers should include to ensure an integration of the contents.

Active participation and autonomy were mentioned in 50% of the articles. In the same way that technology can affect the attitude of students to make them feel more motivated when studying, the articles state that, after the implementation of new teaching methods, students have been made to feel more motivated; and not only that, their participation and independence have also been increased, taking more control over their own education (7, 10, 16, 18). This indicates that the use of new tools in the learning process can provide transversal skills for both professional and student life. Research has shown that in general students have a positive view of the implementation of technologies. Montané E. et al (20) reports that significant groups are motivated by different changes in their learning process. This could show the importance of modernizing teaching, since these changes promise to be a contribution to their academic life.

The development of technical and spatial skills was mentioned in 8.3% of the articles, making it the section with the lowest appearance. This may be due to the fact that most technologies and studies are focused on the ability to transfer knowledge that is rather theoretical, but that does not ignore the fact that there is a precedent that different technologies can provide complex knowledge that could be more difficult to integrate with traditional teaching methods (10). Kok, DL et al (21) investigated digital learning in areas such as oncology, reaching the conclusion that the adaptation process that will take place in the next decade will be driven by the benefits that technology promises, such as its flexibility. This could indicate that the implementation of teaching technology in more advanced subjects and in clinical or practical contexts is a success.

In total, 11 articles were not included in this review by year of publication, and of these, only 2 met the rest of the inclusion criteria described above. One of these focused on the use of a computer-based dermatology tutorial (CAI) called "VisualDX Integrated Morphology Module" in a group of students, compared to the implementation of a traditional lecture to another group (22), while the other article compared the use of a graphic monitor and the use of a slide projection in the same group of students (23). Both technologies are included in the category of multimedia resources, with the graphic monitor also being considered an online learning technology. In both studies, it was determined that there was no significant difference in the results of the exams to which the students were exposed, so they concluded that the use of technology neither improved nor worsened learning, that is, there is no real influence of its use on students. This may be due, in the case of the second article, to the fact that the study was not really comparative, since the graphic monitor (technology) was used first and then the photographic slides (traditional) in the same students, failing to observe the real impact that this technology can have, considering that part of the study objective was to evaluate whether the graphic monitor can be an effective alternative to traditional slides in the teaching of dermatology (23). And in general, it could be due to the recent incorporation of technologies in the context of Medical Education in the years 1992 (23) and 2008 (22).

Only 3D printing model technology has an influence on the development of technical and spatial skills. This is explained in the review by Heinze A. et al (24), where some of the digital images from different imaging examinations are processed and the elements of interest are printed separately. This unique 3D visualization provided by the models allowed: Students to better recognize lesion sites by printing a renal tumor; better surgical planning by printing the lesion in its context; lower risk of complications during surgical procedures by printing the exact anatomy of the patient, allowing the identification of complex or uncommon anatomies.

Strengths and Limitations

This systematic review covers studies with a wide geographic and temporal diversity, providing a comprehensive overview of the impact of technologies on morphology learning. In addition, a wide variety of technologies were examined, and the results obtained were consistent, reinforcing the validity of the findings.

However, limitations were identified in the reviewed studies. First, the sample size in some studies was limited, which may affect the generalizability of the results. Second, the heterogeneity of the studies makes direct comparison and generalization of the findings difficult. Finally, the lack of long-term data limits the understanding of the sustained impact of using these technologies in teaching.

Future Research

For future research, it is recommended to consider the analysis of contextual factors such as the learning environment, the level of experience of students, and the availability of technological resources. This approach will allow for providing more personalized and contextually relevant recommendations. In addition, it is essential to conduct longitudinal studies that assess the long-term impact of technology use on academic performance and skill development, in order to better understand the sustained effect of these tools in medical education.

Recommendations

From the systematic review conducted, several key findings were identified regarding the impact of technologies on learning morphology in medical education. These findings suggest important implications for educational practice and directions for future research. To achieve an improvement in learning morphology through the use of technologies, we recommend the recommendations set out in Table 6.

Table 6. Recommendations for educational practice and future research

Recommendation	Description
Integration of 3D animations and interactive platforms.	Include technological tools that facilitate the visualization of complex structures to improve academic performance.
Use of gamification tools.	Implement tools like Kahoot! and Poll Everywhere to increase participation and engagement in Morphology classes.
Incorporation of simulations and visual models.	Use simulations and virtual environments in practical training to develop clinical skills in a safe environment.
Flexible teaching strategy designs.	Combining in-person and online methods to ensure learning continuity, even in unforeseen circumstances.
Regular evaluation of the impact of technologies.	Monitor and adjust teaching strategies based on the use of technologies, taking into account student performance and feedback.
Teacher training in educational technologies.	Provide training to teachers in the use of technologies to maximize their effectiveness in the classroom.
Personalization of learning.	Adapt technologies to individual students' needs to optimize educational outcomes.

5. Conclusions

- The systematic review suggests that the implementation of advanced technologies in the teaching of morphology has a positive impact within medical education.
- The use of digital and virtual microscopes, 3D models, interactive platforms and multimedia resources has significantly improved academic performance and the understanding of complex anatomical structures. In addition, these tools foster motivation, engagement and autonomy in learning, allowing for more active participation of students.
- The development of technical skills has also been aided by the use of these technologies, better preparing students for clinical settings.
- The accessibility of digital resources allows for flexible and personalized learning, improving academic preparation.
- Although some studies showed no significant differences in academic performance, no negative effects related to technology use were reported.
- Further long-term research is recommended to assess their sustained impact and explore the customization of these tools to optimize their effectiveness in teaching morphology.

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References.

1. Inzunza O, Koenig C, Salgado G. *Human Morphology.* UC Editions: Santiago, Chile, 2017. ISBN: 978-956-14-2043-4. https://isbn.cloud/9789561420434/morfologia-humana/
2. Bravo A. Anatomy has evolved: teaching and learning anatomy in the 21st century. What has changed? *Morfolia* , *2019, 11* (1), 3-10. https://revistas.unal.edu.co/index.php/morfolia/article/view/80518/71244
3. Carpio E. Teaching microscopic anatomy without microscopes. *Educ Med Super, 2020, 34* (2). http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S0864-21412020000200021 .
4. Mompeó B. Methodologies and materials for learning human anatomy: perceptions of 'digital native' medical students. *FEM: Journal of the Medical Education Foundation* , 2014, 17(2), 99-104. https://scielo.isciii.es/scielo.php?script=sci_arttext&pid=S2014-98322014000200007 .
5. Emadzadeh A, EidiBaygi H, Mohammadi S, Etezadpour M, Yavari M, Mastour H. Virtual Dissection: an Educational Technology to Enrich Medical Students' Learning Environment in Gastrointestinal Anatomy Course. *Med Sci Educ* , 2023, 33, 1175-1182. https://doi.org/10.1007/s40670-023-01867-z
6. Page MJ, McKenzie JE, Bossuyt PM, et al. PRISMA 2020 statement: a guideline for systematic review. *Rev Esp Cardiol* , 2021, 74(9), 710-713. https://www.revespcardiol.org/es-declaracion-prisma-2020-una-guia-articulo-S0300893221002748
7. Becerra DG, Grob LP, Rodríguez RÁ, Barker MM. Academic achievement and perception of two teaching methods in histology: Light and digital microscopy. *Int J Morphol* , 2015, 33(3), 811-816. http://dx.doi.org/10.4067/S0717-95022015000300001
8. Hsiao CC, Tiao MM, Chen CC. Using interactive multimedia e-Books for learning blood cell morphology in pediatric hematology. *BMC Med Educ* , 2016, 16(1), 290. https://doi.org/10.1186/s12909-016-0816-9
9. Donkin R, Askew E, Stevenson H. Video feedback and e-Learning enhances laboratory skills and engagement in medical laboratory science students. *BMC Med Educ* , 2019, 19(1), 310. https://doi.org/10.1186/s12909-019-1745-1
10. Zhang S, Chen F. The Effects of Computer-Aided Animation Technology in the Teaching of Hematological Medicine. *CAD Comput Aided Des Appl* , 2021, 18(S3), 58-69. https://doi.org/10.14733/cadaps.2021.S3.58-69
11. Alzahrani AAH, Alhassan EM, Attia MA, Albanghali MA. Enhancing dental carving skills of preclinical dental hygiene students using online dental anatomy resources. *Open Dent J* , 2019, 13(1), 499-504. https://doi.org/10.2174/1874210601913010499
12. Becerra D, Grob L, Assadi JL, Astorga C, Tricio J, Melelli R, Silva C, Sabag N. Academic Achievement and Perception of Two Teaching Methods in Histology: Light and Digital Microscopy. Pilot Study. *Int J Morphol* , 2018, 36(3), 811-816. http://dx.doi.org/10.4067/S0717-95022018000300811
13. Felszeghy S, Pasonen-Seppänen S, Koskela A, Nieminen P, Härkönen K, Paldanius KMA, Gabbouj S, Ketola K, Hiltunen M, Lundin M, Haapaniemi T, Sointu E, Bauman EB, Mahonen A. Using online game-based platforms to improve student performance and engagement in histology teaching. *BMC Med Educ* , 2019, 19(1), 273. https://doi.org/10.1186/s12909-019-1701-0
14. Odeh H, Kaddumi EG, Salameh MA, Al-Khader A. Interactive Online Practical Histology Using the Poll Everywhere Audience Response System: An Experience During the COVID-19 Lockdown. *Int J Morphol* , 2022, 40(1), 102-106. https://doi.org/10.4067/S0717-95022022000100102
15. Schoenherr DT, Dereski MO, Bernacki KD, Khayyata S, Attardi SM. Development and evaluation of an online integrative histology module: simple design, low-cost, and improves pathology self-efficacy. *Med Educ Online* , 2022, 27(1), 2011692. https://doi.org/10.1080/10872981.2021.2011692
16. Ullah R, Siddiqui F, Adnan S, Afzal AS, Zafar MS. Assessment of blended learning for teaching dental anatomy to dentistry students. *J Dent Educ* , 2021, 85(7), 1301-1308. https://doi.org/10.1002/jdd.12606
17. Zoia S, et al. Impact of COVID-19 Pandemic on Academic Process in Higher Medical Institutions: Optimal Model of Organization and Methodology of Teaching under Quarantine Conditions. *J Educ Soc Res* , 2023, 13(2), 93-100. https://doi.org/10.36941/jesr-2023-0119
18. Rinaldi VD, Lorr NA, Williams K. Evaluating a technology supported interactive response system during the laboratory section of a histology course. *Anat Sci Educ* , 2017, 10(4), 328-338. https://doi.org/10.1002/ase.1667
19. Halalsheh, R., Al-Rawashdeh, A., & Rababah, E. (2023). Medical students' perceptions of factors that Impact their performance in human physiology course: suggestions for improving course presentation. BMC Medical Education, 23(1), 705. https://doi.org/10.1186/s12909-023-04661-y

20. Montané, E., Vilaplana, C., Riera, J., Pujol, M., Méndez, M., Mas, A., Vara, A., & Parés, D. (2023). Medical students' opinion of their learning process. Medical Science Educator, 33(5), 1183–1190. https://doi.org/10.1007/s40670-023-01873-1
21. Kok, D.L., Dushyanthen, S., Peters, G., Sapkaroski, D., Barrett, M., Sim, J., & Eriksen, J.G. (2022). Screen-based digital learning methods in radiation oncology and medical education. Technical Innovations & Patient Support in Radiation Oncology, 24, 86–93. https://doi.org/10.1016/j.tipsro.2022.10.003
22. Jenkins S, Goel R, Morrell DS. Computer-assisted instruction versus traditional lecture for medical student teaching of dermatology morphology: A randomized control trial. *J Am Acad Dermatol* , 2008, 59(2), 255-259. https://doi.org/10.1016/j.jaad.2008.04.026
23. Sneiderman CA, Cookson JP, Hood AF. Use of computer graphic images in teaching dermatology. *Comput Med Imaging Graph* , 1992, 16(3), 151-152. https://doi.org/10.1016/0895-6111(92)90069-L
24. Heinze, A., Basulto-Martinez, M., Suárez-Ibarrola, R. 3D printing and its benefits in the field of medical education, training and patient counseling. *Rev. Esp. Edu. Med.* , 2020, 1(1), 1-8. https://doi.org/10.6018/edumed.421221