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Technology Application in Enhancing Visualization Skills in Learning Engineering Drawing: A Systematic Review

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ABSTRACT

In today's dynamic engineering landscape, where design and innovation are at the forefront, effectively communicating and translating complex ideas through precise engineering drawings is an indispensable skill. However, students often encounter challenges in learning engineering drawing due to the complexity of visualizing and translating three-dimensional objects as well as the need for precise technical communication and spatial reasoning skills. The integration of technology application in engineering drawing shows positive impact in empowers students to visualize and understand complex spatial structures through interactive digital tools. such as Computer-Aided Design (CAD) software and 3D modelling. Therefore, the study aims to review how technology-based approaches able to enhance students' visualization skills in learning engineering drawing. This study employs a systematic literature review that adheres to PRISMA to find the primary data based on a few keywords such as "visualization skill and engineering drawing". Based on advanced searching on SCOPUS and Web of Science found (n=26). Expert Scholar decided to develop four themes, which are (1) Augmented Reality in Engineering Education, (2) Teaching Methods and Pedagogical Approaches, (3) Spatial Abilities and Visualization in Engineering Education and (4) Skill Development and Improvement in Engineering Drawing. The findings of this comprehensive analysis indicate that while most studies report positive outcomes in students' visualization skills through targeted interventions, there remains a dearth of longitudinal assessments and standardized measures for evaluating progress. In conclusion, this systematic review underscores the importance of continued research and innovation in the realm of engineering drawing education, advocating for a holistic approach that integrates both traditional and technology-driven methods to enhance visualization skills.

Keywords:

Visualization skills; Engineering students; Engineering drawing; Vocational education

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1. Introduction

Engineering drawing, an essential component of engineering education, serves as the fundamental means through which engineers communicate intricate concepts, designs, and solutions [1-4]. Proficiency in this discipline stands as a foundational requirement, enabling the transformation of abstract ideas into tangible, practical realities. Many recent studies [5-7] have shown that the development of adept visualization skills within the context of engineering drawing remains a persistent and formidable challenge, presenting hurdles for both students grappling with its complexities and educators tasked with transferring this vital competence. Recognizing this pervasive issue, educators and researchers have increasingly turned to technology as a potential solution, harnessing the power of digital tools to enhance the learning process. The potential of the technology approach in enhancing visualization skills in learning engineering drawing is a topic of great significance in contemporary education. As technology continues to advance and permeate every aspect in lives, it has the potential to revolutionize the way engineering drawing is taught and learned.

Technology, in the form of computer software, virtual reality, and 3D modelling tools, allows for highly interactive learning experiences. Students can manipulate and visualize complex engineering drawings in a dynamic and engaging manner, promoting a deeper understanding of spatial structures. The modalities and tools employed in creating and interpreting technical drawings have similarly advanced in an era characterized by the constant evolution of engineering disciplines. This evolution encompasses not only traditional manual techniques but also modern digital technologies and sophisticated computer-aided design (CAD) software [8-10].

The motivation for undertaking this systematic review stems from contemporary engineering projects' escalating complexity and interdisciplinary nature. Proficiency in the rudiments of drawing no longer suffices; students must adeptly navigate the demands of digital design, three-dimensional modelling, and collaborative engineering methodologies [6,11]. Consequently, this article aspires to provide a comprehensive and current synthesis of existing scholarly research, elucidating the most effective strategies, methodologies, and technological approaches for enhancing students' visualization competencies within the context of engineering drawing. The review's objective is to contribute substantively to the ongoing discourse within engineering education by consolidating empirical research findings and scholarly insights. It seeks to offer valuable guidance to educators, curriculum developers, and policymakers invested in equipping engineering students with the indispensable visualization skills requisite for success in the ever evolving and multidisciplinary landscape of engineering practice.

The questions addressed herein hold practical implications for engineering students' preparedness to meet the multifaceted demands of their future careers. Through the amalgamation of current knowledge, this article aims to serve as a compass for educators navigating the pedagogical challenges associated with enhancing visualization skills among engineering students [11-13]. Furthermore, it serves as a clarion call to the broader engineering education community, urging the recognition of the paramount significance of this skill set and advocating for its development as an integral component of engineering curricula [14-17]. In the forthcoming sections, the article navigates the labyrinth of research literature, analysing the strategies, methodologies, and tools that have demonstrated effectiveness in augmenting visualization skills within the realm of engineering drawing. The aim is to provide a comprehensive resource that informs evidence-based decision-making in engineering education, empowering the next generation of engineers with the visualization proficiency requisite for engineering excellence.

2. Literature Review

Engineering drawing, also termed technical drawing or engineering graphics, forms the bedrock of effective communication in the engineering and design domains [18]. It furnishes an exact and intricate visual portrayal of objects, systems, or structures, relaying crucial information to engineers, architects, manufacturers, and other stakeholders. Engineering Drawing holds a pivotal role in the curricula of diverse engineering disciplines. In the realm of engineering education and practice, the ability to visualize and transform abstract concepts into precise graphical representations is integral to innovation, problem resolution, and proficient communication [18-20]. This aptitude, recognized as visualization, serves as the conduit linking theoretical knowledge to practical implementation, rendering it an essential asset for aspiring engineers and seasoned professionals.

On the other hand, visualization skills, often referred to as visual thinking or spatial reasoning, are cognitive abilities that enable individuals to manipulate and process visual information mentally, particularly in their mind's eye [4,21]. These skills involve the capacity to create, manipulate, and analyse mental images, graphs, diagrams, or other visual representations of objects, ideas, or concepts. As Rogers *et al.,* highlighted, visualization plays an integral role across diverse domains, including science, engineering, mathematics, art, and design [22]. It is a formidable problem-solving tool, allowing individuals to simulate scenarios, devise innovative solutions, and anticipate outcomes. Additionally, these skills are instrumental in education, aiding comprehension, and retention of intricate subjects. In fields like architecture and engineering, visualization skills underpin the translation of design concepts into tangible structures [17,23,24].

However, engineering undergraduates, particularly those in their first year, frequently encounter challenges when it comes to mastering and addressing ED problems that necessitate the visualization of 3D objects. The development of visualization skills in learning engineering drawing poses several substantial challenges [14,15,25,26]. Firstly, the cognitive demands inherent in engineering drawing, which often involves intricate 2D and 3D representations, can overwhelm students, necessitating the ability to manipulate and interpret complex visual information mentally [22,27]. Secondly, a lack of prior exposure to technical drawing or deficiencies in foundational skills from secondary education can create a steep learning curve for many engineering students. Furthermore, limited hands-on practice and practical applications of engineering drawing concepts can hinder skill development, and varying learning styles among students call for diverse teaching approaches.

The Engineering Drawing course encompasses projection, sectioning, and solid development. It necessitates students to conceptualize, envision, and create drawings based on specified criteria. Additionally, the course covers orthographic projections, where the conversion of 3D objects into 2D representations is essential [28,29]. Engineering students commonly engage in orthographic projections, involving the mental transformation of 3D scenarios into 2D sketches. This process relies on the learner's spatial aptitude. In a 2021 publication by Papakostas *et al*., it was emphasized that engineering students often encounter challenges when acquiring visualization skills [30]. They found that individual differences in spatial ability among students necessitate tailored support and practice to ensure equitable skill development. Table 1 shows the difficulties in engineering drawing course experienced by students stated by Kadam *et al.,* [18].

Table 1
Difficulties in Engineering Drawing Course Experienced by Students [18]

Statement/ Indicator	Agree		Disagree		Mean	SD
	F	%	F	%		
Understanding sectional drawing	33	83	7	17	*1.95	0.85
Lack of understanding of sectional drawing principles	31	77	9	23	2.40	0.73
Have drawing models	21	53	19	47	3.38	0.74
Familiar with EGD line-types	26	65	14	35	1.70	0.72
Relevant previous topics of sectional drawing	20	50	20	50	2.88	0.69
Have EGD background	5	12	35	88	3.40	0.50
Lack of knowledge on 2D/3D sectional drawing	24	60	16	40	1.65	0.83

Table 1 shows that most students have difficulties when understanding sectional drawing, have poor engineering drawing the background and lack understanding of the two-dimensional and three-dimensional sectional drawing. Most of the problems are related to understanding the complex concepts and principles of engineering drawing. The discovery aligns with prior research conducted by Ugliotti *et al*., which identified challenges among certain students in comprehending and achieving proficiency in concepts like orthographic applications, such as projections, orthographic to isometric conversion, dimensioning, and related aspects [31]. Additionally, there were reported difficulties among students in mentally envisioning objects, which was closely associated with deficiencies in visualization skills.

Traditional teaching methods may not effectively address diverse learning styles and needs, making it challenging to foster strong visualization skills in all students [25,32-34]. Addressing these issues necessitates innovative instructional approaches, curriculum enhancements, and support mechanisms to ensure that students in engineering programs can develop robust visualization skills essential for their future careers. Inadequate instruction and outdated teaching materials further compound these difficulties, underscoring the importance of effective pedagogical approaches and up-to-date resources. Both traditional and contemporary teaching approaches support the facilitation of subject comprehension; however, they do not assure the eradication of challenges in understanding spatial relationships, especially when visualizing [26,34,35].

To address these challenges effectively, academic institutions must adopt a comprehensive approach that incorporates interactive teaching methods, hands-on projects, peer learning opportunities, access to CAD software, and personalized support services, all of which are crucial in equipping students with the essential visualization skills required in engineering drawing. The integration of technology into engineering education has ushered in a transformative era for enhancing students' visualization skills, with a particular focus on engineering drawing. Over the past two decades, a body of research has emerged, shedding light on the impact of technology-based approaches in this domain. Historically reliant on manual drafting techniques, engineering drawing education has seen a profound shift towards technology-driven pedagogy, prominently featuring Computer-Aided Design (CAD) software. This transition has not only revolutionized the creation and modification of engineering drawings but also created interactive digital environments.

3. Material and Methods
3.1 Identification

The systematic review involves three key stages employed to select numerous relevant papers for this study. Initially, the first phase entails identifying keywords and searching for related terms through resources like thesauri, dictionaries, encyclopaedias, and previous research. Once all relevant terms are determined, search queries are constructed and executed on the Scopus and Web of Science (WoS) databases, as detailed in Table 2. In the initial phase of the systematic review, our study successfully retrieved 186 papers from both databases.

Table 2
Search string

Scopus	TITLE-ABS-KEY ((visualization OR spatial OR imagination) AND (skill* OR abilit*) AND (*engineering AND drawing* OR *technical AND drawing*) AND *engineering AND student*) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023)) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) Access Date: 16 September 2023
WoS	(visualization OR spatial OR imagination) AND (skill* OR abilit*) AND (*engineering AND drawing* OR *technical AND drawing*) AND *engineering AND student* (Topic) and Review Article or Article (Document Types) and 2023 or 2022 or 2021 or 2020 (Publication Years) and English (Languages) and Education Educational Research or Engineering (Research Areas) Access Date: 16 September 2023

3.2 Screening

Ignoring duplicate papers is important in the initial screening stage (8 articles). Researchers established specific inclusion and exclusion criteria, excluding 118 papers in the first phase, while 60 articles were evaluated in the second phase. The primary focus was on research articles as they are a primary source of valuable knowledge. This study did not consider other forms of publications such as book series, books, chapters, conference proceedings, and publications that were still in press. Furthermore, the review was restricted to studies conducted in the English language only. The study timeline was set for four years, from 2020 to 2023 (see Table 3).

Table 3
The selection criterion is searching

Criteria	Inclusion	Exclusion
Language	English	Non- English
Document Type	Article, Review	Book, Book Chapter Conference paper, conference review paper
Source Type	Journal	Conference proceeding, book, book series
Year/Timeline	2020- 2023	< 2020
Accessibility	Accessible and full text available	Inaccessible

3.3 Eligibility

At the eligibility level, there are 60 articles available. During this stage, a thorough evaluation of article titles and crucial content was conducted to verify their alignment with the inclusion criteria and the objectives of the ongoing study. Consequently, 34 articles were excluded because due to the out of field, title not significantly and abstract not related on the objective of the study based on empirical evidence. This led to the retention of 26 articles for subsequent review.

3.4 Data Abstraction and Analysis

In this study, an integrative analysis technique was employed as one of the assessment strategies to evaluate and consolidate various research approaches, encompassing quantitative, qualitative, and mixed methods. The primary objective of the proficient investigation lay in the identification of relevant subjects and subtopics. Data gathering marked the initial phase of theme development. Subsequently, the most recent publications on visualization abilities in engineering drawing learning were reviewed by the authors. Ongoing investigations cover both the research findings and the methodology employed in all the studies. Collaboration with other co-authors was undertaken to derive themes from the study's data context. A log documenting analyses, opinions, challenges, or relevant thoughts during the data analysis process was maintained. The findings underwent scrutiny to identify disparities in the theme design approach. It's crucial to emphasize that any differences in ideas were discussed by the authors. The created themes were eventually modified to ensure consistency. Three specialists, namely three experts in TVET (Dayana Farzeeha Ali and Marlissa Omar, specialized in visualization skills and Nur Hazirah Noh@Seth, an expert in engineering drawing) and two in engineering education (Noor Hidayah Che Lah and Aimi Ruzaini Ahmad, an expert in educational technology), conducted the analysis. This expert review process delineates the domain and guarantees clarity, significance, and appropriateness for each subtheme. Figure 1 illustrates the screening and selection process using a flow PRISMA diagram.

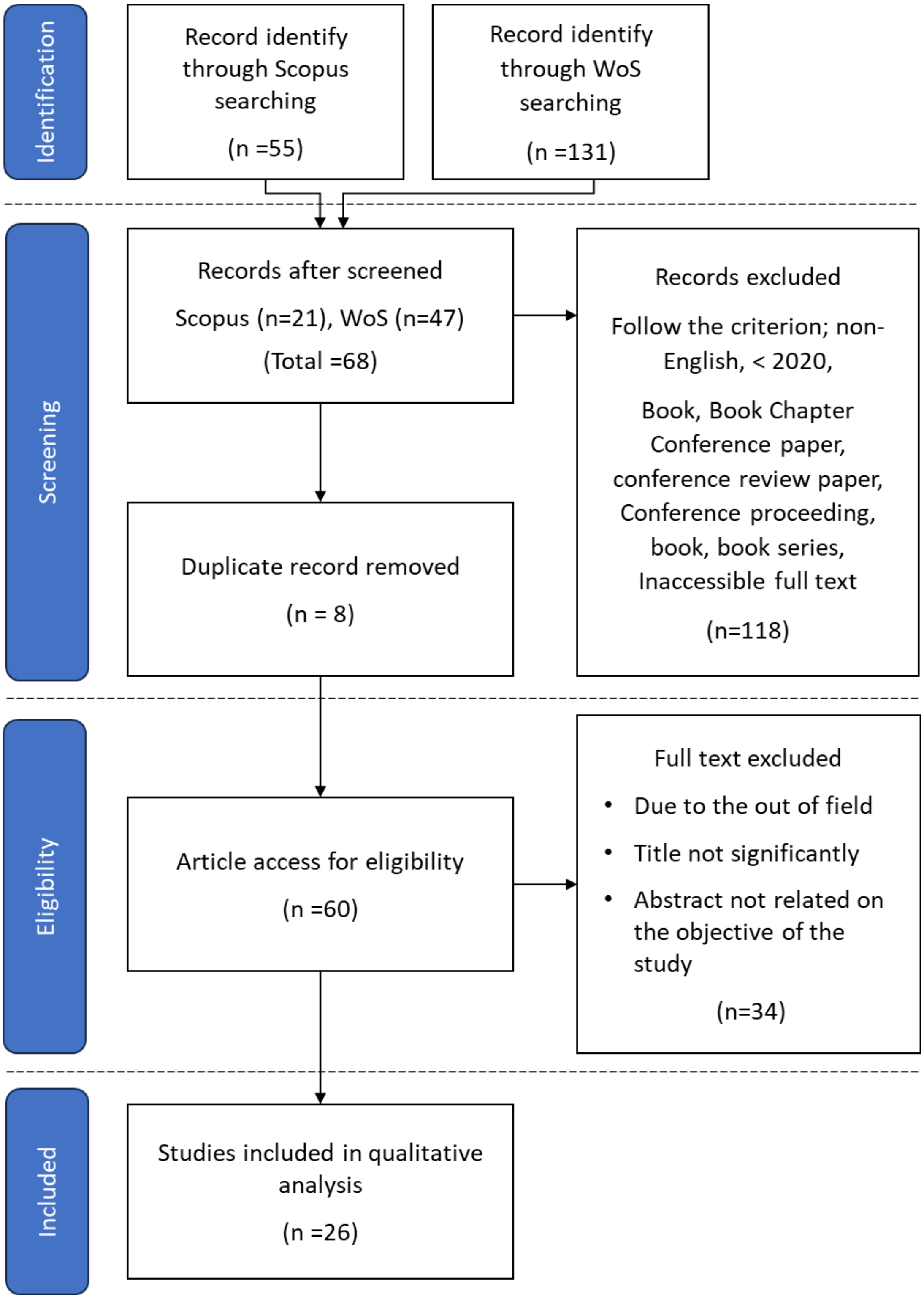

Fig. 1. Flow diagram of the proposed search study [37]

4. Result and Finding

Enhancing visualization skills is paramount in the pursuit of mastering engineering drawing, a fundamental aspect of the academic and professional world for engineers and architects alike. Developing these skills requires a multifaceted approach. Based on the searching technique, 26 articles were extracted and analysed. All articles were categorized based on four main themes:

augmented reality in engineering education, teaching methods and pedagogical approaches, spatial abilities and visualization in engineering education, and skill development and improvement in engineering drawing.

4.1 Augmented Reality Technology Application in Engineering Education

Table 4 presents a summary of research papers examining the utilization of Augmented Reality (AR) in engineering education, particularly in the context of enhancing spatial aptitude training for students over the past decade. Scholars have investigated the advantages of AR, and there has been growing interest in its application across educational levels. Engineering students often encounter challenges in acquiring visualization skills, making AR an increasingly prominent tool for improving student learning outcomes. Augmented reality technology has garnered significant attention across various fields due to its distinctive real-time interactivity and its capacity to incorporate virtual objects within 3D video environments [36]. The findings demonstrate that, for the purpose of enhancing students' comprehension and mastery of traditional mechanical courses and overcoming the limitations of conventional courseware teaching methods, a teaching assistant system has been devised and constructed by integrating augmented reality technology with established teaching approaches, as detailed in reference [24]. On the side of smartphone applications, the 3D representation of mechanical components can be exhibited by scanning mechanical engineering schematics, permitting rotation, zooming, and cross-sectional examination of the models. This approach enables the realization of 3D visualization and interactive manipulation of 2D drawings found in textbooks, achieving the objectives of enhanced imagery, diversity, and effective instruction.

Table 4
Summary of augmented reality in engineering education theme

Authors	Title	Method	Findings
Papakostas *et al.,* [30]	Exploration of Augmented Reality in Spatial Abilities Training: A Systematic Literature Review for the Last Decade	Reviewed 32 studies (published since 2010) on AR in spatial ability training, adaptivity, personalization, and evaluation methods.	AR offers potential in spatial ability training, using various evaluation methods, with adaptivity and personalization being key.
Del Cerro Velázquez & Méndez [38]	Application in augmented reality for learning mathematical functions: A study for the development of spatial intelligence in secondary education students	Studied Geogebra AR's impact on fourth-year math students' academic performance and spatial skills within a contextualized methodological environment.	Geogebra AR integration can influence fourth-year math students' academic performance and spatial skills.
Qu *et al.,* [24]	Design and Implementation of Teaching Assistant System for Mechanical Course based on Mobile AR Technology	Developed a teaching assistant system using Vuforia AR to enhance mechanical engineering instruction with interactive 3D models.	The system improves teaching efficiency by providing interactive 3D visualization of 2D textbook drawings.
Wen *et al.*, [39]	Using Cloud-Based Augmented Reality to 3D-Enable the 2D Drawings of AISC Steel Sculpture: A Plan-Reading Educational Experiment	Used cloud-based AR to enhance 2D drawings with interactive 3D models, tested its impact on student comprehension.	AR-enhanced 3D augmentation improves students' understanding of complex 2D drawings compared to traditional paper-only methods.

Awuor *et al.,* [40]	The effect of 3D-stereogram mobile AR on engineering drawing course outcomes among first-year vocational high schoolers with different spatial abilities: a Bloom's taxonomy perspective	Conducted a quantitative experiment with 69 first-year vocational high school mechanical engineering students in northern Taiwan.	High spatial ability improved drawing skills and understanding in AR-enhanced learning, with potential for better concept comprehension in engineering.
Tumkor [41]	Personalization of engineering education with the mixed reality mobile applications	Employed MR for object visualization in engineering drawing classes to test its impact on student visualization skills.	MR applications improved student visualization skills, but further research is needed to understand individual variations in benefits.
Wen *et al.,* [39]	Using Cloud-Based Augmented Reality to 3D-Enable the 2D Drawings of AISC Steel Sculpture: A Plan-Reading Educational Experiment	Used cloud-based AR to enhance 2D drawings with interactive 3D models, tested its impact on student comprehension.	AR-enhanced 3D augmentation improves students' understanding of complex 2D drawings compared to traditional paper-only methods.

4.2 Technology Application in Teaching and Pedagogical Approaches

The integration of technology into education has revolutionized teaching and pedagogical approaches, reshaping the way knowledge is imparted and absorbed. In today's classrooms, technology is not merely an accessory but an essential component of the educational landscape. Interactive whiteboards, tablets, multimedia presentations, and various digital resources have transformed traditional teaching methods, creating dynamic and immersive learning environments.

Various studies have indicated a correlation between the study of engineering drawing and the enhancement of spatial ability. Successful instructional methods and pedagogical strategies have been documented in prior works. The effectiveness of interdisciplinary learning in improving students' visualization skills has been demonstrated. The findings of the current investigation reveal diverse pedagogical approaches to address challenges related to visualizing spatial relationships in mastering engineering drawing. Both conventional and contemporary teaching techniques contribute to subject instruction but do not assure the complete elimination of learning obstacles, particularly in visualizing spatial connections. Table 5 shows summary of teaching methods and pedagogical approach's theme.

Table 5
Summary of teaching methods and pedagogical approach's theme

Authors	Title	Method	Findings
D. Vergara *et al.,* [42]	Interdisciplinary learning methodology for supporting the teaching of industrial radiology through technical drawing	Introduced a novel educational method linking industrial radiology and technical drawing, enhancing spatial ability with ICT-based tools.	This approach can contribute to achieving UN's 2030 sustainable development goals.
Ariffin *et al.,* [2]	Visualization skills among engineering students using problem-based learning Fogarty model	Assessed engineering students' visualization skills using the PBL Fogarty Model, involving 68 Malaysian students.	Strong visualization skills enhance learning and mastery of new knowledge and approaches.
Sharma *et al.,* [27]	Fostering higher order thinking skills in engineering drawing	Quantitative research. Explored development of higher-order thinking skills in engineering drawing	Combining spatial visualization with manual drafting improved engineering drawing understanding and assessment performance.

Fraile-Fernández *et al.,* [43]	Constructionist learning tool for acquiring skills in understanding standardized engineering drawings of mechanical assemblies in mobile devices	Developed ARPAID mobile app for teaching mechanical assembly representation. Created teaching material and evaluated using classroom activity.	ARPAID enhances students' understanding of mechanical assembly representation in engineering Graphic Design courses.
Sawant *et al.,* [4]	An Attempt to Enhance the Visualization, Imagination and Drawing Skill of Freshman Engineering Students through Problem Based Learning Approach	Quantitative research design exploring student's engagement in active learning to enhance visualization, imagination, and drawing skills in and outside the classroom.	As a result of the systematic implementation of problem-based learning (PBL), student engagement with the learning process has increased, leading to improvements in the achievement of course outcomes (COs) and the overall course exam results.
Sierra-Uria *et al.,* [44]	Reading technical drawings: a learning-teaching proposal for engineering schools	Designed a resolution method based on comprehension indicators for engineering schools using a didactic research approach.	Integrating dynamic images, physical models, and technology improved spatial visualization and outperformed traditional teaching methods.
Da Silva & Agostinho [45]	A Strategy for Teaching and Learning Technical Drawing	Developed an active learning framework for industrial engineering students using manual sketching, origami, and computer-based drawing.	The framework enhanced students' spatial understanding and problem-solving skills in industrial engineering drawing.

4.3 Spatial Abilities and Visualization in Engineering Education

Spatial visualization ability plays a significant role in the cognitive development of a child. Various factors influence its growth, including general intelligence, problem-solving abilities, gender, engagement in building games, experience with engineering drawings and 3D modelling, among others. Engineers often rely on drawings and sketches for communication, making the comprehension of technical information through visual representations a crucial skill in engineering practice. Proficiency in spatial skills is essential for grasping technical drawings and is consequently vital for success in engineering. Regrettably, gender disparities are evident in spatial skills, with males typically displaying stronger abilities, potentially contributing to the underrepresentation of women in the field of engineering. Therefore, the ability of an engineer to visualize 3D image is a cognitive skill that is essential to succeed in basic engineering drawing subjects (see Table 6).

Table 6
Summary of spatial abilities and visualization in engineering education theme

Authors	Title	Method	Findings
Hoffmann and Németh [46]	Is it a cube? Common visual perception of cuboid drawings	Experimental design. Examined how 153 first-year arts and engineering students perceive and evaluate cuboid drawings.	Students from diverse backgrounds had varying perceptions in distinguishing true cubes from general cuboids.
Safhalter *et al.,* [47]	Development of spatial thinking abilities in engineering 3D modelling course aimed at lower secondary students	Quasi Experimental Research Design. Investigated the impact of SketchUp 3D modelling on spatial thinking in 166 11–14-year-old students with pre-and post-tests.	SketchUp training enhanced spatial thinking skills among students, considering previous 3D modelling experience and grades.

Sharma & Kumar [29]	Thinking Through Art – A creative insight into mechanical engineering education	Comparative analysis is conducted on the performance of a pilot group of students. Initially, these students have no prior artistic skills, but they undergo pre-training in artistic abilities as a component of their engineering education.	Artistic skills training in engineering education improves student performance significantly.
Sorby *et al.,* [48]	An examination of the role of spatial ability in the process of problem solving in chemical engineering	Quantitative Research Design using pre-test post-test. Tested spatial cognition in 3rd-year chemical engineering students and assessed problem-solving performance from a prerequisite course.	A robust positive correlation ($r = 0.59$, $p < 0.00001$) affirms the connection between spatial skills and effective engineering problem-solving.
Potter *et al.,* [49]	Three-dimensional spatial perception and academic performance in engineering graphics: a longitudinal investigation	Investigated the correlation between 3D spatial perception and engineering graphics pass rates through the utilization of high-quality course materials focused on imagery.	High imagery course materials improved 3D spatial perception in engineering students, benefiting their performance in engineering graphics.
Mendez *et al.,* [50]	Assessment of Visual and Memory Components of Spatial Ability in Engineering Students who have Studied Technical Drawing	Quantitative Research Design. Quasi Experimental involved control and treatment group.	Students with technical drawing background showed improved spatial performance in various cognitive processes, including mental rotation.

4.4 Skill Development and Improvement in Engineering Drawing

Engineering drawing serves as a valuable tool for capturing geometric characteristics, conveying engineering concepts, and generating a blueprint for the intended product. Typically, engineering students engage in orthographic projections, wherein a 3D scenario is envisioned and its 2D depiction is sketched. Skill development and improvement in engineering drawing are crucial aspects of engineering education. Engineering drawing is engineers' language, serving to communicate complex design ideas, plans, and specifications (see Table 7).

Table 7
Summary of skill development and improvement in engineering drawing theme

Authors	Title	Method	Findings
Kadam *et al.,* [18]	Enhancing engineering drawing skills via fostering mental rotation processes	Quantitative Research Design. Implemented a 3D visualization training program for engineering undergraduates, assessing its impact on problem-solving performance.	Results demonstrate that successful training improves students' problem-solving performance in the context of ED.
Taraszkiewicz [51]	Freehand drawing versus digital design tools in architectural teaching	Quantitative Research Design. Studied students' architectural design abilities using traditional and digital methods at Gdańsk University of Technology.	Digital methos shows significant improvement in design abilities.

J. N. Marwa *et al.,* [52]	Enhancing Spatial Ability Skills in Basic Engineering Drawing Using a 3D Solid Model	Employed quasi-experimental design, tested 3D solid model to enhance spatial ability in 43 first-year technology education students.	The experimental group, including non-engineering students, showed improved spatial ability after using the 3D model.
Prieto *et al.,* [53]	Does spatial visualization ability improve after studying technical drawing?	Quantitative Research Design.	Technical drawing instruction improved spatial visualization skills in engineering students.
Kosa & Karakus [23]	The effects of computer-aided design software on engineering students' spatial visualization skills	Used quasi-experimental design with PSVT:R tests on 116 mechanical engineering freshmen, with CAD-based instruction for the experimental group.	CAD-based instruction led to enhanced spatial visualization in the experimental group when compared to the control group.
Mitrovic *et al.,* [54]	New approach to 3D modelling in computer graphics course	Utilized Sloodle virtual environment for teaching spatial skills via Computer Graphics Sloodle course with LSL scripting.	The course improved students' spatial visualization skills using complex virtual environments and scripting.

5. Discussion

The utilization of technology in the realm of engineering drawing education has been a game-changer, significantly enhancing students' visualization skills. In this discussion, we explore the multifaceted impact of technology applications in this domain, acknowledging the opportunities and challenges it presents. The discussion of the results begins with first theme about augmented reality in engineering drawing. The recent surge in research on Augmented Reality (AR) applications in education has yielded compelling results, highlighting a significant enhancement in students' spatial abilities, particularly in the context of engineering education. While AR has proven to be a powerful tool for improving spatial cognition and visualization skills, it also excels in creating immersive and experiential learning environments, thereby enhancing overall course effectiveness and student engagement. Figure 2 shows the use of augmented reality in different fields of study [55].

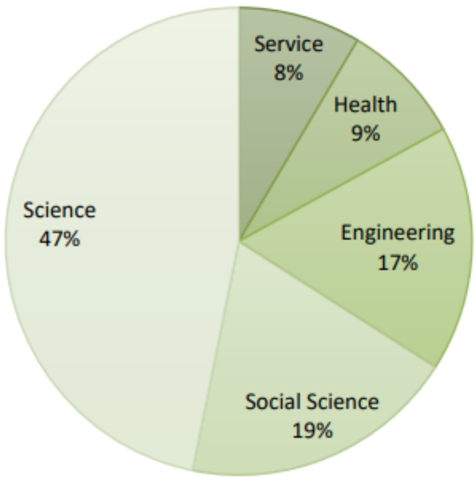

Fig. 2. The Use of Augmented Reality in Different Field of Study [55]

Apart from all these fields, the educational field also received similar interest in the application of augmented reality, especially as teaching and learning tools [56]. Virtual reality and gamification offer immersive and engaging experiences that transcend traditional pedagogy. However, the paucity of diverse and comprehensive learning content within AR applications poses a notable challenge, necessitating further research and development in this area. However, the integration of technology also poses challenges related to screen time, the digital divide, data privacy, and cybersecurity. In this rapidly evolving educational landscape, educators and institutions must adapt, embracing technology's potential while addressing its challenges, to prepare learners effectively for the demands of the 21st century Additionally, the positive reception of AR by students and its demonstrated capacity to enhance plan-reading accuracy underscore its value as a pedagogical asset. Statistical analyses reveal that learners' spatial abilities, especially in understanding and applying knowledge, are significantly influenced by AR, further cementing its role in shaping successful educational outcomes. Furthermore, the inclusion of students' prior CAD experiences and technology interests elucidates the potential benefits of Mixed Reality (MR) technology in education, promising to revolutionize teaching practices and deepen students' comprehension of complex engineering concepts for an ever-evolving future.

One of the most striking advantages of technology in engineering drawing education is the level of interactivity it introduces. Through Computer-Aided Design (CAD) software, virtual reality, and 3D modelling tools, students can actively engage with complex spatial structures. This dynamic interaction not only stimulates interest but also promotes a deeper understanding of engineering drawings. The ability to manipulate, visualize, and even create designs in a digital environment offers a hands-on learning experience that is invaluable in enhancing visualization skills. The collective findings from these studies offer valuable insights into enhancing spatial skills and problem-solving abilities in various educational contexts, with a particular focus on engineering drawing and technology education. Firstly, the training interventions have proven successful in improving students' problem-solving performance in the realm of engineering drawing, affirming the positive impact of targeted instruction on this skillset. Moreover, integrating 3D solid models as a teaching tool has demonstrated its effectiveness in enhancing spatial ability among technology education students, suggesting the need for judicious incorporation into basic engineering drawing education. The results underscore the importance of complementing 3D solid model usage with other teaching methodologies to maximize its educational benefits. Additionally, the research findings highlight that spatial visualization, as an aptitude, is amenable to enhancement through training, with improvements observed across a moderate number of students, irrespective of gender. Furthermore, the positive effects of CAD-based engineering drawing courses on students' spatial visualization skills and their predictive value for success in such courses emphasize the significance of these skills in engineering education. Lastly, the utilization of virtual environments like Sloodle fosters collaborative learning, enhancing knowledge acquisition efficiency and visualization capabilities among participants, reinforcing the value of technology-driven educational platforms in today's dynamic learning landscape.

In context of teaching and pedagogical approaches, Technology facilitates multimodal learning, accommodating diverse learning styles and preferences. Visual, auditory, and kinaesthetic learners can all benefit from technology-enhanced learning as these tools offer various ways to interact with and understand engineering drawings. This versatility ensures that students can choose the mode of learning that best suits their individual needs. Integration of spatial visualization exercises, mobile applications, problem-based learning approaches, and dynamic learning materials have all showcased their potential to enhance students' spatial cognition and problem-solving capabilities. The results consistently reveal significant improvements in students' understanding, engagement, and performance across these diverse educational approaches. Technology applications enable immediate feedback and assessment. Students can receive real-time feedback on their work, and instructors can track progress more effectively. This feedback loop is instrumental in the learning process, helping students identify areas that require improvement and guiding their skill development. This body of research underscores the importance of tailoring teaching methods to bolster spatial visualization skills, equipping students with essential tools to excel in multifaceted disciplines and adapt to evolving educational paradigms. Moreover, the utilization of technology like SketchUp in early technical and technological education showcases its potential to effectively improve students' spatial visualization abilities, regardless of their prior experiences or grade levels. This underscores the significance of introducing spatial modelling tools to support the development of spatial skills in children. Additionally, the influence of preliminary training in fine arts on subjects such as Engineering drawing, Strength of Materials, and Machine tools indicates that a combination of theoretical, conceptual, problem-oriented, and spatial visualization ideas has a notable impact on student performance in these areas, underscoring the adaptability of spatial skills through instruction. these findings collectively advocate for incorporating targeted training and innovative teaching tools, such as 3D models and CAD-based courses, to enhance spatial skills and problem-solving abilities, offering valuable implications for educators seeking to optimize their teaching methods in engineering and related fields.

6. Conclusion

Technology's role in enhancing visualization skills in learning engineering drawing is undeniable. It brings interactivity, real-world simulations, accessibility, and flexibility to the learning experience, catering to diverse learning styles and providing immediate feedback. Through tools like CAD software and virtual environment, learners are transported into a vividly detailed world, where complex engineering concepts transform into tangible visuals. This digital leap not only bridges the gap between theory and practice but also nurtures an intuitive understanding of engineering designs, fostering a generation of engineers equipped with a robust visual acumen. Thus, technology stands as a cornerstone in sculpting the future of engineering education, making learning not just informative but visually immersive and intuitive.

However, to fully harness the potential of technology, it is essential to address the associated challenges and continue to innovate pedagogical approaches. As technology continues to evolve, the future of engineering drawing education holds even more promise in preparing students for successful careers in engineering and related fields.

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