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Effect of teaching tools in spatial understanding in health science education: A systematic review
Intérêt des outils pédagogiques d'aide à la perception spatiale dans l'enseignement des sciences de la santé : revue systématique

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Article abstract

Background: The concept of spatial orientation is integral to health education. Students studying to be healthcare professionals use their visual intelligence to develop 3D mental models from 2D images, like X-rays, MRI, and CT scans, which exerts a heavy cognitive load on them. Innovative teaching tools and technologies are being developed to improve students' learning experiences. However, the impact of these teaching modalities on spatial understanding is not often evaluated. This systematic review aims to investigate current literature to identify which teaching tools and techniques are intended to improve the 3D sense of students and how these tools impact learners' spatial understanding.

Methods: The preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines were followed for the systematic review. Four databases were searched with multiple search terms. The articles were screened based on inclusion and exclusion criteria and assessed for quality.

Results: Nineteen articles were eligible for our systematic review. Teaching tools focused on improving spatial concepts can be grouped into five categories. The review findings reveal that the experimental groups have performed equally well or significantly better in tests and tasks with access to the teaching tool than the control groups.

Conclusion: Our review investigated the current literature to identify and categorize teaching tools shown to improve spatial understanding in healthcare professionals. The teaching tools identified in our review showed improvement in measured, and perceived spatial intelligence. However, a wide variation exists among the teaching tools and assessment techniques. We also identified knowledge gaps and future research opportunities.

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Reviews, Theoretical Papers, and Meta-Analyses

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Intérêt des outils pédagogiques d'aide à la perception spatiale dans l'enseignement des sciences de la santé : revue systématique

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Abstract

Background: The concept of spatial orientation is integral to health education. Students studying to be healthcare professionals use their visual intelligence to develop 3D mental models from 2D images, like X-rays, MRI, and CT scans, which exerts a heavy cognitive load on them. Innovative teaching tools and technologies are being developed to improve students' learning experiences. However, the impact of these teaching modalities on spatial understanding is not often evaluated. This systematic review aims to investigate current literature to identify which teaching tools and techniques are intended to improve the 3D sense of students and how these tools impact learners' spatial understanding.

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Résumé

Contexte : Le concept d'orientation spatiale fait partie intégrante de l'enseignement des professions de la santé. Les étudiants utilisent leur intelligence visuelle pour se représenter mentalement en 3D des images en 2D comme des radiographies, de l'IRM et des coupes tomodensitométriques, ce qui constitue une lourde charge cognitive. On développe actuellement des technologies et des outils pédagogiques innovants pour améliorer l'expérience d'apprentissage des étudiants. Cependant, l'impact de ces ressources pédagogiques sur la perception spatiale est rarement évalué. L'objectif de cette revue systématique de la littérature était de recenser les outils et techniques pédagogiques destinés à améliorer la perception 3D des apprenants et d'évaluer les effets de ces outils sur leur perception spatiale.

Méthodes : Suivant les lignes directrices PRISMA, nous avons consulté quatre bases de données avec des termes de recherche multiples, analysé les articles recensés en fonction de critères d'inclusion et d'exclusion, et évalué leur qualité.

Résultats : Dix-neuf articles correspondaient aux critères d'inclusion. Les outils pédagogiques axés sur l'amélioration de la perception spatiale peuvent être regroupés en cinq catégories. L'examen a révélé que les résultats obtenus par les groupes expérimentaux ayant utilisé l'outil pédagogique pour effectuer les tests et les tâches demandés sont aussi bons ou significativement meilleurs que les résultats obtenus par les groupes témoins.

Conclusion : Notre revue de la littérature visant à recenser et catégoriser les outils pédagogiques disponibles a montré que ces derniers améliorent la perception spatiale, notamment l'intelligence spatiale mesurée et perçue, des professionnels de la santé. Toutefois, il existe une grande variation entre les divers outils pédagogiques et techniques d'évaluation. Nous avons également relevé des lacunes dans nos connaissances et des pistes de recherche future.

Introduction

Spatial ability, also known as spatial intelligence, or visual intelligence, is defined as "the ability to generate, retain, retrieve, and transform well-structured visual images."[1] Helping learners develop a mental model of an object and its interaction with its surrounding has always been the key to teaching many subjects that are foundational to health professional education, including anatomy and physiology.[2,3] Thus, spatial intelligence is an essential aspect of health professional education. The ability to build a mental model by orienting an object in one's mind needs a conceptual arrangement of the elements of that object and the ability to determine the 3D orientation of the elements in relation to one's body,[4] indicating the possibility of some people being better than others in this skill. Genes, hormones, gender, age, and environment can cause individual differences in spatial abilities, and this skill can be significantly improved by training.[4-7] Developing a clear understanding of the spatial relationship of the anatomical structure is a crucial part of medical, dental, and allied health professional education.[8,9] Students studying to be healthcare professionals use their visual intelligence to develop a three-dimensional mental model from two-dimensional images from tools including x-rays, magnetic resonance imaging (MRI), and computed tomography (CT).[9]

Computer-based 3D models have more benefits than the traditional pedagogical approaches of teaching anatomy and can improve spatial understanding.[9] One study showed that when 3D models are presented to students at a fixed angle, there is a significant disadvantage to students with poor spatial abilities.[8] Another showed that when learners can control the rotation of the 3D computer model with a hand-held mouse, their spatial understanding is improved, suggesting that learner control as an essential key to successfully integrating complex spatial information.[10]

Virtual and augmented reality (VR and AR) are two new technologies with the immense potential to improve learners' spatial ability when used as a teaching tool. These technologies can either offer the experience of being present in the virtual world (VR) or incorporate a digital object in our natural world (AR). VR applications enable users to spatially visualize and interact with 3D objects in a virtual world,[11] a beneficial feature for medical, primarily surgical education. In recent years, VR, AR and other technology-infused teaching tools have been widely available in health professional education. However, the effectiveness of these teaching tools on different aspects of learning is not well documented, and thus no consensus exists regarding the advantages of these teaching tools. In this context, a careful evaluation of the current literature is needed to identify the evidence-based impact of these teaching tools on students' learning.

From a theoretical perspective, teaching anatomy and physiology using conventional methods (e.g., 2D images, static bench-top models) places heavy cognitive loads on students to form mental reconstructions of complex structure and dynamic cellular events.[12,13] The Cognitive Load Theory suggests that learning becomes difficult when the brain's limited resources are taxed due to the intrinsic and extrinsic loads of the subject matter.[14] An educator can play an active role in reducing the extrinsic load of the students. Many technology-infused teaching tools can provide additional visualization of the 3D anatomical structures, that instructors can use to help students reduce the extrinsic load of forming a mental model. Constructivist learning theory also supports the use of interactive and immersive tools. Constructivism states that learning occurs when the individual interacts with their environment. Integration of this interaction with learners' existing knowledge allows them to construct new meaning and understanding.[15,16]

Our systematic review aimed to investigate current literature to identify which tools or teaching pedagogy are designed to improve students understanding of 3D models and how these tools affect students' spatial performance. Our specific research questions are as follows:

(i) What tools are being used in health professions education improve spatial intelligence?

(ii) How are the tools evaluated for the effectiveness of improving spatial intelligence?

(iii) How effective are these tools in improving spatial intelligence?

Methods

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines for our systematic review.[17] The Medical Education Research Study Quality Instrument (MERSQI) tool was used to assess the quality of the studies included in the review.[18]

Search strategy

We searched four databases that were most relevant to our search questions: PubMed, CINAHL, Web of Science, and Education Research Complete. The search was performed in July 2021 and included all the articles published between 2011-2021. Because of the rapid evolution of VR and AR technologies, we limited our search to a 10-year bracket to capture the widespread application, and incorporation of VR, AR, and other high-tech teaching modalities in health professional education curriculum. We employed a free text strategy to search the databases using combinations of the following terms: "teaching tool," "learning tool," "spatial understanding," "mental rotation," "3D understanding." The search parameters of the free text terms and the results of combining different search terms are listed in Table 1.

Table 1. Details of search terms and search results

Search Parameters			
Free text term	PubMed search parameters		
Teaching tool	("education"[MeSH Subheading] OR "education"[All Fields] OR "teaching"[All Fields] OR "teaching"[MeSH Terms] OR "teaches"[All Fields] OR "teach"[All Fields] OR "teachings"[All Fields] OR "teaching s"[All Fields]) AND "tool"[All Fields]		
Learning tool	("learning"[MeSH Terms] OR "learning"[All Fields] OR "learn"[All Fields] OR "learned"[All Fields] OR "learning s"[All Fields] OR "learnings"[All Fields] OR "learns"[All Fields]) AND "tool"[All Fields]		
Spatial understanding	("spatial"[All Fields] OR "spatialization"[All Fields] OR "spatializations"[All Fields] OR "spatialized"[All Fields] OR "spatially"[All Fields]) AND ("comprehension"[MeSH Terms] OR "comprehension"[All Fields] OR "understand"[All Fields] OR "understanding"[All Fields] OR "understands"[All Fields] OR "understandability"[All Fields] OR "understandable"[All Fields] OR "understandably"[All Fields] OR "understandings"[All Fields]		
Mental rotation	("mental"[All Fields] OR "mentalities"[All Fields] OR "mentality"[All Fields] OR "mentalization"[MeSH Terms] OR "mentalization"[All Fields] OR "mentalizing"[All Fields] OR "mentalize"[All Fields] OR "mentalized"[All Fields] OR "mentally"[All Fields]) AND ("rotate"[All Fields] OR "rotated"[All Fields] OR "rotates"[All Fields] OR "rotating"[All Fields] OR "rotation"[MeSH Terms] OR "rotation"[All Fields] OR "rotations"[All Fields] OR "rotational"[All Fields] OR "rotator"[All Fields] OR "rotators"[All Fields])		
3D understanding	"3D"[All Fields] AND ("comprehension"[MeSH Terms] OR "comprehension"[All Fields] OR "understand"[All Fields] OR "understanding"[All Fields] OR "understands"[All Fields] OR "understandability"[All Fields] OR "understandable"[All Fields] OR "understandably"[All Fields] OR "understandings"[All Fields])		
Search Results			
Search Terms	Database	Number of Papers	Year
Teaching tool AND Spatial understanding	PubMed	101	2011-2021
Teaching tool AND Mental rotation	PubMed	25	2011-2021
Learning tool AND 3D understanding	PubMed	109	2011-2021
Teaching tool AND Spatial understanding	CINAHL	10	2012-2020
Teaching tool AND Mental rotation	CINAHL	5	2011-2021
Learning tool AND 3D understanding	CINAHL	32	2011-2021
Teaching tool AND Spatial understanding	Web of Science	150	2011-2021
Teaching tool AND Mental rotation	Web of Science	16	2011-2021
Learning tool AND 3D understanding	Web of Science	287	2011-2021
Teaching tool AND Spatial understanding	Education Research Complete	45	2011-2021
Teaching tool AND Mental rotation	Education Research Complete	15	2011-2021
Learning tool AND 3D understanding	Education Research Complete	74	2011-2021
	Total	869	

Inclusion and exclusion criteria

To answer our specific research question, we included studies that evaluated the spatial understanding of learners. According to our established inclusion-exclusion criteria (Table 2), articles were screened in three steps: (i) Based on title only, (ii) Based on abstract, and (iii) Full article review. The study selection process is outlined in Figure 1. Our final inclusion includes research articles that focused on assessing the effectiveness of a teaching tool, modality, or pedagogical approach designed to improve the spatial understanding of healthcare professional education. One author (NS) did the article screening (all three steps) and assessment of the study quality using the MERSQI tool. Two authors (NS and AC) sequentially contributed to the article review (Step iii). As Step iii was performed sequentially, no discrepancies occurred.

Data extraction

We extracted data from the eligible studies focusing on study design, research participants, areas of interest, type of teaching tool used, assessment of the learners' spatial understanding, and the study's key outcomes. After data extraction from the literature to the chart (Appendix A, Table 4), the results relevant to the research questions were synthesized.

Table 2. Inclusion and exclusion criteria

	Inclusion	Exclusion
Language	English	Non-English
Year of study	Studies published between 2011-2021	Studies published before 2011
Study focus	Health professional education	Non- health professional education
	Didactic/Surgery/Simulation	Technical drawing, mathematics, geography, physics, astronomy, engineering
	Tools to improve education	Tools to improve patient care, clinical practice.
		Wet lab studies, review articles
	Studies to assess spatial understanding of learners	Only describing the teaching tool, without assessment.
		Assessing engagement, academic performance, satisfaction.
	Graduate and Undergraduate post-secondary education	K-12 education, graduate education
Study design	Any	None
Setting	Any	None
MERSQI score	5 or higher	Below 5

Assessment of study quality

We used the Medical Education Research Study Quality Instrument (MERSQI) tool to assess the quality of the studies included in our review.[18] MERSQI quantitatively evaluates quantitative studies in six domains: study design, sampling, type of data, validation of evaluation instrument, data analysis, outcomes measured.[18] This is a validated and widely used tool that scores an article between five (lowest quality) to 18 (highest quality).[19] The articles included in our review scored from seven to 15. The detail of the assessment of study quality is shown in Appendix A, Table 5.

Results

Review flow

The initial search identified 869 articles from four databases (PubMed, CINAHL, Web of Science and Education Research Complete). The first screening removed 34 duplicates, keeping 835 articles for review by title only. Screening by title removed 669 articles that were either wet-lab research, unrelated to education, unrelated to health science, or involved in K-12 education. Screening by title retrieved 166 potential articles to be reviewed by abstract. Abstract inspection removed 117 pieces of literature primarily for not being related to health education or not assessing spatial understanding among learners. We had 49 articles selected for full-text evaluation, during which, 30 articles were removed primarily for not addressing our research questions, finally incorporating 19 studies in our systematic review. Details of the review flow are included in Figure 1.

Features of the reviewed studies

Our review includes 19 research articles, 89% (n = 17) of which used quantitative research methods including, evaluating pre-test to post-test differences, scores in author-designed tests or formal academic examinations, or surveys based on Likert scales to collect data. Only 11% of our qualified articles (n = 2) followed a mixed-method study design, collecting both quantitative (test scores, survey) and qualitative (focus groups) data. Most of the studies (68 %, n = 13) were from medical schools, 10 % (n = 2) from dental schools, 5% each (n = 1) from nursing and veterinary schools. The remaining 10% (n = 2) were from other health professional programs (biomedical science and kinesiology). The 13 studies that concentrated on medical education focused on surgery (n = 8). A specific breakdown of areas of interest is shown in Figure 2. As our selected articles used either quantitative or mixed-method studies, we used the MERSQI tool to assess the quality of our included articles. The mean MERSQI score of our studies was 11.9 (range: 7.0-15.0), which falls within the range identified as being acceptable.[13]

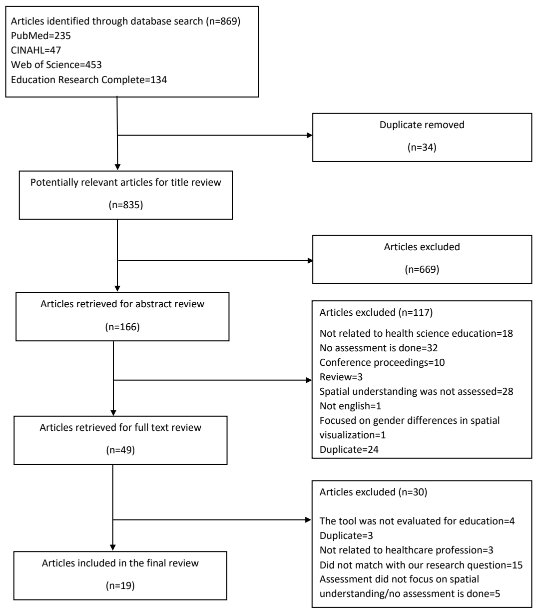

Figure 1. Flow diagram explaining the study selection process

Teaching tools and techniques used

Our systematic review identified teaching tools and pedagogical approaches designed to improve the spatial understanding in healthcare professional education. We have categorized these tools as i) 3D printed models, ii) 3D reconstruction of 2D CT images, iii) VR-based models, iv) 3D digital animations, and v) others that included tools that did not fit within any of our categories.

3D printed models. 3D printing is expected to revolutionize health care and health science education.[15] It is a manufacturing method in which any imaginable 3D shape can be created by depositing materials such as plastic or metal in layers.[20,21] To print a 3D object, users need to design and define the object's structure in a computer-aided design (CAD) file.[20] Five studies included in our systematic review created 3D printed anatomical models for medical education (Appendix A, Table 4, Table 5).[23,27,33,39,40]

3D reconstruction of 2D CT images. Radiologists often find it challenging to diagnose based on axial CT images alone as they lack information on the third dimension (e.g., sagittal, and coronal dimensions).[41] The application of 3D computer rendering algorithms allowed the formation of images in the third dimension from data acquired in the axial plane, which is improved significantly by the recent development of multidetector CT scanners.[41] 3D reconstructed CT images were used by five studies that are included in our review (Appendix A, Table 4; Table 5).[26,28,31,32,39] Wada et al. (2019),[31] for example, selected six patients who underwent laparoscopic transabdominal pre-peritoneal repair (TAPP) surgery. The preoperative CT images of those patients were used for 3D reconstruction and used as a teaching tool for surgery students.[31]

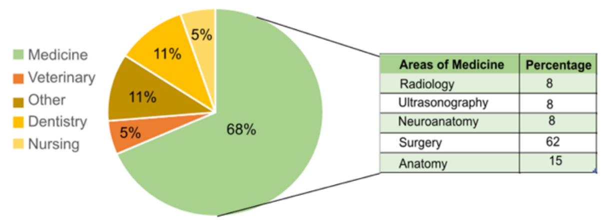

Figure 2. Field of interest in literature included in the systematic review.

60% of the studies included in this review are focused on the learners from medical schools. The remaining includes dentistry, nursing, veterinary science, and other areas of health science education. Literature that broadly focused on medical education is further explored to specific filed of interest. Within medical education, 62% studies focused on learners from the division of surgery, and 15 % focused on anatomy. Other field of interest includes radiology, ultrasonography, and neuroanatomy.

Virtual Reality based models (VR models). Three studies included in our review used VR-based models as an educational tool.[24,35,38] A VR-enhanced ultrasonography training program was designed for medical students to teach ultrasonography using a virtual model of the human body.[24] For another human anatomy class of medical students, a VR-based teaching platform was created in which the students could interact with the virtual human model, identify anatomical structures on a computer-generated cadaveric specimen, and then draw these structures on a virtual skeleton using a 3D drawing tool.[38] The detail of the three VR-based teaching tools is found in Appendix A, Table 4 and Table 5.

3D digital animation. Two studies used 3D digital animation to create a dynamic visualization platform of anatomical structure and physiological processes (Appendix A, Table 4, and Table 5).[30,37] Hoyek et al. (2014) used 3D animations to teach human anatomy to undergraduate health science students.[37] Gao et al., 2020 studied the effectiveness of a 3D animated model of a pregnant horse to teach an obstetrics course to veterinary students.[30]

Table 3. Summary of teaching tools, learners, and the learners' feedback

Teaching Tools	Learners	Findings
3D printed models		
Models of acetabular fractures (Awan et al., 2019)[23]	Radiology residents	Post-test scores were higher for students who received 3D models during lectures.
Models of congenital heart disease (Biglino et al., 2017)[27]	Cardiac nurses	80% of the students thought that 3D models helped in the appreciation of overall anatomy.
Model of the bladder (Fan et al., 2019)[40]	Surgery students	Students who used the model showed better accuracy in understanding the spatial structure of the bladder.
Model of Cleft lip and palate (CLP) (AlAi et al., 2018)[33]	Surgery students	The use of 3D printed models significantly improved the mean test scores of students.
Model of synostosis (Lane et al., 2020)[39]	Surgery students	The survey showed that students using 3D printed models improved their understanding of the surgical approach.
3D reconstruction of 2D CT images		
Pancreatic cancer patients (Lin et al., 2020)[32]	Surgery students	Students who learned with 3D images performed better in questions regarding tumor staging and surgery planning.
Patients from transabdominal pre-peritoneal repair surgery (Wada et al.,2020)[31]	Surgery students	Survey results showed that most students could understand the surgery anatomy by the 3D simulation extremely well.
CT of head and neck vascular anatomy (Cui et al., 2017)[36]	Medical students	Students who used the stereoscopic 3D models increased their ability to identify the head and neck vascular anatomy correctly.
CT from patients to generate head and neck anatomy (Yao et al., 2014)[26]	Surgery students	The survey suggests improvement in the perceived understanding of the anatomy after the 3D educational module session.
CT from patients to generate head and neck anatomy (Yeo et al., 2018)[28]	Surgery students	Students with 3D models took a shorter time to complete the surgery plan.
VR Models		
VR model of the human body (Hu et al., 2020)[24]	Ultrasonography students	Students who used the VR model showed significantly higher scores in ultrasonography performance tests.
Interactive VR platform (Kolla et al., 2020)[38]	Medical students	Students responded in a survey that the VR platform improved their 3D understanding.
Second Life (Morales-Vadillo et al., 2019)[35]	Dentistry students	Students who used Second Life (SL) scored significantly higher in questions designed to test the spatial interpretation of the anatomical structure.
3D digital animation		
Human anatomy (Hoyek et al.,2014)[37]	Undergraduate health science students	The students, who studied with 3D digital animation scored higher in questions that required spatial ability.
3D animated model of a pregnant horse (Gao et al., 200)[30]	Veterinary students	The use of 3D animated model significantly increased the students' final examination scores.
Others		
3D tooth morphology quiz (TMQ) app (Lone et al., 2019)[22]	Dentistry Students	No difference in test scores between students who used, or did not use the app. Students with low MRT scores gradually performed better in tests after using the app.
Clay modeling (Akle et al., 2018)[25]	Neuroanatomy students	Quiz scores of students who constructed the models were significantly higher than students who studied with traditional methods.
Digital surgical microscope to transmit a high-resolution 3D image (Weiss et al., 2021)[29]	Surgery students	75% of the participants agreed that 3D visualization was more useful to identify anatomical structures.
3D Atlas of Human Embryology (Chekrouni et al., 2020)[34]	Biomedical students	The class that used 3D Atlas showed significantly higher exam scores.

Others. We identified some teaching tools that did not fit within the abovementioned categories. A 3D tooth morphology quiz is a computer application that allows students to study tooth morphology from multiple viewpoints and levels of magnification. Students can interact with the app and rotate the 3D tooth image to obtain a spatial understanding of the different surfaces of the tooth.[22]

Akle et al. (2018) asked students to build a clay model of a specific anatomical structure of the brain. After the model building activity, students were asked to take a computer-based activity where they had to identify the brain's structures in 2D images.[25]

Weiss et al. (2020) used a digital surgical microscope to transmit a high-resolution 3D image as a teaching tool for the surgery students. The students observed the live surgical procedures with passive (polarized) 3D glasses in real-time.[29]

The 3D Atlas of Human Embryology (3D Atlas) is a freely available online collection of interactive 3D computer files in Portable Document Format (PDF) representing developing human embryos.[34] These interactive digital 3D models of developing embryos can be rotated, manipulated in 3D space, and interactively viewed from all sides.[34]

Assessment of spatial understanding

The studies included in our review evaluated learners' spatial understanding in one of the following ways:

(i) By evaluating test-scores, specially designed with questions that require 3D comprehension to answer

(ii) By assessing the accuracy of a given task needing spatial intelligence to perform

(iii) By correlating student performance and mental rotation test (MRT)

(iv) By analyzing student perception

(i) By evaluating test-scores, specially designed with questions that require 3D comprehension to answer. Thirteen studies evaluated students' test scores to evaluate their ability to answer the questions that require spatial intelligence.[22-26,32-37,39,40] To assess the teaching tool of interest, researchers compared pre-test and post-test scores or compared test scores between experimental and control groups (Appendix A, Table 4).

(ii) By assessing the accuracy of a given task needing spatial intelligence to perform. Two studies assessed teaching tools for surgery students by evaluating the accuracy and required time for surgery planning using that tool.[28, 40] Yeo et al. 2017 provided surgery students with 3D reconstructions of preoperative CT images.[28] Fan et al., 2019 assessed the accuracy of the surgical plan by groups of students who either used or did not use the 3D printed model as a teaching and learning tool.[40]

(iii)By correlating student performance and mental rotation test (MRT). Two studies included in this review evaluated the correlation between learners' Mental Rotations test (MRT) scores and their performance in tests.[22,36] All participants were allowed to take the MRT in one study, where male students scored significantly higher than female participants. In the first test (tooth morphology questions that require spatial ability to answer), male students outperformed female counterparts, indicating a positive correlation between the test performance and MRT scores. After using the computer application called the 3D tooth morphology quiz (TMQ) app for three weeks, the students took another test, where the difference between male and female participants disappeared. The authors concluded that the improved performance in female participants in assessments could result from training with the application (TMQ) and increased familiarity with the material.[22] Another study found that students with a low spatial ability (low score in MRT) improved their post-test scores to a level of students with a higher spatial ability (high score in MRT) after using the 3D model as a learning tool.[36]

(iv)By analyzing student perception. Student perception of their 3D intelligence was another essential assessment tool used by several studies. Thirteen studies included in our review collected and analyzed student perception data either from surveys (quantitative data) or focus groups (qualitative data) (Appendix A, Table-4).[25-34,38-40]

Effect of the teaching tools in spatial understanding

The research groups have taken several approaches to evaluate the effectiveness of the teaching tools in developing or improving learners' spatial intelligence. Although the assessment tools varied widely among literature, the application of technology is shown to positively impact the overall spatial understanding of the students.

To assess the impact of 3D printed models, several evaluation methods were used, including the comparison between pre-test and post-test scores;[23] evaluation of the accuracy of a given task,[40] performance in test questions specially designed to assess learners spatial understanding,[33,39] and surveys to collect student perception of their learning.[40,39,33,27] Awan et al., 2019[23] reported that the post-test scores were higher for students who received 3D printed models during their lecture than the group that did not. Students who used 3D printed models as learning modality scored significantly higher[33] or similar[39] in tests compared to the control group, who did not have access to the 3D printed models. Fan et al. (2019)[40] divided surgery students into groups to limit their access to 3D printed models as an additional tool that can aid in surgical planning. The study found that the student group who could use both CT images and 3D printed models showed higher accuracy in their given task to plan the surgery. Survey results confirm that 3D models improved students' visualization, understanding of spatial orientation, comprehension of anatomically complex structures, and overall learning experience.[27,33]

Multiple studies in our review used computer-based 3D models reconstructed from the 2D CT images (Appendix A, Table 4). When used as a tool to aid in surgical planning, Yeo et al. (2017) and Lin et al. (2019) found that most surgery residents perceived that 3D models improved their confidence with the surgical plan.[28, 32] In a similar study by Wada et al. (2020), self-report survey results showed that reconstructed 3D simulations helped most surgery students to understand the surgery anatomy exceptionally well (40%) or very well (47%).[31] Yao et al. (2014) reported that the learners recognized that the addition of 3D imaging accelerated their understanding of sinus anatomy.[26] Students who learned with 3D images performed better in questions related to tumor staging and surgery planning[32] and increased their ability to correctly identify the head and neck vascular anatomy,[36] indicating an improvement in their 3D perception. Cui et al. (2017)[36] reported that 3D models improved the post-test scores of students with weaker spatial intelligence.

Questions designed to assess learners' spatial understanding[35,24] and surveys to collect students' perceptions of their 3D intelligence[38] were used to evaluate VR-based teaching tools. Hu et al. (2020) reported that the students in the experimental group who used a VR model of the human body scored significantly higher than the control group in ultrasonography performance tests, which requires spatial understanding. The finding of Hu and his colleagues indicates that the VR model of the human body facilitated 3D conceptualization and thus led to faster and better development of ultrasonographic competency.[24] Similarly, the dentistry students who used Second Life (SL), a VR-based interactive learning platform, scored significantly higher than the control group in questions designed to test the spatial interpretation of the anatomical structure.[35] When questioned about learners' perception of their 3D understanding, Kolla et al. (2020)[38] found that 78.6% of the participants reported that VR was "much better" than lecture for learning 3D anatomical relationships.

Students who had access to 3D digital animations scored higher in questions requiring spatial ability.[37] Using a 3D animated model in a veterinary course significantly increased students' final examination scores compared to the previous year's cohort. A survey identified students' agreement that the 3D animation tool improved their ability to understand the spatial orientation of the anatomical structure.[30]

Lone et al., 2018 randomly divided students into two groups, one used the 3D tooth morphology quiz (TMQ) application, and the other group used extracted real teeth to study tooth morphology. The two groups showed no significant differences in their mean exam scores; however, a positive correlation was found between students' performance on the tooth morphology quiz (TMQ), and scores on the final examination. In this study, male participants scored significantly higher than female participants in the mental rotation test (MRT) initially taken by the participants. Male participants also scored higher than the female counterparts in the first mock assessment, although this difference disappeared in later examinations.[22]

The activity of making clay model improved the test scores of the students compared to the control group, who studied with traditional methods. Focus group discussions also revealed that the modeling activity reduced the students' time spent studying the topic and increased their understanding of spatial relationships between structures in the brain.[25]

Weiss et al., 2020 used a digital surgical microscope with the capability to transmit a high-resolution 3D image allowing students to observe the live surgical procedures with passive (polarized) 3D glasses in real-time. Survey results showed that 75% of the students agreed that 3D visualization of the surgical field was more helpful in identifying the anatomical topography and structures than 2D representation.

The application of the 3D Atlas, a collection of interactive 3D models of the human embryo, positively impacted students' learning experience. The class that used the 3D Atlas showed significantly higher exam scores. Moreover, in the survey, 71% of the students agreed that the 3D atlas led to a better understanding of embryology.[34]

A summary of the different groups of teaching tools, the learners, and the learner's feedback is represented in Table 5. Teaching tools from all the groups have positively impacted students' learning and scores in tests requiring spatial understanding. Certain tools improve accuracy, confidence, and reduce surgery planning time for surgery students and residents. Survey and focus group data indicate student satisfaction and perceived improvement in spatial understanding.

Discussion

Our systematic review investigated current literature to identify teaching tools used in healthcare education to improve students' spatial understanding. We grouped the educational tools into five major categories: 3D printed models; 3D reconstruction of 2D CT images; virtual reality-based models (VR models); 3D digital animation; and others. The wide variation among the teaching tools is evident, including the most cutting-edge VR models and simple techniques like clay modeling or animated videos. Technologies are rapidly being incorporated in health professional education. Our review identified the positive impact of more straightforward techniques on improving students' spatial intelligence.

When the effectiveness of a teaching tool was evaluated by comparing between control and experimental group, studies reported that with access to the teaching tools, the experimental groups performed equally well or significantly better in tests and tasks than the control group. No negative impacts were reported. Although this improved or maintained academic performance is attractive, one should be cautious in drawing conclusions, as less than half (47.3%) of the included studies conducted randomized controlled trials. Many studies reporting positive impacts of a teaching tool conducted single-group post-test only or single-group cross-sectional studies (Table 4). A small number of high-quality control groups and a wide variation of teaching tools limits recommendations for evidence-based teaching practice.

One of major weakness of the studies, included in this review is the absence of theory-driven application and evaluation of educational technologies. One of the purposes of educational theories is to predict learning outcomes and explain their underlying mechanisms. Our review reveals that theoretical considerations were omitted in most studies and future work must include clear and meaningful connections to educational principles and theories.

Most studies focused on measured outcomes like knowledge acquisition and skill development. Scores of specially designed tests or the accuracy of completing a task requiring spatial intelligence were measured to evaluate the effectiveness of a teaching tool. Several studies reported reaction level outcomes, reporting student perception of increased confidence, satisfaction, and 3D understanding after using these technologies. Only two studies in our systematic review correlated students' performance with the mental rotation test (MRT). The teaching tools improved students' performance in spatially complex questions.[22,36] The findings of Lone et al. (2018)[22] and Cui et al. (2017)[36] may be explained by Cognitive Load Theory.[14] Students with low spatial intelligence (low score in MRT) face difficulty forming 3D mental pictures from a given 2D image. The technology eased this difficulty, where students could rotate a computer-generated or 3D printed model, which reduced the extrinsic load of forming mental pictures for those students. Lone et al. (2018) also supported this idea by suggesting that the increasingly better performance of female participants (who had significantly lower MRT scores than the male students) could be a result of training and increased familiarity with the material.[22] Spatial intelligence is a skill that can be acquired and improved by practice. Improvement in test scores or perceived improvement in mental rotation skills does not always reflect the ability of a teaching tool to benefit students with a lower capacity for spatial rotation (low scores in MRT). This knowledge gap needs to be addressed in future research.

Spatial intelligence is an integral part of medical education and an essential surgical skill. The majority of the literature included in our review revolved around surgery (Figure 2).

The most common surgical teaching tools included 3D reconstruction of 2D CT images and 3D printed models. 3D understanding is required by students from many other health professional disciplines like dentistry, veterinary medicine, and nursing. However, these groups are less represented and rarely included in studies. Future research should focus on evaluating the impact of these teaching tools on students from other health professional disciplines.

The quality of the included studies was evaluated using the MERSQI tool, which assesses an article based on study design, number of sample institutions, response rate, type of data, method of data analysis, outcome, and validity evidence for evaluation instrument (Table 2). The average MERSQI score of the studies included in this review is 11.9, indicating good quality of the research and the legitimacy of the results reported. The quantitative analysis studies had a large sample size and thus reported statistically significant findings. However, none of the included studies had valid evidence for evaluation, suggesting the scope of further research in this area.

The teaching tools identified in our review show improvement in the learners' spatial intelligence or perceived spatial intelligence. However, the wide variation among the assessment technique, study participants, and application areas makes direct comparison unrealistic between the teaching tools. Our findings also indicate that the application of teaching tools to improve spatial intelligence in medical education is a less explored area of educational research, and further studies are needed in this area.

Limitations

One major limitation of this study is that only one author (NS) did the article screening and assessment of the study quality using the MERSQI tool. However, two authors (NS and AC) contributed to the article review. We acknowledge that our findings are based on the few articles that met our inclusion criteria and are relevant to our research question. Readers must also be mindful that negative results may have been missed due to publication bias.

Conclusion

Our review identified teaching tools evaluated for their impact on spatial understanding in healthcare education. The application of technologies in creating models and modalities facilitates students' learning. By creating visual, interactive models, these tools have reduced the cognitive load students experience when forming complex anatomical mental models. Thus, using these tools can free cognitive resources for the student to examine dynamic relationships between elements. Our study identifies and provides collective information on available teaching tools shown to improve spatial learning. Medical educators may find this information valuable for choosing an appropriate teaching tool for their students. We believe our review will also be a helpful guide for developing, evaluating, and incorporating these teaching technologies into existing curriculum to improve students' spatial understanding.

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Appendix A.

Table 4. Detail of the studies included in the systematic review

Author, Year, Country	Research Method	Research Aim / Question	Research Participants	Area	Brief Description Of the study	Type of Tool	Assessment to measure the visual-spatial ability	Key findings
Lone et al., 2019[22] Ireland	Quantitative	To assess the effectiveness of the tooth morphology quiz (TMQ) as a teaching and learning tool.	50 2nd-year Bachelor of Dental Surgery (BDS) and 14 1st-year diploma in dental hygiene (DDH) students, 5 incompletes (removed) (*n* = 59)	Dentistry Dental hygiene	The participants completed a mental rotation test and a pre-study questionnaire at the beginning of the study. Participants were randomly assigned into two study groups A and B. Group A first accessed the TMQ app for three weeks to study tooth morphology. Students in Group B initially used extracted teeth to study. At the completion of the first block of three weeks, the participants completed a mock examination (Mock 1). After three-week, a post-test and a second mock examination were conducted (Mock 2). Finally, the students completed the final spot examination.	3D tooth morphology quiz (TMQ) app (Computer-based)	Test scores Mental Rotation Test	No significant differences are reported in mean exam scores between Groups A and B, but a comparison with the previous cohort showed significantly improved results. A positive correlation is found between student's performance on the tooth morphology quiz (TMQ), and scores on the final examination and mock assessment. Male participants scored significantly higher than female participants in the mental rotation test (MRT). Male participants also scored higher than the female counterparts in the first mock assessment, although this difference disappeared in later assessments. The increasingly better performance in female participants in mock 2 and final assessments could be a result of training, and increased familiarity with the material.
Awan et al, 2019[23] USA	Quantitative	Explored the benefit of 3D printed models in radiology resident training	22 radiology residents Medical school	Radiology	22 radiology residents were randomly divided into two groups. Both groups received identical presentations. Residents in the experimental group received 3D printed models with which to interact during the presentation, while the control group did not. Both groups received a pre-test and a follow-up post-test three weeks later.	3D printed models	Test questions (Pre-test, post-test)	The post-test scores were significantly different between the experimental and control groups. The median of post-test scores was higher for the group that received 3D models during their lecture compared to the group that did not.
Hu et al., 2020[24] Taiwan	Quantitative	To assess the impact of VR anatomy instruction on the ultrasound	3rd-year medical students (n = 101)	Ultrasonography	The participants were randomly	3D VR model of human body	Test Questions	Participants in the experimental group showed significantly

		competency of novice learners			divided into an experimental (VR) and a control group (traditional). Participants in the VR group used VR as part of their training during the course. The participants in the control group took part in an ultrasound workshop of a similar design. The VR anatomy component was replaced with a review session using a digital atlas. At the end of the workshop, all participants were assessed using a standardized practical multi-station ultrasonography test.			higher scores in ultrasonography performance tests than the control group. The experimental group performed significantly better in six out of ten ultrasound tasks. The authors suggest that the 3D VR model of the human body facilitated the 3D conceptualization and thus led to faster and better development of ultrasonographic competency.
Akle et al, 2018[25] Colombia	Mixed	To examine how building a 3D-clay model affects learners' understanding of periventricular structures of the brain.	Undergraduate Medical students. (89 students in cohort 2013-II, and 62 students in cohort 2014-I). (n =151)	Neuroanatomy	In the control group (2013 cohort), the lecture was taught in one session using 2D images of the human brain and brain slabs in the anatomy laboratory. After four days, students' knowledge was assessed with a 15-question quiz. In the experimental group (2014 cohort), prior to the lecture, a homework assignment, which asked students to build a clay model of the periventricular structures. After the modeling activity, students were asked to take a computer-based activity where they had to identify the periventricular structures of the brain in 2D images. Students took a knowledge quiz four days after the lecture.	Clay modeling	Quiz Student perception (Focus group)	Quiz scores of students who constructed the models were significantly higher than the control group, who studied with traditional methods. Focus group discussion revealed that modeling activity reduced time spent studying the topic and increased understanding of spatial relationships between structures in the brain. The construction of 3D clay models in combination with autonomous learning activities were a valuable and efficient learning tool in the anatomy course.

					Both classes (2013 and 2014 cohorts) were asked to complete a survey about their perception of their abilities and difficulties in mentally rotating the structures.			
Yao et al, 2014[26] USA	Quantitative	To validate the use of 3D reconstruction of computed tomography (CT) for the training of medical students	4th-year medical students (n = 18)	Head and neck surgery	Participants received instruction of the sinus anatomy in two sessions, first through a 2D CT sinus scan review, followed by an educational module of the 3D reconstruction. After each session, participants rated their knowledge of the sinus and adjacent structures on a self-assessment questionnaire.	3D reconstruction of CT images	Survey Test score Student perception	Students' self-Assessment of knowledge suggest significant improvement in the perceived understanding of the anatomy after the 3D educational module session. Every student recognized that the addition of 3D imaging accelerated their education of sinus anatomy.
Biglino et al., 2017[27] UK	Mixed	To assess the feasibility of using 3D models of congenital heart disease (CHD) during a training course for cardiac nurses	Cardiac nurses (n = 100)).	Cardiology Nursing	The 3D models were displayed on a table outside the lecture room, participants were encouraged to access them throughout the five-day course. At the end of the course, participants were asked to complete a short questionnaire.	3D printed models	Survey Student perception	Students found that 3D models helped in the appreciation of overall anatomy (86%), spatial orientation (70%), and anatomical complexity after treatment (66%). There was no statistically significant difference between adult and pediatric nurses' responses.
Yeo et al, 2018[28] Canada	Quantitative	To determine if 3D reconstruction of preoperative CT/MR images helps resident-level trainees in making appropriate surgery plans.	14 Senior level surgical residents Medical school	Surgery Liver resection surgery	10 preoperative patients' CT/MR images were selected and divided into either 2D or 3D groups. The 2D group consisted of raw CT/MR images without the radiologist's report. The 3D group had digital reconstructions that can be rotated in all orientations to view the tumor(s). The Residents were asked to evaluate the images from the 10 cases and write down	3D reconstruction of preoperative CT/MR images	Survey Student perception	The resident from the 3D group took a shorter time to complete the surgery plan. 13 out of 14 residents found the 3D model was easier to use than the 2D. Most residents recognized that the 3D model improved their confidence with the surgical plan.

					the optimal surgical approach for each. Their surgical plan and time (seconds) needed for planning was recorded. The residents completed a pre-study and post- study questionnaire regarding their level of training.			
Weiss et al, 2021[29] Germany	Quantitative	To determine whether otorhinolaryngology trainees gain additional comprehension of the anatomical structures and the surgical site when 3D visualization is used.	Medical students (*n* = 112)	Surgery	Trainees observed the live surgical procedures with passive (polarized) 3D glasses in real-time. At the end of each course, participants were asked to complete a questionnaire that included six questions concerning the comprehension of the anatomy and the surgical steps compared to 2D visualization.	Digital surgical microscope with the capability to transmit a high-resolution 3D image	Survey Student perception	75% of the participants fully agreed to the statement that 3D visualization of the surgical field was more useful to identify the anatomical topography and structures compared to 2D representation.
Gao et al, 2020[30] China	Quantitative	To study the effectiveness of 3D animated model of a pregnant horse as a teaching tool for veterinary obstetrics course.	Total 885 Veterinary students. Exp group: 3rd year, 300 Control group: 275 4th year and 310 5th year students. (*n* =885)	Veterinary	All students received lectures with PowerPoint presentation. Only 3rd year students studied with 3D animated model. The students from 4th and 5th year received traditional teaching. By the end of term, all students were invited to participate in an anonymous survey. Final examination results were compared.	3D animation tool	Survey Student perception	The use of 3D animated model significantly increased the 3rd year students' final examination scores compared to the 4th- and 5th- year students. Students believed the 3D animation tool improved their ability to understand the presentation position and posture of the fetus.
Wada et al, 2020[31] Japan	Quantitative	To investigate the usefulness of the 3D imaging technique in laparoscopic TAPP as an educational tool for medical students	Medical students (*n* = 30)	Surgery	Most students previously studied the surgical anatomy from the textbook, and preoperative CT images. In this study, students were provided with the 3D reconstruction of preoperative computed tomography (CT) images from 6 patients who underwent laparoscopic transabdominal pre-peritoneal repair (TAPP) for inguinal hernia.	3D reconstruction of preoperative images	Survey Student perception	Survey results showed that most students could understand the surgery anatomy by the 3D simulation extremely well (40%) or very well (47%) and agreed on the usefulness of this procedure for learning anatomy.

					Students were asked to complete a survey.			
Lin et al., 2020[32] China	Quantitative	To assess the effectiveness of 3D visualized model as a teaching tool in tumor evaluation and surgery planning.	Medical students (*n* = 88)	Surgery	Surgical residents were randomly divided into two groups (computed tomography, CT) group and 3D group). The groups learned a sample case either on 3D reconstruction visualization tables or CT images. At the end of the course, both groups completed the same test consisting of two pancreatic cases with CT images as well as questionnaires.	3D reconstructions, created by 3D multitouch visualization table (MVT).	Imaging test and Questions Student perception	Students who learned with 3D image performed better in certain questions. For example, the mean scores for questions regarding tumor staging and surgery planning, were consistently and significantly higher in the 3D group. Participants in 3D group agreed that 3D technology was more beneficial in understanding and making surgery planning.
AlAi et al, 2018[33] UK Kuwait	Quantitative	To investigate the use of 3D-printed models in educational seminars compared to the traditional approach.	Medical students (*n* = 67)	Seminar on Cleft Lip and Palate (Department of Surgery)	Participants were randomized into 2 groups. Group 1 (control group) attended a seminar with a PowerPoint presentation. Group 2 (Experimental group) attended a seminar with the same PowerPoint presentation, but with a physical demonstration using 3D-printed models. Knowledge was compared between the groups using a multiple-choice question test before and after the teaching intervention. A survey was done to collect student perception.	3D printed models	Test Questions Student perception	Use of 3D printed models as an additional teaching tool significantly improved the mean test scores Survey results showed that students felt the 3D-printed models significantly improved their learning experiences and visualizations.
Chekrouni et al, 2020[34] Netherlands	Quantitative	To evaluate if the use of the 3D atlas as an additional teaching tool can improve students' learning experiences.	1st-year biomedical students (*n* = 91)	Embryology	The 3D atlas was introduced and integrated in lectures and practical classes of an existing embryology course. The cohort included both new students and repeaters. The test scores were compared between this class and the previous cohort, who did not learn with 3D Atlas.	3D Atlas of Human Embryology (3D Atlas)	Test scores, Survey Student perception	The class that used 3D Atlas showed significantly higher exam scores for both new students and repeaters. In the survey, 71% of the students agreed that the 3D atlas led to a better understanding of embryology.

Morales-Vadillo et al, 2019[35] Peru	Quantitative	To compare the effectiveness of using Second Life (SL) to the traditional teaching methods	3rd year Dentistry students (*n* = 62)	Dentistry	Students were divided into control and experimental group. Students in the experimental group received training on how to use Second Life (SL) software. The control group did not have SL experience. Pre-test and post-test scores were compared between groups.	Second Life (SL) Virtual Reality based tool	Test scores, Questions designed to test spatial interpretation of anatomical structure.	Students who used Second Life (SL) scored significantly higher than the control group in questions designed to test the spatial interpretation of the anatomical structure.
Cui et al, 2017[36] USA	Quantitative	To explore if 3D stereoscopic models created from computed tomographic angiography (CTA) data were effective teaching tools for the head and neck vascular anatomy.	1st year medical students (*n* = 39)	Head and neck vascular anatomy	Students were randomized into either a 2D or a 3D learning session. 2D group used 2D images, snapshots and radiographic images. Students in the 3D learning session learned using 3D stereoscopic models, which they could manipulate and rotate to any angles for visualizations. Students from both groups were assessed using pre and post knowledge test, mental rotation test and satisfaction survey.	3D stereoscopic model	Test scores, Mental Rotation Test Survey	Students who used the stereoscopic 3D models increased their ability to correctly identify the head and neck vascular anatomy. Students with low spatial ability (low score in mental rotation test), use of 3D models in the 3D learning sessions improved their post test scores to a level of students who had high-spatial ability. This result indicates that the use of 3D stereoscopic models can be valuable to students with low spatial abilities.
Hoyek et al, 2014[37] France	Quantitative	To evaluate the effectiveness of 3D digital animation as a teaching tool by comparing two groups from two different academic years.	Undergraduate students of kinesiology (*n* = 391)	Human anatomy	The study included two groups of students from two different years. The 2D group got lessons with power point embedded 2D images. The experimental 3D group received lesson with power point and 3D digital animation. Formal exam scores were compared between groups	3D digital animation	Test scores	The students from 3D group, who studied with 3D digital animation scored higher in questions that required spatial ability.
Kolla et al, 2020[38] USA	Quantitative	To assess the usefulness of VR in teaching anatomy.	1st year medical students (*n* = 28)	Human anatomy	Participants took part in a VR anatomy training exercise during the 2nd and 3rd weeks of a 4-week anatomy course on the musculoskeletal system.	Virtual Reality (VR) anatomy platform	Survey Student perception	In response to question related to 3D understanding, (78.6%) of the participants reported VR to be “much better” and (17.9%) of the participants reported VR to be “somewhat better” than lecture for learning 3D anatomical relationships.

					At the end, students were asked to complete a survey.			
Lane et al, 2020[39] USA	Quantitative	To investigate the educational values of 3D printed craniofacial pathology models.	2nd year medical students (*n* = 44)	Surgery	Students were randomly assigned to a control group or model group. Both groups received power point presentations. Besides power point, the experimental model group was also provided with 3D-printed models created using patient-specific preoperative computed tomography data. A survey using the Likert scale evaluated participants' learning experience. Pre- and post-module scores on a quiz were recorded.	3D printed models	Test score Survey Student perception	The survey showed that students in the experimental group using 3D printed model scored higher in understanding of the anatomy and visualization of the pathology, gaining an improved understanding of surgical approach. The mean pre- and post-module quiz scores between groups were similar.
Fan et al, 2019[40] China	Quantitative	To evaluate the effectiveness of 3D printed models of bladder to improve students' understanding of bladder anatomy	1st year clinical medical students (*n* = 54)	Surgery	Students were divided into three groups who used either: (i) 3D models and CT images (ii) only 3D models and (iii) only CT images. All patients were given two patients datasets to describe the anatomical characteristics and surgical processes. The patients' 3D models were provided to the 3D+CT and 3D groups, and CT imaging data were provided to the 3D+CT and CT groups.	3D printed models	Surgery planning Survey	Students in the 3D+CT group and the 3D group exhibited better accuracy than those in the CT group in understanding the spatial structure of the bladder and radical cystectomy (RC) processes. There was no difference between the 3D+CT group and the 3D group. In the self-evaluation survey students from 3D and 3D + CT group scored higher than only CT group.

Table 5. Quality assessment using MERSQI

	MERSQI Score breakdown								
Author, Year	Study design	Sampling institution	Response rate: ≥ 75%	Type of Data	Validity evidence for evaluation instrument scores	Data analysis sophistication	Data analysis appropriate	Outcome	Total MERSQI Score
Lone et al., 2019[22]	Randomized cross-over trial (3)	1 (0.5)	(1.5)	Objective (3)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, skills (1.5)	12.5
Awan et al., 2019[23]	Randomized controlled trial (3)	1 (0.5)	(1.5)	Objective (3)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, skills (1.5)	12.5
Hu et al., 2020[24]	Randomized controlled trial (3)	1 (0.5)	(1.5)	Objective (3)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, skills (1.5)	12.5
Akle et al., 2018[25]	Nonrandomized, 2 groups (2)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, skills, satisfaction (2.5)	13.5
Yao et al., 2014[26]	Single group, post-test only (1)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, skills, satisfaction (2.5)	12.5
Biglino et al., 2017[27]	Single group, cross-sectional (1)	1 (0.5)	(1.5)	Assessment by study participants (1)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Perception, satisfaction (1)	8
Yeo et al., 2018[28]	Nonrandomized, cohort study (2)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	13.5
Weiss et al., 2021[29]	Single group, post-test only (1)	1 (0.5)	(1.5)	Assessment by study participants (1)	NA	Descriptive analysis only (1)	Appropriate for study: 1	Perception, satisfaction (1)	7
Gao et al., 2020[30]	Nonrandomized, 2 groups (2)	1 (0.5)	(1.5)	Assessment by study participants (1)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Perception, satisfaction (1)	9
Wada et al., 2020[31]	Single group, cross-sectional (1)	1 (0.5)	(1.5)	Assessment by study participants (1)	NA	Descriptive analysis only (1)	Appropriate for study: 1	Perception, satisfaction (1)	7
Lin et al., 2020[32]	Randomized, controlled (3)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	14.5
AlAi et al., 2018[33]	Randomized, controlled (3)	2 (1)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	15
Chekrouni et al., 2020[34]	Nonrandomized, 2 groups (2)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	13.5
Morales-Vadillo et al., 2019[35]	Randomized controlled (3)	1 (0.5)	(1.5)	Objective (3)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, skills (1.5)	12.5
Cui et al., 2017[36]	Randomized, controlled (3)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	14.5
Hoyek et al., 2014[37]	Nonrandomized, 2 groups (2)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	13.5
Kolla et al., 2020[38]	Single group, cross-sectional (1)	1 (0.5)	(1.5)	Assessment by study participants (1)	NA	Descriptive analysis only (1)	Appropriate for study: 1	Perception, satisfaction (1)	7
Lane et al., 2020[39]	Randomized, controlled (3)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	14.5
Fan et al., 2019[40]	Randomized, controlled (3)	1 (0.5)	(1.5)	Objective and assessment by participants (4)	NA	Beyond descriptive analysis (2)	Appropriate for study: 1	Knowledge, perception (2.5)	14.5