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Keeping Pace with 21st Century Skills: The Role of Computer-Aided Design in Teaching Engineering Graphics and Design

Zime Ngcobo*
The University of the Witwatersrand
Johannesburg, South Africa

Abstract. In the era of the Fourth Industrial Revolution, the cultivation of 21st-century skills, such as creativity, critical thinking, collaboration, and digital literacy, has become increasingly important in technical education. This study examined the role of computer-aided design (CAD) in enhancing the teaching and learning of Engineering Graphics and Design in South African schools. It addresses the gap in knowledge about teachers' technological readiness and pedagogical integration by exploring their attitudes toward CAD use and its potential to develop essential learner competencies. Guided by an interpretivist paradigm, the study employed a qualitative systematic synthesis of 10 peer-reviewed articles published between 2020 and 2025, retrieved from SCOPUS, Google Scholar, and Web of Science. Using the PRISMA 2020 framework and the integrated TPACK–P21 framework, Boolean search strings related to "AutoCAD", "engineering graphics and design", and "21st-century skills" were applied. Thematic analysis revealed that teachers acknowledge CAD's value in improving students' spatial visualisation and fostering innovation, but widespread adoption is hindered by challenges such as limited access to technology, expensive software licences, and inadequate professional development. The study recommends targeted teacher training, curriculum updates, and sustainable resource allocation to support CAD integration in Engineering Graphics and Design instruction. By linking traditional drawing techniques with digital pedagogies, this research contributes to technology-integrated education and provides practical insights for advancing digital teaching strategies. Its findings extend beyond South Africa, offering globally relevant recommendations for aligning technical education with the demands of a rapidly evolving, technology-driven world.

Keywords: computer-aided design (CAD); Engineering Graphics and Design (EGD); 21st-century skills; teacher readiness; TPACK

*Corresponding author: Zime Ngcobo; *zime.ngcobo@wits.ac.za*

1. Introduction

Engineering Graphics and Design (EGD) is a subject in the South African school curriculum designed to teach internationally recognised drawing principles and has applications in both academic and technical contexts (Department of Basic Education, 2011). The discipline emphasises technical drawing skills, as well as abstract thinking, visualisation, and interpretation of mechanical, civil, and electrical design problems (Department of Basic Education, 2011).

Certain areas of EGD, particularly isometric drawing, require learners transform two-dimensional orthographic representations into three-dimensional isometric views, which requires advanced spatial reasoning and visualisation skills because of the highly abstract nature of the task (Mlambo et al., 2023). This highlights the need for innovative pedagogical approaches that integrate digital technology to support learners in mastering complex drawing concepts. During the Fourth Industrial Revolution (4IR), education systems worldwide are under pressure to prepare learners for future work environments that demand essential 21st-century skills and personal qualities that extent beyond classroom learning. These skills encompass critical thinking, creativity, collaboration, communication, and digital literacy (Voogt & Roblin, 2012). In EGD, these skills translate into the ability to solve design problems, apply creative reasoning to technical tasks, and use digital tools to visualise and effectively communicate design ideas.

However, the persistent reliance on static, manual drawing methods has limited opportunities for developing such competencies. Traditional chalkboard teaching of isometric drawings, which relies heavily on static 2D representations, does not adequately support the development of these skills. In contrast, technology-enhanced instruction, particularly through computer-aided design (CAD) software, such as the commonly used AutoCAD, provides learners with interactive and dynamic platforms to engage with design problems. CAD tools allow learners to manipulate objects, rotate models, and test design solutions virtually, thereby fostering spatial reasoning, creativity, and iterative problem-solving competencies that align directly with 21st-century learning outcomes (Kok & Bayaga, 2019).

CAD is widely used in professional engineering and design industries, making it a relevant educational tool for bridging school learning with workplace practice. Research showed that CAD enhances learners' ability to visualise 3D objects, improves their technical accuracy, and develops transferable skills that are applicable across STEM disciplines (Sailer et al., 2021). By integrating CAD into EGD instruction, learners not only gain mastery over difficult concepts such as isometric drawing but also acquire digital competencies essential for future employability in engineering and technical fields.

Furthermore, CAD supports the principles of inclusive education by enabling multiple means of representation and expression, which are key to addressing diverse learner needs. However, studies indicated that many in-service teachers lack the technological pedagogical skills necessary to integrate CAD effectively, often because of insufficient training or resistance to adopting new tools (Alazam et al., 2014; Mlambo, 2024). This skills gap represents a critical barrier to transforming EGD teaching into a truly 21st-century, inclusive learning experience.

1.1 Problem Statement

Despite the acknowledged value of CAD in improving spatial visualisation and fostering 21st-century competencies, learner performance in isometric drawing continues to be a major concern in South African EGD classrooms. The Department of Basic Education's (2023) Grade 12 EGD diagnostic report consistently identifies learners' inability to convert 2D orthographic drawings into 3D isometric projections as a weakness, with poor results recorded from 2019 to 2023. This persistent underperformance has been linked to learners' limited spatial visualisation abilities and the continued use of traditional, chalkboard-based teaching methods (Mlambo, 2024).

The abstract and spatially complex nature of EGD requires dynamic instructional approaches that support learners in visualising three-dimensional structures, an aspect inadequately addressed through static, two-dimensional techniques (Yue & Chen, 2001). CAD tools such as AutoCAD have been shown to provide interactive 3D environments that promote deeper conceptual understanding and problem-solving (Kok & Bayaga, 2019; Xie et al., 2018), but their integration into classroom practice remains limited because of systemic and pedagogical barriers. The integration of digital technologies into classroom teaching in the 21st century is important but shaped by contextual factors such as the availability of technological resources, students' adaptability, and institutions' level of preparedness (Ampo et al., 2025).

In-service teachers often lack the technological pedagogical knowledge and confidence required to effectively integrate CAD into EGD instruction. Negative attitudes toward technology, coupled with insufficient pre-service exposure and ongoing professional support, further hinder the adoption of digital teaching methods (Alazam et al., 2013; Mlambo et al., 2023). Consequently, learners are deprived of the interactive, technology-enhanced experiences that could improve their spatial reasoning, creativity, and problem-solving skills, competencies vital for academic success and future employability. Addressing this gap in teacher readiness is therefore essential for transforming EGD education in South Africa.

Strategic interventions, including technological pedagogical content knowledge (TPACK)-based professional development, curriculum alignment, and improved access to CAD resources, are necessary to bridge the divide between traditional teaching practices and the digital skills demanded by the contemporary industry (Mhlungu & Mlambo, 2025).

1.2 Research Objectives

- To investigate EGD teachers' technological pedagogical readiness for integrating CAD into teaching;
- To explore teachers' attitudes and experiences regarding CAD use in EGD classrooms;

- To evaluate how CAD integration contributes to the development of learners' 21st-century skills, including critical thinking, collaboration, and digital literacy; and
- To propose strategies for effective teacher training and curriculum support that enable the integration of CAD for inclusive and effective EGD teaching.

1.3 Research Questions

- What are the current levels of readiness, knowledge, and attitudes among in-service EGD teachers regarding the integration of CAD into teaching?
- How can CAD integration support the development of 21st-century skills such as digital literacy, critical thinking, and collaboration in EGD classrooms?
- What training and support strategies are needed to equip teachers with the technological pedagogical knowledge required for effective CAD integration in EGD?

1.4 Significance of the Study

This study makes a significant contribution to the field of technology-integrated education by demonstrating how CAD can enhance the teaching and learning of EGD in secondary schools. It bridges the gap between traditional technical drawing practices and 21st-century pedagogical approaches that emphasise creativity, collaboration, critical thinking, and digital literacy. By employing a qualitative systematic synthesis, the study provides a comprehensive understanding of how CAD supports the development of essential learner competencies while identifying barriers such as inadequate teacher training, limited resources, and insufficient technological infrastructure. Through this, the research advances theoretical and practical knowledge on the integration of digital tools in technical education, offering evidence-based insights into the pedagogical value of CAD.

Furthermore, the manuscript contributes to the global discourse on digital transformation in education by contextualising CAD integration in South Africa, a setting that represents other developing contexts facing similar technological and pedagogical challenges. It provides actionable recommendations for curriculum design, teacher professional development, and policy reform and positions CAD as a critical enabler of inclusive and future-oriented learning. The study thus extends its relevance beyond the South African context, informing international efforts to align technical education with global educational priorities such as the United Nations' Sustainable Development Goal 4 on quality education. In doing so, it reinforces the role of digital pedagogies in preparing both teachers and learners for the demands of a technology-driven world.

2. Literature Review

This section reviews existing research on the integration of CAD resources in the teaching and learning of EGD. It looks at how CAD supports the development of 21st-century skills such as creativity, critical thinking, problem-solving, and spatial visualisation, and identifies persistent barriers to its effective use in secondary school education. Grounded in both local and international studies, the review highlights gaps in teacher preparedness, access to technology, and curriculum alignment that hinder meaningful integration of digital tools in EGD classrooms. By integrating theoretical and empirical perspectives, this section creates a foundation for understanding how CAD can transform EGD pedagogy in South Africa and beyond by providing a framework for addressing the technological and pedagogical challenges that accompany digital innovation in technical education.

2.1 Current Pedagogies in Teaching EGD

EGD is a core technical subject offered at further education and training level. According to the EGD Grade 10–12 Curriculum and Assessment Policy Statement document, one of the objectives of the subject is to delve into the core knowledge and principles that underpin the disciplines of mechanical technology, civil technology, and electrical technology, (Department of Basic Education, 2011). These fields are rooted in engineering, which applies scientific knowledge and mathematical principles to solve practical problems and design functional systems.

Isometric drawing plays a huge role in EGD education to expose learners to the 3D aspects of objects. This pictorial projection displays all three dimensions of an object in a single view, allowing for direct measurement of their true sizes, if needed. Isometric drawings provide a visual representation of an object's form, making it readily understandable, even for those unfamiliar with orthographic projection (Department of Basic Education, 2011).

This type of drawing presents the object's length, width, and height (or depth/thickness) simultaneously, giving the observer a clear understanding of its overall shape and dimensions. Mlambo (2024) noted that isometric drawings use various lines and hatching styles, each with distinct visual representations. According to Kok (2020), this information is crucial when converting between 3D and 2D representations, regardless of the direction of conversion (see Figure 1).

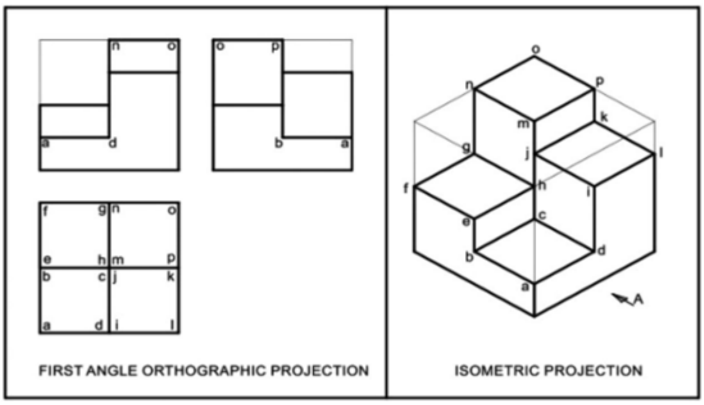

Figure 1: A model to explain 2D to 3D visuospatial cognition (Kok, 2020)

Khoza (2017) studied the pedagogical content knowledge and teaching practices of EGD teachers and found that teachers face significant challenges in South

African public schools. A key finding is the severe constraint of limited instructional time that hinders teachers' ability to adequately cover the curriculum. This time pressure is compounded by a scarcity of essential resources. Furthermore, Khoza (2017) pointed out that teachers reported shortages of traditional drawing instruments and physical models, which are crucial for hands-on learning. Even more concerning is the lack of access to updated, technology-based resources, depriving both teachers and learners of opportunities to engage with modern tools and techniques.

These resource limitations, coupled with the time constraints, significantly compromise the quality of education, particularly in areas like isometric drawing. Isometric drawing requires learners to develop and apply spatial reasoning skills to mentally manipulate 2D shapes to visualise their 3D forms. This skill is already challenging for many learners, and the absence of adequate resources and sufficient instructional time makes it even more difficult for teachers to effectively support learners' development in this critical area. Ultimately, these combined challenges create a significant barrier to learners' mastery of essential EGD concepts.

Mtshali (2023) perceived TPACK as a paramount additional kind of knowledge that EGD teachers should have. This type of knowledge is highly relevant in the 21st century, as it enables teachers to design and deliver lessons that foster key competencies such as problem-solving, critical thinking, and digital literacy. The TPACK framework, developed by Mishra and Koehler (2006), provides a valuable lens for understanding how teachers effectively integrate technology into their instruction. Developing TPACK is an ongoing process that requires teachers to experiment, reflect, and continuously refine their practice to effectively leverage the potential of technology for teaching and learning.

According to Mlambo et al. (2023), there are two primary factors that affect the use and adoption of CAD software: A lack of access to technological resources, meaning schools may not have the necessary hardware or software, and a lack of teacher training and expertise to effectively use digital technology resources such as CAD software. These limitations create barriers to effective CAD integration, hindering learners' ability to develop crucial spatial skills and potentially limiting their understanding of isometric drawing and other related EGD concepts. Essentially, the potential of CAD to transform EGD instruction remains largely untapped because of the lack of resource and knowledge gaps.

2.2 Role of CAD in Teaching EGD

CAD is internationally recognised as a transformative tool in EGD because of its capacity to support spatial visualisation, precision, and creativity. In higher education contexts, CAD software enables learners to manipulate three-dimensional objects, rotate views, and simulate real-world design challenges, thereby bridging abstract concepts with practical application (Yue, 2006). Studies from the United States and Europe consistently showed that CAD enhances learners' visuospatial abilities and reduces cognitive load by offering dynamic visualisations that are not possible through traditional static drawing methods

(Martín-Dorta et al., 2008) and (Dilling & Vogler, 2021). Furthermore, CAD allows for iterative design processes in which students can experiment with prototypes, test errors, and refine solutions, fostering problem-solving and innovation, key skills for future engineers and designers (Bernal et al., 2021). These affordances align strongly with the educational demand for integrating technology into STEM education to develop both technical and higher order thinking skills. Beyond improving visualisation and technical accuracy, CAD also facilitates collaborative and project-based learning environments, essential in preparing students for global professional practices. Research in Asia highlighted how CAD-integrated classrooms promote teamwork and communication as learners work on shared design projects using cloud-based CAD platforms (Ismail, et al., 2025).

Similarly, studies in Australia demonstrated that CAD supports inquiry-based and design-oriented pedagogies to allow students to engage in authentic engineering tasks and transfer learning to real-world contexts (Shih & Sher, 2021) and (Moore, et al., 2020). These international findings underscore the broader affordances of CAD in education, not only as a technical drawing tool but also as a pedagogical enabler that cultivates 21st-century skills, including creativity, collaboration, and digital literacy. The literature thus positioned CAD as a central resource in rethinking EGD education to meet the demands of rapidly evolving technological industries.

Mtshali (2023) stated that CAD software is a powerful technological tool for enhancing teaching and learning in EGD. Isometric drawing, a core concept in EGD, demands strong spatial reasoning abilities that require learners to mentally visualise a 2D object as if it were a 3D form, rotating it in their minds to view it from different perspectives. CAD offers a significant advantage in this regard, as it allows for the dynamic demonstration and display of objects in three dimensions. This visual representation can greatly aid learners in developing their spatial understanding and making the abstract concept of isometric drawing more concrete. However, despite the potential benefits of CAD, several obstacles prevent learners from fully benefiting from this technology.

Xie et al. (2018) argued that CAD tools with modelling and simulation capabilities offer effective platforms for engineering design education. This is because much of design thinking is abstract and generally applicable, making it learnable through the creation of functional computer models and transferable to real-world problems. CAD software provides learners with the ability to bring abstract and impossible objects to life, instead of making assumptions about the specific shape and appearance of the object.

Yue (2006) emphasised the long-recognised importance of spatial visualisation skills in engineering graphics education. The introduction of CAD into classrooms in the 1980s, coinciding with the rise of microcomputers, marked a significant shift. Since then, the advancements in both computer hardware and software have been remarkable, leading to the widespread adoption of 3D solid modelling CAD in various industrial applications. Consequently, spatial visualisation proficiency is no longer just beneficial but has become a necessary skill for learners pursuing degrees in engineering and technology fields. These technological advancements and their impact on industry have reignited and intensified teachers' focus on developing and enhancing learners' spatial visualisation abilities. Virtual manipulatives, like CAD software used to teach isometric drawing, offer a promising avenue for improving the teaching and learning of spatial skills (Moyer-Packenham & Westenskow, 2013). This potential highlights the importance of researching and developing effective methods and resources for spatial skills instruction.

2.3 Conceptual Framework

The conceptual framework for this study was guided by the integration of two key models: the TPACK framework and the partnership for 21st century learning (P21) framework. The TPACK model (Mishra & Koehler, 2006) provides a lens for examining the specific knowledge teachers need to integrate technology effectively. It breaks down a teacher's expertise into three core domains: content knowledge, pedagogical knowledge, and technological knowledge. In the context of this study, content knowledge refers to the teacher's deep understanding of EGD principles and isometric drawing; pedagogical knowledge relates to effective teaching methods for these concepts; and technological knowledge involves knowing how to use CAD software like AutoCAD. The synthesis of these three areas, TPACK, is the relevant, holistic knowledge that enables a teacher to use CAD as a transformative tool, not just as a digital replacement for a drawing board.

While TPACK focuses on the teacher's knowledge, the P21 framework provides the broader context by defining the skills learners need to succeed in the modern world (Khodamoradi, 2024). This framework emphasises skills such as creativity, critical thinking, collaboration, and communication. Integrating these two frameworks allowed for a comprehensive study. By teaching isometric drawings with CAD, a teacher is not only imparting content knowledge (EGD principles) but also fostering key 21st-century skills. For instance, using CAD software in EGD promotes critical thinking as learners must analyse a 3D object to represent it accurately in 2D. It also fosters creativity as they can digitally manipulate and innovate designs, and it encourages communication and collaboration when working on group projects or sharing designs in a digital format (Henríquez & Hilliger, 2024).

The research was therefore guided by a conceptual framework where TPACK and P21 were interconnected, as shown in Figure 2. The study explored how a teacher's development of TPACK (i.e., their ability to seamlessly combine their knowledge of EGD, teaching methods, and CAD software) directly leads to the effective development of 21st-century skills in their learners. This approach moves the focus beyond simply measuring learners' ability to draw an isometric view in CAD, and instead, it assesses how this technology-driven learning experience enhances their problem-solving, innovation, and teamwork abilities, preparing them for future careers. The integrated framework served as a roadmap for investigating how an intentional, technology-rich pedagogical approach can both impart foundational knowledge and equip learners with the essential competencies for a technology-driven professional landscape.

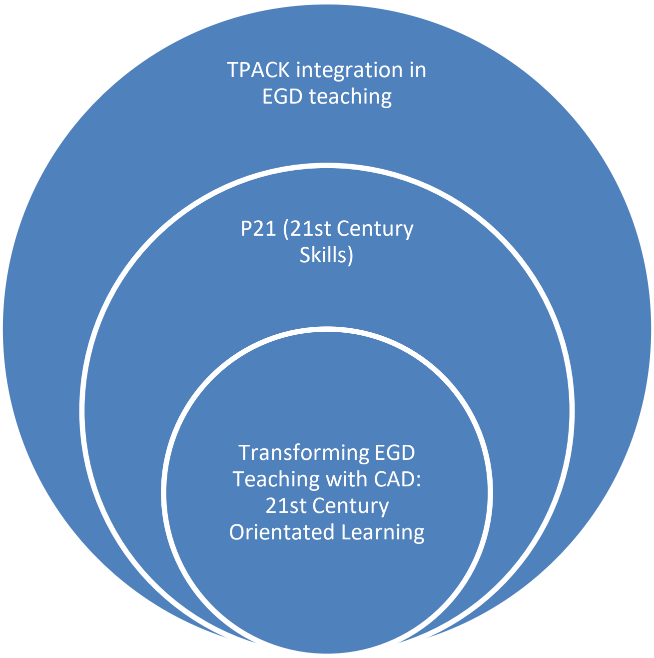

Figure 2: The Integrated TPACK–P21 Framework for CAD-Based EGD Teaching

The reviewed literature highlighted the immense potential of CAD to transform EGD instruction and promote 21st-century skills. However, a clear research gap exists in understanding how South African EGD teachers practically integrate CAD, given their varying levels of technological readiness and training. Most existing studies focused on conceptual benefits or technical affordances rather than on exploring teacher experiences, contextual barriers, and curriculum alignment. Therefore, this study sought to fill this gap by systematically synthesising recent empirical evidence (2020–2025) to examine how CAD integration can enhance both teaching practices and learner skill development in EGD classrooms.

3. Methodology

This study employed a qualitative systematic synthesis to explore how CAD contributes to the development of 21st-century skills in the teaching and learning of EGD. The approach was guided by an interpretivist paradigm, which emphasises understanding meaning and experience rather than quantification. This constructive and interpretive methodology was ideal for gaining a deep understanding of the 'what', 'why', and 'how' of teaching practices (Lim, 2025). The synthesis drew upon previously published empirical studies to identify themes related to teachers' readiness, pedagogical practices, and challenges integrating CAD tools into EGD classrooms.

The research operated within the interpretivist paradigm, driven by the subjective experiences and perceptions of teachers regarding CAD integration. This approach acknowledges that knowledge is not a linear process and that there is no single path to intellectual growth (Potrac et al, 2014). The study recognises that the beliefs and teaching choices of EGD teachers are a reflection of their personal experiences. Consequently, an inductive research approach was employed to closely examine the causes of challenges and reach conclusions based on the personal experiences shared by teachers.

3.1 Identification and Selection of Data

A rigorous identification and selection process was conducted to ensure methodological transparency and reliability. The review focused on peer-reviewed articles published between 2020 and 2025, obtained from three major databases: SCOPUS, Google Scholar and Web of Science. The 2020–2025 period was chosen to reflect the significant and accelerated adoption of digital technologies in education, largely influenced by the COVID-19 pandemic. To enhance representativeness, additional exploratory searches were performed on the Web of Science database.

To systematically and reproducibly identify the most pertinent studies, a Boolean-guided search string was used. The search string was validated by two experts in technical education and educational technology, respectively, to ensure alignment with the study's focus and terminology. This structured method, which combines keywords with logical operators like AND and OR, allowed for a precise retrieval of articles, ensuring the search process was both rigorous and verifiable.

The following specific search string was used to extract data from SCOPUS: ("computer aided design" OR "CAD" OR "AutoCAD")) AND ("isometric drawing*" OR "engineering graphics and design" OR "EGD" OR "technical drawing*" OR "spatial visualization")) AND ("teaching" OR "instruction" OR "education" OR "pedagogy" OR "teacher*" OR "learning")) AND ("21st century skill*" OR "digital literacy" OR "creativity" OR "critical thinking" OR "problem solving" OR "collaboration" OR "innovation")) AND ("Secondary schools" OR "High schools")) AND ("South Africa").

Furthermore, the inclusion criteria in Table 1 was used for the literature search and selection, and the following new search string was generated: (TITLE-ABS-KEY ("computer aided design" OR "CAD" OR "AutoCAD") AND TITLE-ABS-KEY ("isometric drawing*" OR "engineering graphics and design" OR "EGD" OR "technical drawing*" OR "spatial visualization") AND TITLE-ABS-KEY ("teaching" OR "instruction" OR "education" OR "pedagogy" OR "teacher*" OR "learning") AND TITLE-ABS-KEY ("21st century skill*" OR "digital literacy" OR "creativity" OR "critical thinking" OR "problem solving" OR "collaboration" OR "innovation") AND TITLE-ABS-KEY ("Secondary schools" OR "High schools") AND TITLE-ABS-KEY ("South Africa")).

Table 1: Inclusion criteria for literature search

Publication period	2020–2025
Type of document	Article, book chapter, book, review, conference paper
Subject area	Technology and engineering education domain, focusing specifically on EGD
Study focus	CAD use in EGD or related technical drawing subjects
Study setting/Education level	Secondary school level
Population	Teachers, learners, or mixed participants
Research method	Qualitative, quantitative, or mixed-methods
Language	English
Country or region	South Africa
Database sources	SCOPUS, Google Scholar and Web of Science

The following exclusion criteria were used:

- Studies not related to education or CAD integration;
- Grey literature, conference abstracts, or unpublished dissertations;
- Studies not based on secondary school settings; and
- Articles without accessible full texts.

A comprehensive search yielded a total of 62 records across the SCOPUS and Google Scholar databases, supplemented by additional searches in the Web of Science. To present the systematic process of study extraction and selection of studies, a Preferred Reporting Items for Systematic qualitative synthesis and Meta-Analyses (PRISMA) diagram was used. This diagram, shown in Figure 3, based on the guidelines by Moher et al. (2009), provided a clear, step-by-step visual representation of how articles were identified, screened, and included in the review, ensuring the process was both transparent and reproducible.

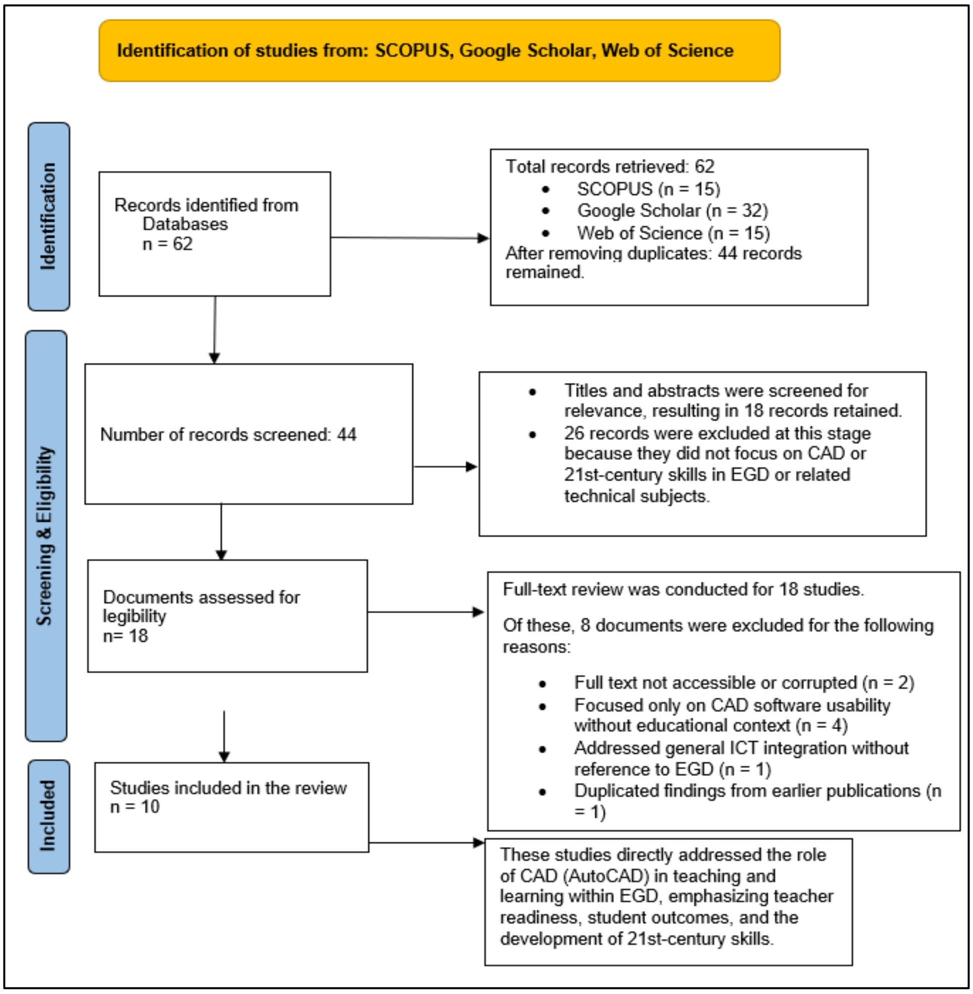

Figure 3: PRISMA diagram for data selection

3.2 Data Analysis

The data were analysed using thematic analysis and followed the six-step process outlined by Braun and Clarke (2006): familiarisation, coding, theme generation, reviewing, defining, and reporting. Through this process, two dominant themes emerged:

- Teachers' readiness and TPACK; and
- The transformative role of CAD in promoting 21st-century skills.

The results were synthesised narratively to highlight convergence and divergence across studies, ensuring analytical coherence and traceability to the research objectives.

4. Findings and Discussion

This systematic qualitative synthesis examined the complex dynamic of integrating CAD into the teaching of EGD in South African secondary schools. In the era of the 4IR, equipping learners with 21st-century skills such as critical thinking, creativity, collaboration, and digital literacy is important to prepare them for future work environments.

Based on a systematic qualitative synthesis of ten relevant studies, two main themes emerged regarding the integration of CAD into EGD instruction. The findings address key objectives related to teacher readiness, the development of 21st-century skills, and effective teacher training. The identified themes are 1) teachers' readiness and TPACK, and 2) the transformative role of CAD in promoting 21st-century skills. Table 2 below discusses these themes, supported by the literature.

Table 2: Data extracted from the six relevant studies

Author(s) and year of publication	Study methodology	Research context	Findings related to teachers' integration of CAD into EGD teaching and the development of 21st-century skills	Themes
Mlambo (2024)	Qualitative; semi-structured interviews	Secondary schools	Teachers observed that learners struggled with spatial visualisation, a skill central to isometric drawing. AutoCAD was used to provide dynamic visual aids, improving understanding.	Transformative role; attitudes toward CAD
Mlambo et al. (2023)	Qualitative; semi-structured interviews	Secondary schools	Some teachers indicated a lack of educational software like AutoCAD because the licence is expensive and there is a shortage of computers that can support AutoCAD.	Teachers' readiness; technological pedagogical skills
			Some teachers indicated that they do not have information and communication technology (ICT) tools to support the integration.	Teachers' readiness; technological pedagogical skills
			EGD teachers from uMgungundlovu District are integrating ICT into teaching and learning, as most were exposed to technology during their training at university	Transformative role; attitudes toward CAD
Maeko (2025)	Qualitative; interviews; classroom observations	Secondary schools	When integrating ICT into their lessons, teachers revealed that they employ a variety of software and online platforms that facilitate interactive and immersive learning	Transformative role; attitudes toward CAD

Author(s) and year of publication	Study methodology	Research context	Findings related to teachers' integration of CAD into EGD teaching and the development of 21st-century skills	Themes
			environments, allowing learners to visualise complex engineering concepts and engage with design processes in real time.	
			Teachers revealed that ICT tools, such as CAD software, help improve the accuracy of linework and reduce errors in drawings, allowing learners to focus on the creative aspects of problem-solving.	Transformative role; attitudes toward CAD
			The worksheets given to learners were prepared before using AutoCAD, which showed that the teachers' choice of technology was relevant to the content being taught and was exceptional	Transformative role; attitudes toward CAD
Mhlungu & Mlambo (2025)	Qualitative; semi-structured interviews	Secondary schools	Lack of ICT resources as a significant barrier to integrating technology into EGD classrooms.	Teachers' readiness; technological pedagogical skills
			Four of five teachers had never received CAD-specific training. Limited hardware and outdated software restricted teaching innovation.	Teachers' readiness; technological pedagogical skills
Mlambo (2023)	Qualitative; semi-structured interviews	Secondary schools	Several teachers indicated that their biggest challenge is the lack of availability of ICT resources in schools.	Teachers' readiness; technological pedagogical skills
			One challenge is the lack of educational software	Teachers' readiness; technological pedagogical skills
Zwane et al. (2021)	Systematic qualitative synthesis	Secondary schools	It is also required that learners use advance technological drawing	Transformative role; attitudes toward CAD

Author(s) and year of publication	Study methodology	Research context	Findings related to teachers' integration of CAD into EGD teaching and the development of 21st-century skills	Themes
			methods using CAD to be relevant in the 21st century and the 4IR.	
Mtshali (2023)	Qualitative; document analysis; semi-structured interviews	Secondary schools	It was apparent that CAD cannot be ignored as means to aid learners' mastery of content representation.	Transformative role; attitudes toward CAD
Candiote (2023)	Mixed-methods approach; document analysis; surveys	Secondary schools	The resources needed to offer CAD include not only the hardware and software but also the licencing. Many respondents suggested that they do not even have a venue available for the infrastructure.	Teachers' readiness; technological pedagogical skills
			Many participants stated that they were not receiving the support they needed to use CAD successfully. The results showed that the participants' attitude towards CAD were mainly due to the lack of, or limited, training.	Teachers' readiness; technological pedagogical skills
			It is important to have CAD instruction at least once a week in Grage 10 to cover the basic principles of the programme in time. The participants agreed that CAD is perceived as useful because of its importance in completing of the practical assessment task and for further career opportunities	Transformative role; attitudes toward CAD
			Teachers expressed a strong need for content workshops to enhance their confidence and competence in teaching.	Teachers' readiness; technological pedagogical skills

Author(s) and year of publication	Study methodology	Research context	Findings related to teachers' integration of CAD into EGD teaching and the development of 21st-century skills	Themes
Blose (2023)	Qualitative; semi-structured interviews; classroom observation	Secondary school	The teacher had limited awareness of the various methods and digital technology resources that can be used to teach graphics. As a result, learners' ability to grasp visuals are restricted by their inadequate comprehension and expertise.	Teachers' readiness; technological pedagogical skills
Maeko, Mlambo & Khoza (2023)	Qualitative; semi-structured interviews; classroom observation	Secondary schools	In terms of TCK, the study showed that teachers are able to select and utilise technologies that are well-suited to conveying EGD content, such as using AutoCAD to reinforce technical drawing skills or videos to explain spatial relationships.	Teachers' readiness; technological pedagogical skills

4.1 Major Findings

4.1.1 Teacher Readiness and the Lack of CAD Integration

The study's findings consistently reveal structural and professional constraints that severely impede the integration of CAD into EGD instruction. This confirms the well-documented promise versus structural constraints dynamic, where the potential benefits of technology are undermined by a lack of institutional support and resources (Mulaudzi, 2024). A primary barrier identified across multiple studies is the severe lack of physical resources. Mlambo et al. (2023) and Mhlungu and Mlambo (2025) both highlighted that teachers face a critical shortage of ICT tools and computers powerful enough to run sophisticated software like AutoCAD. This is a fundamental challenge, as the software's demanding technical specifications mean it cannot run on outdated or underpowered equipment.

Beyond hardware limitations, the high cost of CAD licences and the limited provision of educational software by schools present significant financial barriers (Mlambo, 2023). This lack of access forces teachers to rely on outdated methods or, in some cases, to not use the technology at all. The problem is compounded by a profound lack of professional development. Mhlungu and Mlambo (2025) uncovered a startling finding: Four out of five teachers have not received any EGD content-specific training since the start of their careers. This systemic lack of ongoing training means teachers are not equipped with the necessary technological pedagogical knowledge to effectively use CAD. They may have the foundational content knowledge of EGD, but without training, they lack the skills to integrate technology in a way that enhances learning. This underscores the critical need for sustained teacher support and development. This skills gap undermines the potential of CAD to transform EGD teaching into a 21st century learning experience.

4.1.2 The Transformative Role of CAD in EGD to Develop 21st Century Skills

Despite the significant barriers to implementation, the findings reveal a clear recognition of CAD's potential to transform EGD instruction. Teachers see the software not just as a tool for drawing but as a powerful medium for enhancing learner understanding and developing crucial skills. A key finding is CAD's ability to help learners overcome the common and persistent challenge of spatial visualisation. Mlambo (2024) confirmed that the ability to mentally construct a 3D object from its 2D views is foundational to proficiency in EGD. By using CAD, teachers can provide learners with a dynamic, interactive environment that makes abstract concepts more concrete, directly bridging this cognitive gap that often hinders learning.

The transformative impact of CAD extends beyond simple visualisation, as its use is also instrumental in cultivating essential 21st-century skills. The precision of the software allows learners to create accurate drawings efficiently, freeing up cognitive resources to focus on the creative and problem-solving aspects of design (Maeko, 2025). This aligns with the principles of the P21 framework, which emphasises skills like critical thinking, creativity, and digital literacy. By integrating CAD, teachers can create a learning environment that not only imparts technical knowledge but also prepares learners for the demands of a technology-driven workforce, where the ability to use digital tools to solve complex problems is paramount (Ramatsetse et al., 2023).

4.1.3 Teachers' Attitudes to and Experiences with CAD Use

The findings reveal a significant dichotomy in teachers' attitudes toward CAD integration. On one hand, teachers perceive CAD as highly useful and relevant because of its importance in completing the practical assessment task and for learners' further career opportunities in engineering and technical fields (Maeko, Mlambo & Khoza, 2023). They recognise the software's ability to help learners visualise complex concepts, improve drawing accuracy, and focus on the creative aspects of problem-solving.

On the other hand, many teachers have a negative or hesitant attitude, primarily because of the lack of, or limited, training they have received. For teachers trained before the widespread adoption of digital technologies, the lack of technological pedagogical skills and insufficient exposure to the tools during their initial training creates a strong resistance to adopting new tools. This attitudinal challenge is directly linked to the identified barriers, creating a vicious cycle: Insufficient professional development (TPACK deficit) leads to negative or resistant attitudes, which in turn results in the limited use of CAD, despite recognising its value. The findings stress that merely providing access to the software is insufficient because the lack of teacher confidence and competence, stemming from inadequate training, is a psychological barrier to transforming EGD teaching. Addressing this attitudinal gap requires sustained, content-specific workshops to enhance teachers' confidence and competence, as requested by the teachers themselves.

The findings reveal a challenge rooted in the TPACK of EGD teachers. Although teachers universally recognise CAD's potential to revolutionise EGD instruction, specifically, its ability to significantly enhance spatial visualisation and drawing accuracy, this positive attitude is often outweighed by a profound lack of confidence in actual integration. This deficit stems directly from the scarcity of contextualised professional development programmes. Current training models frequently fail to address the specific pedagogical challenge of merging EGD concepts with complex software functionality. As a result, teachers, fearing a loss of instructional control or classroom time, default to familiar, traditional 2D drawing methods, thereby stalling the necessary technological shift and preventing them from cultivating the crucial skills required by the modern engineering and design industries.

The necessity of CAD integration is further validated by the P21 framework, which serves as the benchmark for educational outcomes. The dynamic nature of CAD-based learning directly supports the core 21st-century skills that traditional drawing methods cannot fully facilitate. By enabling learners to quickly model, test, and revise designs, CAD inherently fosters critical thinking (as students troubleshoot design failures) and creativity (as they explore multiple design solutions). Furthermore, proficiency in the software is a fundamental aspect of digital literacy and a direct prerequisite for technical careers. Thus, the inability to effectively integrate CAD does not just hinder EGD instruction; it represents a systemic failure to equip learners with the non-academic, high-value competencies essential for success in the globally interconnected, technology-driven workforce.

4.2 Developing 21st-Century Skills

The findings reveal that using CAD is a powerful way to cultivate essential 21st-century skills that go beyond traditional drawing competencies. According to Maeko (2025), teachers who effectively integrate ICT tools like CAD can create interactive and immersive learning environments that allow learners to visualise and engage with complex engineering concepts in real time. Beyond simply enhancing digital literacy, this approach also nurtures critical thinking as learners must use the software to analyse problems and arrive at design solutions. This shift from manual to digital creation empowers learners to focus on the higher order thinking skills crucial for their future careers.

Furthermore, the precision and efficiency of CAD software allow learners to perfect their designs, freeing up their cognitive resources to focus on the creative and problem-solving aspects of design. This aligns perfectly with the P21 framework, which champions creativity and critical thinking as foundational skills for success. Ramatsetse et al. (2023) reinforced this by highlighting that proficiency in both hand-drawing and CAD is a prerequisite for careers in engineering and architecture. Therefore, by integrating CAD, teachers are not just teaching a technical skill; they are preparing learners for the demands of a technology-driven professional landscape, ensuring they have the competencies to thrive in a competitive, modern workforce.

5. Limitations of the Review

Although this study offers significant insights into the integration of CAD into EGD and the role of CAD in fostering 21st-century skills, several critical knowledge gaps and practical challenges persist, demanding more focused future research. A major limitation was the heavy reliance on qualitative data, such as interviews and document analyses, with insufficient classroom-based empirical evidence. To move beyond anecdotal findings, future researchers must employ experimental or mixed methods designs to rigorously quantify the actual impact of CAD use on key student outcomes like spatial visualisation, creativity, and critical thinking. Furthermore, longitudinal studies are needed to track how sustained exposure to CAD influences learners' problem-solving and design competencies over their educational careers.

The future research agenda must address the systemic barriers related to professional development, equity, and policy. The TPACK deficit remains an issue, emphasising the need to study the effectiveness of targeted, iterative professional development programmes that specifically build teachers' confidence and skills to use CAD pedagogically, especially in resource-constrained settings. The issue of equity, the unequal distribution of technology, licensed software, and internet access, between urban and rural schools requires context-sensitive research to propose and evaluate practical solutions, such as adopting open-source CAD alternatives or using mobile tools. Finally, to ensure successful, broad-scale integration, researchers must examine how curriculum policies can be restructured to formalise CAD integration as a required learning and assessment tool, ensuring alignment with modern workforce demands and 4IR goals.

6. Conclusion

This study's systematic qualitative synthesis highlighted a critical dichotomy in the teaching of EGD: While CAD possesses immense potential to transform learning, its effective integration is severely hampered by significant structural and professional barriers. The findings show that when these constraints are overcome, CAD can serve as a powerful tool for enhancing learner spatial visualisation skills, a foundational component of EGD proficiency. This technological application not only makes abstract concepts more concrete but also aligns with the TPACK framework, demonstrating how a teacher's combined knowledge of technology, pedagogy, and content can create a truly effective learning environment.

The study's findings also confirm that the successful integration of CAD directly contributes to the development of essential 21st-century skills, as outlined by the P21 framework. By using the software, learners move beyond rote drawing to engage in higher-order thinking, fostering critical thinking, creativity, and problem-solving. This shift from manual to digital work prepares learners for the demands of modern engineering and design careers, where proficiency in digital tools is paramount. Therefore, integrating CAD is not just about updating teaching methods; it is about equipping learners with the competencies needed to thrive in a technology-driven world.

7. Recommendations

Based on the findings, it is recommended that educational stakeholders adopt a multi-pronged approach to overcome existing barriers and fully harness the potential of CAD in the classroom. This strategy should begin with contextualised professional development. Institutions should implement sustained, hands-on programmes that focus on developing teachers' TPACK. These programmes should pair subject specialists with technology coaches to provide practical, relevant training on using CAD to teach EGD concepts. Furthermore, a commitment to strategic resource allocation is essential. Educational authorities must prioritise investing in robust computer labs and securing affordable or free educational licences for software, ensuring equitable access for all learners.

To reinforce the importance of CAD, the EGD curriculum and practical assessment tasks should be updated to fully integrate the software. Making CAD use a core component of both teaching and assessment will ensure its value is recognised by both teachers and learners. Finally, teachers should be encouraged to use CAD as a vehicle for fostering key 21st-century skills from the P21 framework. By emphasising project-based learning and collaborative design, teachers can prepare learners for a modern workforce where digital literacy and problem-solving are paramount. By implementing these recommendations, schools can move beyond the current constraints and create a more inclusive and effective EGD learning environment that truly keeps pace with 21st-century skills.

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