

Teachers' perspectives on the application of Computer-Aided Design in teaching orthographic projection in Engineering Graphics and Design Grade 10, Limpopo Province

Dories Machabedi Mphahlele ¹, Ramongwane Daniel Sephokgole ¹ & Thokozani Isaac Mtshali ¹

¹ Tshwane University of Technology, Pretoria, South Africa.

ABSTRACT

This study explored teachers' perspectives on the application of Computer-Aided Design (CAD) in teaching orthographic projection in Engineering Graphics and Design (EGD) Grade 10, Limpopo, employing a qualitative case study design. Data was collected using semi-structured interviews and classroom observation. Purposive sampling yielded a sample of 9 schools, 9 EGD classrooms, 9 EGD teachers, and 257 learners. Using the Technological Pedagogical Content Knowledge (TPACK) framework, the study concluded that CAD is unequivocally effective and essential to improve EGD outcomes, as confirmed by teacher perspectives and classroom observation. To promote an effective integration of CAD in EGD education, the study recommends that systemic improvements are required in infrastructure, training, and policy across all educational levels. The Department of Education must prioritise the provision of functional Information and Communications Technology (ICT) resources and implement mandatory, ongoing professional development programs to build teachers' confidence and skills. School management teams and teachers are urged to ensure resource accessibility and actively pursue training and support to bridge the digital divide and improve learner outcomes in orthographic projections. The study's goal was to explore the application of CAD in the demonstration of learning orthographic projections in secondary schools in the Limpopo Province. In addition, analyses the teachers' competency in the application of CAD to promote ICT integration in the EGD classroom. Furthermore, this study will assist in improving the quality of the results in EGD.

Keywords: Orthographic projections, Engineering Graphics and Design, Information and Communication Technologies, Computer-Aided Design, Spatial Visualization.

INTRODUCTION

The advancement of information and communication technology (ICT) in the 21st century has brought about changes in enhancing teaching and learning experiences in 21st-century pedagogy. Furthermore,

CORRESPONDENCE – Dories Machabedi Mphahlele Email: dkgokga@gmail.com

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it has transformed traditional teaching and learning methods across academic fields.¹ Engineering Graphics and Design (EGD) is the medium for communicating through drawings in the engineering sector. In this regard, the learners in the EGD classroom learn to read, understand, and interpret graphical text. EGD plays a pivotal role in developing learners' spatial visualisation, problem-solving, and technical communication skills, which are foundational for further studies in engineering and technology-related fields.²

Within the Grade 10 curriculum, orthographic projection constitutes a core component of EGD. Orthographic projection is the “universal language of engineers,” and these two-dimensional (2D) drawings support the three-dimensional (3D) representation, such as the length, the height, and the width of an object. Orthographic projection requires learners to accurately interpret and represent three-dimensional objects in two-dimensional views, a cognitive task that many learners find abstract.³ In many Limpopo secondary schools, teaching and learning orthographic projections in EGD continues to be a major difficulty. Learners in grade 10 frequently struggle to comprehend and accurately convert 3D objects into 2D objects. This challenge is mainly due to inadequate teaching strategies, restricted access to ICT resources, and a dependence on conventional teaching methods.⁴ Therefore, mastering orthographic projections is essential to develop the ability of learners to interpret and communicate complex spatial information accurately, forming a critical foundation for understanding 3D and 2D design concepts. This study aims to explore and understand EGD teachers' perspectives on the application of Computer-Aided Design (CAD) in the teaching of orthographic projection in the Grade 10 classroom, Limpopo. Therefore, the following research questions seek to probe the teachers' perspectives on the application of CAD in teaching orthographic projection:

- What are teachers' perspectives on the application of CAD in teaching orthographic projection?
- How do teachers integrate technology into the teaching of orthographic projection lessons in the EGD classroom?

LITERATURE REVIEW

The application of CAD in the teaching of orthographic projections in the EGD classroom.

The application of CAD refers to the software used in the engineering industry for sketching, designing, developing, and producing various components.⁵ In this study, the researcher alluded to the application of CAD software, a computer/laptop, a projector, and a whiteboard/smart board as technological tools to improve teaching and learning of orthographic projections through ICT/CAD. Orthographic projection, a fundamental concept in EGD, requires learners to visualise and represent 3D to 2D objects. Orthographic projection is still one of the most conceptually challenging topics for learners in Grade 10 since it calls for a high degree of spatial thinking, precision, and visualisation. In addition, requires learners to develop and apply strong visualisation skills to accurately interpret and construct multiple views of an object. Mastery of this topic involves the ability to mentally manipulate and visualise objects from different perspectives, specifically the front, top, and side views, which is fundamental to understanding the principles of EGD. To illustrate these ideas, EGD teachers have traditionally used manual sketching techniques with tools such as T-squares, set squares, and compasses. Although these traditional methods are successful in helping learners acquire fundamental graphical abilities, they frequently restrict their capacity to dynamically visualise spatial linkages and transformations between 2D and 3D representations.⁶ Orthographic projection requires learners to develop and apply strong

¹ Philani Brian Mlambo, “Information and Communications Technology in Engineering Graphics and Design Classrooms: A Post COVID-19 Era,” *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika* 7, no. 2 (2023): 160–75.

² Samuel Dumazi Khoza, “Difficulties in Sectional Drawing: A Case of Student Teachers at a University Based in the Eastern Cape,” 2013.

³ G.V. Sharma and Ravikumar Dumpala, “Teaching of Mechanical Engineering Concepts through Three-Dimensional Geometric Modeling,” *International Journal of Mechanical Engineering Education* 43, no. 3 (2015): 180–90.

⁴ Moses Makgato and Samuel Khoza, “Difficulties Experienced by Pre-Service Teachers and Lecturers in Engineering Graphics and Design Course at a University in South Africa,” *International Journal of Educational Sciences* 14, no. 1–2 (2016): 157–66.

⁵ Sharma and Dumpala, “Teaching of Mechanical Engineering Concepts through Three-Dimensional Geometric Modeling.”

⁶ Sam Ramaila and Umesh Ramnarain, “Pedagogical Implications of the South African CAPS Curriculum in STEM Education,” *South African Journal of Education* 42, no. 1 (2022): 1–9.

visualisation skills to accurately interpret and construct multiple views of an object. Mastery of this topic involves the ability to mentally manipulate and visualise objects from different perspectives, specifically the front, top, and side views, which is fundamental to understanding the principles of EGD. EGD teachers are expected to possess specific competencies that support and enhance learning amongst learners. Therefore, to engage meaningfully with specific sections of the EGD curriculum, specifically to teach orthographic projections, they should be proficient enough to clearly explain and demonstrate orthographic concepts to learners and demonstrate that hidden edges from the view are drawn as dashed lines.⁷ Furthermore, they should be able to demonstrate how a change in one view affects other views in dimensioning and scale and are able to demonstrate how to convert 3D to 2D views. A teacher demonstrates content knowledge (CK) by deeply understanding the EGD Curriculum and Assessment Policy Statement (CAPS), especially the prescribed content on orthographic projections. This understanding enables teachers to grasp not only what must be taught but also the conceptual depth and progression embedded within the curriculum. The EGD CAPS describes the fundamental ideas, drawing conventions, and visualisation techniques that learners need to acquire to correctly depict three-dimensional objects in two dimensions. As a result, teachers with excellent CK can connect theoretical ideas to real-world drawing applications, organise lessons logically, and interpret the curriculum successfully.⁸ Furthermore, CK encompasses a conceptual grasp of how EGD fosters spatial reasoning, problem-solving, and visualisation abilities in addition to information.

The application of CAD in teaching orthographic projections embodies a sophisticated pedagogical approach that leverages technology to enhance learners' understanding and visualisation of complex graphical concepts. Teachers' lesson planning should be aligned to the CAPS curriculum, ensuring compliance with the Annual Teaching Plan (ATP) and prescribed textbooks.⁹ In this context, teachers who are well-versed in the EGD CAPS material are better able to match curriculum objectives with their lessons and assessment tasks, guaranteeing that learners acquire both technical accuracy and conceptual comprehension. The integration of CAD in the teaching of orthographic projections exemplifies the application of technological knowledge (TK), highlighting the pivotal role of digital tools in enhancing conceptual understanding and technical proficiency within EGD. In this study, TK is essential in a way that improves teachers' ability to select the appropriate available technology resources and use them to transform teaching and learning. Using technology tools, educators can dynamically demonstrate complex graphical concepts, allowing learners to interactively alter and investigate 2D and 3D representations. According to the demands of modern technical education, this integration reduces the gap between academic knowledge and real-world application while also enhancing learners' conceptual understanding.¹⁰ The introduction of CAD in EGD has significantly influenced the teaching and learning of orthographic projection, transforming how learners acquire and apply graphical communication skills. CAD offers immense potential to improve spatial visualisation, conceptual understanding, precision, and learner engagement, all of which are essential to mastering orthographic projection. By providing dynamic, visual, and interactive learning environments, CAD enables both teachers and learners to explore complex geometrical and design concepts with greater clarity and efficiency than traditional manual drawing methods.¹¹ The application of CAD in EGD classrooms has brought about a significant transformation in the quality of teaching and learning, particularly around orthographic projection. Studies discovered that CAD transforms abstract concepts into simpler, more accessible and understandable concepts.¹² Studies emphasise that the integration of

⁷ Akeem Usman, "Competencies Required by Technical Drawing Teachers in Technical Colleges," *IOSR Journal of Research & Method in Education (IOSRJRME)*, 2014.

⁸ Douglas Thembinkosi Sibusiso Sotsaka, "An Exploration of the Interface between Grade 11 Engineering Graphics and Design Teachers' Understanding of Assembly Drawing and Their Practice: A Case Study of the UThukela District, KwaZulu-Natal" (University of KwaZulu-Natal, 2015).

⁹ Albert Christoffel Kemp, "A Framework for Advanced Information Communication Technologies Integration within Higher Education Engineering Graphics and Design to Improve Spatial Visualization" (PhD thesis, North-West University, Potchefstroom, 2020).

¹⁰ Ramaila and Ramnarain, "Pedagogical Implications of the South African CAPS Curriculum in STEM Education."

¹¹ S. Molefe and T. Steyn, "Teacher Professional Development for Technological Integration in South African Secondary Schools," *Journal of Education and Practice* 12, no. 14 (2021): 11–22.

¹² Mlambo, "Information and Communications Technology in Engineering Graphics and Design Classrooms: A Post COVID-19 Era."

ICT and CAD makes abstract concepts in EGD more easily understood by the learners.¹³ However, the impact of CAD is not solely positive and depends greatly on teacher competence, resource availability, and pedagogical alignment. Studies in South African schools have revealed that some teachers face challenges in using CAD effectively due to inadequate training, limited access to computer laboratories, and inconsistent software licensing.¹⁴ Furthermore, CAD demonstrably offers significant pedagogical advantages; systemic constraints, specifically the lack of ICT resources in schools, critically limit its impact on teaching quality.¹⁵ Therefore, where these barriers exist, the quality of teaching and learning may be compromised, leading to uneven learner outcomes. Therefore, the successful use of CAD represents a critical advancement in improving both instructional quality and learner achievement in South African EGD classrooms.

THEORETICAL FRAMEWORK

The study adopted the theory of Technological Pedagogic Content Knowledge (TPACK) due to its relevance in the 21st century. TPACK is in line with the education system's need for technological transformation to suit the needs of the generation of learners in the digital era.¹⁶ TPACK is an emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology).¹⁷ Below is the TPACK model that underpinned the study

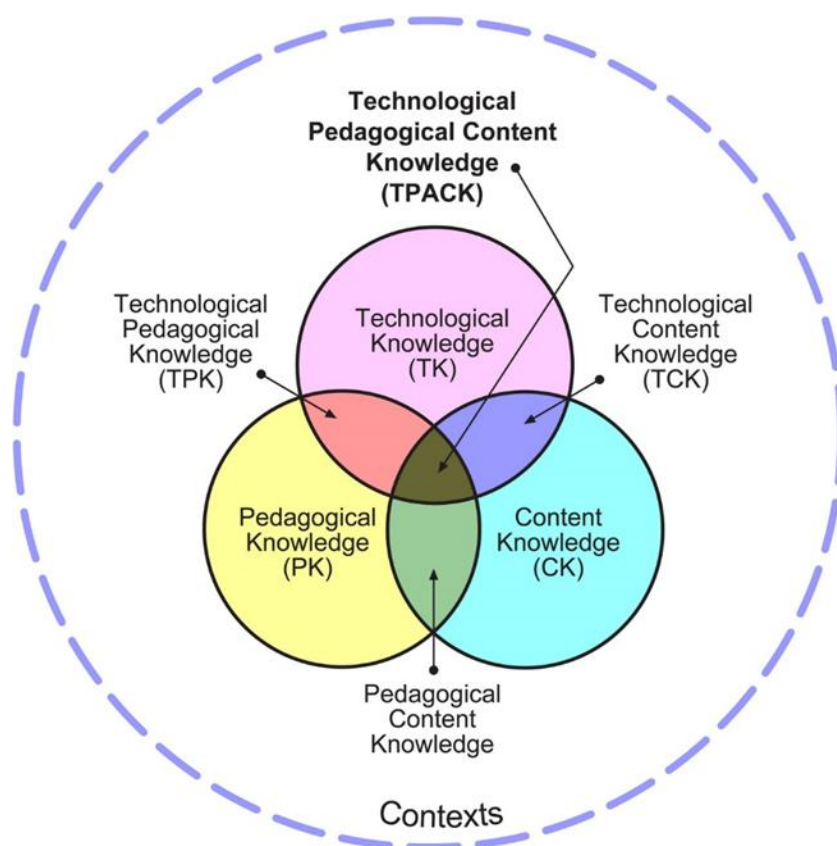


Figure 1: The TPACK Model (Mishra & Kohler, 2006)

¹³ Jorge Rodriguez and Luis G Rodriguez-Velazquez, "Spatial Visualization Skills in Courses with Graphics or Solid Modeling Content," in *2017 IEEE Global Engineering Education Conference (EDUCON)* (IEEE, 2017), 1778–81.

¹⁴ Molefe and Steyn, "Teacher Professional Development for Technological Integration in South African Secondary Schools."

¹⁵ Abdulwahab Alharbi, "A Review of the Internal and External Factors Affecting Teachers' ICT Use in Classroom," *International Journal of Education and Research* 9, no. 12 (2021): 105–16.

¹⁶ Harwati Hashim, "Application of Technology in the Digital Era Education," *International Journal of Research in Counseling and Education* 1, no. 2 (May 17, 2018): 1, <https://doi.org/10.24036/002za0002>.

¹⁷ Punya Mishra and Matthew J Koehler, "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge," *Teachers College Record* 108, no. 6 (2006): 1017–54.

TPACK is a framework that introduces the relationships and the complexities between all three basic components of knowledge (content, pedagogy and technology).¹⁸ It is worth mentioning that not all components of TPACK were used, but only three were, as they were relevant to the scope of the study. At the intersection of these three knowledge types is an intuitive understanding of teaching content with appropriate pedagogical methods and technologies.

Content Knowledge (CK)

CK is defined as the expertise in a particular topic to be learnt by the student teacher, as provided by the professors at the universities.¹⁹ Therefore, in this case, the EGD teacher should have good and up-to-date CK and skills in the subject matter, which is the orthographic projections concept in this study. CK refers to a teacher's comprehensive understanding of the subject matter they teach, including the underlying theories, principles, and concepts that shape the discipline. In the context of this study, CK is related to the mastery of orthographic projection by the teacher. This includes an in-depth understanding of orthographic projection principles, projection methods, spatial visualisations and conventions.

Pedagogical Knowledge (PK)

PK is the teachers' comprehensive knowledge concerning the teaching and learning strategies and techniques. It encompasses knowledge of how learners acquire and construct understanding and how to structure lessons, assess learning outcomes, and create supportive learning environments. Within the context of EGD, PK involves knowing how to teach complex graphical concepts such as orthographic projection in a manner that promotes learners' spatial reasoning, visualisation, and problem-solving skills. Teachers with strong PK can select and apply appropriate instructional strategies that align with learners' cognitive levels and prior experiences. Effective PK also allows teachers to diagnose and address common learning challenges, such as difficulties in visualising spatial relationships or understanding projection planes.²⁰

Technological Knowledge (TK)

TK is defined as the application of technological resources and devices.²¹ It involves knowing how to use technological tools effectively, troubleshoot common issues, and integrate them meaningfully into classroom instruction. In the context of EGD, TK encompasses the ability to use both traditional drawing instruments and modern technological tools such as CAD software to improve the graphical communication skills of learners. For EGD teachers, TK involves more than just using CAD software; it also entails comprehending how technology might change orthographic projection instruction and learning. Learners can handle 3D models, explore numerous perspectives, and gain a better understanding of how 2D representations connect to 3D objects.²²

Technological Pedagogic Content Knowledge (TPACK)

TPACK is knowledge that has emerged that surpasses the three key components, as it represents an understanding that comes from ongoing interactions among content, pedagogical, and technology knowledge. In this regard, the EGD teacher should have the ability to provide instruction thoroughly and effectively using digital technologies to demonstrate and learn orthographic projection. The TPACK framework emphasises how crucial it is to match CAD technology with both educational approaches and fundamental graphical content while teaching orthographic projections in the context of EGD. In addition to knowing how learners understand these abstract spatial concepts (PK) and the

¹⁸ Mishra and Koehler, "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge."

¹⁹ Sotsaka, "An Exploration of the Interface between Grade 11 Engineering Graphics and Design Teachers' Understanding of Assembly Drawing and Their Practice: A Case Study of the UThukela District, KwaZulu-Natal."

²⁰ Ramaila and Ramnarain, "Pedagogical Implications of the South African CAPS Curriculum in STEM Education."

²¹ Mishra and Koehler, "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge."

²² Ramaila and Ramnarain, "Pedagogical Implications of the South African CAPS Curriculum in STEM Education."

principles of projection (CK), teachers also need to know how to use CAD tools to improve visualisation, accuracy, and learner engagement (TK).

METHODOLOGY

This study deemed it appropriate to employ a qualitative research approach guided by the research purpose, which was to explore teacher perceptions when applying CAD to teach orthographic projection in a Grade 10 EGD classroom.²³ This approach is relevant to this study as it allowed an in-depth understanding of teachers' views on the application of CAD in teaching orthographic projection in EGD classrooms. A case study research design was employed to gain an in-depth understanding of teachers' views on the use of CAD in teaching orthographic projection, which is relevant to this study, as a case study is defined as an appropriate approach for answering descriptive or exploratory questions.²⁴ Nine (9) EGD schools and nine teachers, nine EGD classrooms and 257 learners from the three districts of Limpopo province were purposefully selected.²⁵ Data was collected using semi-structured interviews and classroom observation since the researchers aimed to detail the participants. All ethical considerations were followed, where information letters were sent to schools after permission to conduct the study was sought from the Department of Education, Limpopo.²⁶ Consent forms were issued to participants, and issues of voluntary withdrawal on or before the commencement of the study were mentioned.²⁷ The researcher also made it clear that there would be no remuneration for participating in the study and that the study would not cause any harm to the teachers.²⁸ In addition, the researcher applied for ethical clearance from the institution's (Tshwane University of Technology) ethics committee to follow the university protocol to conduct research.²⁹ The study used pseudonyms to shield the identities of the participating EGD teachers and learners. Furthermore, the data was kept confidential and private.

Table 1: The sampling of the study

Sampled Districts	Sampled Schools	Sampled Classroom	Sampled Teachers	Sampled Learners
District 1	School A	1	1	31
	School B	1	1	23
	School C	1	1	28
District 2	School D	1	1	37
	School E	1	1	16
District 3	School F	1	1	42
	School G	1	1	36
	School H	1	1	19
	School I	1	1	25
Total Districts =N3	N=9	N=9	N=9	N=257

²³ S. B Merriam and E. J Tisdell, *Qualitative Research: A Guide to Design and Implementation*, 4th ed, 2016.

²⁴ John Creswell, *Research Design: Qualitative, Quantitative and Mixed Methods* (Sage Publications., 2003).

²⁵ Louis Cohen, Lawrence Manion, and Keith Morrison, *Research Methods in Education*, vol. 6 (routledge London, 2009).

²⁶ C. C. Nnebue, "The Epidemiological Transition: Policy and Planning Implications for Developing Countries," *Nigerian Journal of Medicine* 19, no. 3 (2010).

²⁷ Lokesh P Nijhawan et al., "Informed Consent: Issues and Challenges," *Journal of Advanced Pharmaceutical Technology & Research* 4, no. 3 (2013): 134–40.

²⁸ Jean McNiff, "Action Research: All You Need to Know," 2017.

²⁹ Nnebue, "The Epidemiological Transition: Policy and Planning Implications for Developing Countries."

PRESENTATION OF FINDINGS

Presentation of Data from Semi-Structured Interviews Based on PK and TK.

Pedagogical Knowledge (PK)

How do you use CAD to show the application of orthographic projections in real-world scenarios?

To respond to the PK theme, this question explored the ways teachers introduce a topic and how they link it to real-world scenarios for learners to understand. The responses from the teachers produced the following sub-themes:

- Play the AutoCAD video
- Play PGegd video
- A cardboard box
- Physical 3D models
- Textbook, chalk and chalkboard

Play the AutoCAD video.

Most participants indicated that they play AutoCAD videos to show learners the application of orthographic projections in real-world scenarios. In response to the question, teachers said:

Play AutoCAD video on Simulation and modelling of ideas and concepts to simplify the orthographic projection (Teacher C).

I use AutoCAD to demonstrate learning ideas in playing a video of orthographic showing rotation of a 3D drawing to prepare learners for the field of work (Teacher D).

The AutoCAD video shows architectural drawings and creates 2D orthographic projections of buildings, showing floor plans, elevations, and sections (Teacher A).

Play PGegd video

One teacher revealed that she plays PGegd videos to show the application of orthography in real-world scenarios. In response to the question:

I play PGegd video to assist them in visualising the 3D object and additionally to understand how a 3D view rotates in real life (Teacher B).

A cardboard box

One teacher further revealed that he does not have CAD facilities, but he uses a cardboard box to show learners 3D. In response to the question:

Don't have CAD, but I use a cardboard box for learners to understand the views in the real world (Teacher E).

One teacher further revealed that he does not have CAD facilities, but he uses a cardboard box to show learners three sides of a 3D object.

Physical 3D models

Another teacher indicated that she uses 3D physical models to at least assist learners to visualise 3D views in the real world. In response to the question:

In our school, we use 3D models that can be disassembled into different sides with different colours per side to make learners understand due to a lack of ICT facilities (Teacher F).

Textbook, chalk and chalkboard

Many teachers use textbooks, chalk, and chalkboards to explain to learners what is written in the textbook about orthographic projections in the real world. In response to the question, teachers said:

Demonstrate using the textbook, chalk and a chalkboard because we do not have CAD facilities (Teacher I).

I just use a textbook, chalk, and a chalkboard (Teacher H).

I used the Mind Series textbook and explained orthographic projections and showed some important notes on the chalkboard (Teacher G).

The data revealed a predominant trend in which teachers actively integrated technological resources to enhance the application and contextualisation of orthographic projections in the real world within the CK domain. Specifically, most participants reported leveraging CAD software, such as AutoCAD, and specialised PGegd video tutorials to demonstrate the practical use of projections. Complementing this digital approach, several teachers detailed the use of tangible instructional aids, including simple cardboard constructions and physical three-dimensional models, to facilitate learners' ability to differentiate between various multi-view projections. However, this incorporation of contemporary tools and physical aids was consistently paired with, or superseded by, traditional didactic methodologies; most teachers indicated a sustained reliance on foundational resources such as textbooks, chalk, and chalkboards for the primary explanation and demonstration of orthographic concepts. This finding indicates a hybrid pedagogical model in which technology and physical models function as supplementary enhancements to traditional teaching methodologies.

How do you feel about the application of CAD to teach and demonstrate EGD?

The application of CAD in teaching EGD elicited positive emotions from teachers, who highlighted its benefits in the following sub-themes as emerged:

- Improvement of quality results
- Prepare learners for the field of work
-

Improvement of quality results

Teachers emphasised that CAD enhances the quality of learners' results, particularly orthographic projections. In response to the question, teachers said:

I think it is very important to use technology tools or CAD to improve the quality of results in EGD. (Teacher B).

My thinking is that using CAD will lead to improvement of results (Teacher A).

As we are in this fourth industrial revolution, when using CAD, learners' improvements in results are testimony (Teacher D).

Prepares learners for field of work

Most of the teachers agreed that CAD equips learners with relevant skills required in the field of work. In response to the question, teachers said:

I think CAD is the most progressive and pragmatic way to go in the 21st century, because learners' spatial skills are developed, and CAD provides relevant skills that are needed in the 4th industrial revolution (Teacher C).

I strongly believe that the use of CAD in EGD is fundamental because it simplifies graphics and gives learners the necessary skills to empower them for the working environment. (Teacher F).

As we are in the 4th industrial revolution, it is important that our learners learn the skills that will be beneficial even in the field of work (Teacher E).

It is very important for our learners to be equipped with the skills of using CAD to prepare them for the field of work in this digital era (Teacher G).

As we are in the 4th industrial revolution, CAD exposes and prepares learners for real-world applications (Teacher I).

I do not use CAD, but I think in this digital era it is of the utmost importance that our learners are equipped with relevant technical skills that are beneficial even in the field of work as they compete in 4IR. (Teacher H).

The findings indicate that teachers perceive CAD as a valuable tool for improving teaching and learning in EGD, particularly to improve quality results and prepare learners for the demands of 4IR. The overwhelming consensus among teachers underscores the need to integrate CAD and other ICT tools into EGD pedagogy to ensure that learners are adequately equipped with relevant skills for the digital age.

When presenting orthographic projection, what teaching methods and strategies did you employ, and why?

The exploration of teaching methods and strategies employed by educators when presenting orthographic projections in EGD revealed three primary sub-themes:

- The constructivist and visual approach
- Learner centred and visual approach
- Traditional method of teaching

The constructivist and visual approach

Some teachers adopted a constructivist and visual approach, leveraging technology to improve learning outcomes. In response to the question, teachers said:

The constructivist approach: at the same time, my learners will be watching an AutoCAD orthographic projection video as a demonstration. (Teacher C).

I use a laptop, Optoma visualiser, whiteboard and a projector and JPegd orthographic video to demonstrate to them orthographic projections. (Teacher B).

Learner centred and visual approach

A learner-centred and visual approach was also employed, prioritising the learners' needs and abilities. In response to the question, teachers said:

Learner-centred, visual and interactive approach. Learners must be drawing as I demonstrate through an AutoCAD video on how to project using instruments and measurements the different views (front, top and left). (Teacher A).

Firstly, I use AutoCAD software for demonstrations, videos, and animations. (Teacher D).

Traditional method of teaching

Most teachers relied on traditional teaching methods due to limited ICT resources and training. In response to the question, teachers said:

I use a card box to demonstrate the views, and I draw on a worksheet using a drawing board with instruments, a projector, a visualiser, and a whiteboard. Due to limited resources (Teacher E).

I use chalk and a chalkboard to teach orthographic projections. Because we do not have ICT resources (Teacher H).

I use textbooks, chalk and chalkboards to have a clear understanding of what is being explained in different views. Because I am unable to access technology tools, as they are always locked. (Teacher G).

Due to a lack of skills to operate ICT tools, Madam, I demonstrate to my learners by drawing on a chalkboard using chalkboard instruments. (Teacher I).

In our school, I use 3D models that can be disassembled on different sides with different colours, due to a lack of resources (Teacher F).

The findings suggest that while some teachers are using constructivist and learner-centred approaches to teach orthographic projections, many are constrained by limited ICT resources and training, resorting to traditional teaching methods. The use of technology, such as AutoCAD and visual aids, appears to enhance learning outcomes and engagement.

Technological Knowledge (TK)

What potential does CAD have for orthographic projection education and learning?

The exploration of teachers' perspectives on the potential of CAD in teaching and learning orthographic projections revealed three primary sub-themes:

- Facilitate visualisation skills.
- Enhance learners' understanding.
- Emphasise the learner's problem-solving abilities.

Facilitate visualisation skills

Teachers were positive about CAD's potential, citing its ability to facilitate visualisation skills. In response to the question, teachers said:

It makes it easier for learners to grasp the content in terms of visualising objects without having to confirm using real-life models (Teacher B).

The images that we can find in CAD are more easily visualised than those in a textbook. You can view the 3D simultaneously in CAD, and using the textbook, you can support using models (Teacher H).

CAD simplifies the concept of visualisation; hence, it will assist learners in spatial and interpretive skills in reading drawings (Teacher C).

Enhances learners' understanding

Most teachers agreed that CAD enhances learners' understanding of orthographic projections. In response to the question, teachers said:

Yes, Madam, CAD enhances a deeper understanding of orthographic projections (Teacher A).

CAD makes difficult concepts easily understood or simplified (Teacher I).

AutoCAD has the potential to enhance learners' understanding and communicate technological ideas (Teacher D).

Yes, it does have potential; AutoCAD makes complex concepts such as orthographic projection easily understood. (Teacher G).

It makes difficult concepts such as orthographic projection easily understood (Teacher E).

Emphasise the learner's problem-solving abilities.

Some teachers believed that CAD demonstrations with animated visuals can emphasise learners' problem-solving abilities. In response to the question, teachers said:

Yes, I strongly believe the CAD demonstration with animated visuals can easily emphasise the learner's problem-solving ability and understanding of orthographic projections (Teacher F).

I do not use CAD, but I believe that CAD demonstrations with animated visuals can easily emphasise problem-solving skills in how to convert 3D views into 2D (Teacher H).

The traditional way of using 3D models can no longer emphasise the true intention of explanation. But I believe the CAD demonstration with animated visuals can easily emphasise orthographic projections (Teacher F).

The findings indicate that teachers recognise the potential of CAD to facilitate visualisation skills, improve learners' understanding, and promote problem-solving skills.

What is the impact of CAD in the quality of teaching and learning orthographic projections?

The exploration of the impact of CAD on the quality of teaching and learning orthographic projections revealed four primary sub-themes:

- Assist in transforming abstract concepts into easier concepts
- Development of spatial visualisation skills
- Enhances learners understanding
- Lack of ICT/CAD resources

Assist in transforming abstract to easier concepts

Some teachers reported that AutoCAD has a positive impact on transforming abstract concepts into easier concepts. In response to the question, teachers said:

AutoCAD has a positive impact on teaching and learning because it transforms difficult concepts like orthographic projections into simple concepts (Teacher D).

AutoCAD has a positive impact on teaching and learning orthographic projections because it assists in transforming abstract concepts into easier concepts (Teacher A).

Development of spatial visualisation skills

One teacher reported that AutoCAD helps to develop spatial visualisation skills. In response to the question:

When properly used, indeed CAD has a positive impact because it makes it easier for learners to visualise and understand 3D to 2D objects (Teacher C).

Enhances learners' understanding

One teacher reported that JPEGD software improves learners' understanding of 3D views to orthographic projections. In response to the question:

I use JPEGD software, which has an impact because the current generation learns easily by what they see, so it enhances learners' understanding of 3D view to orthographic projection very well (Teacher B).

Lack of ICT/CAD resources

Most teachers reported that they lack ICT/CAD resources, which prevents them from using CAD. In response to the question, teachers said:

I do not use CAD due to limited resources in my school (Teacher E).

No CAD resources, as I indicated earlier (Teacher H).

I do not use CAD in my classroom (Teacher F).

No, I am not using CAD (Teacher I).

I do not use CAD, Madam (Teacher G).

The findings suggest that teachers recognise the potential benefits of CAD in teaching and learning orthographic projections. However, limited resources and lack of training remain significant challenges.

Presentation Of Data from the Classroom Observation Based on CK, PK, and TK

The analysis of the nine classroom observations

Table 1: Teacher A: High TPACK Integration

Component	Observation Findings
Content Knowledge (CK)	Teacher A demonstrated a deep understanding of orthographic principles, projection techniques, dimensioning, and notations, aligning instruction precisely with CAPS. The teacher effectively scaffolded learning by systematically explaining concepts such as hidden edges (dashed lines) versus visible edges (solid lines), indicating a high level of expertise.
Pedagogical Knowledge (PK)	Highly structured lesson using an AutoCAD video for presentation and prior knowledge checks. The teacher demonstrated high accuracy while drawing projection views on the whiteboard, followed by active learner practice.
Technological Knowledge (TK)	Exhibited a high level of competence and confidence in integrating all available tools: AutoCAD software, laptop, projector, and whiteboard. The use of a projected AutoCAD video, specifically demonstrating how dimensioning affects views, was highly effective in enhancing visualisation.

Table 2: Teacher B: High TPACK Integration

Component	Observation Findings
Content Knowledge (CK)	Teacher B displayed a deep understanding of orthographic principles and methods, using both the whiteboard and laptop effectively. The teacher demonstrated strong knowledge by being able to competently and accurately address all learner questions without struggle, affirming a high level of CK.
Pedagogical Knowledge (PK)	Lesson presentation used a JPegd video to check prior knowledge, followed by accurate drawing demonstrations on the whiteboard using set squares and a marker. The teacher successfully structured the lesson and circulated around the class to assist individuals.

Technological Knowledge (TK)	Demonstrated competence in selecting and using relevant technologies, including a mobile whiteboard, projector, laptop, and JPegd video, specifically chosen to support the teaching of orthographic projections. The effectiveness of the technology tools was evident in the resulting improved learner understanding of orthographic projections.
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Table 3: Teacher C: High TPACK Integration

Component	Observation Findings
Content Knowledge (CK)	Teacher C was observed in a dedicated EGD lab; the teacher demonstrated a deep understanding of orthographic principles, dimensioning, and notations, ensuring alignment with CAPS. The teacher effectively scaffolded instruction by breaking down complex context and providing step-by-step explanations of line types (hidden and visible edges), affirming a high level of expertise.
Pedagogical Knowledge (PK)	The lesson used a multimodal approach, featuring an AutoCAD video and a PowerPoint presentation for step-by-step instruction, with strategic pauses for emphasis. The teacher demonstrated high accuracy in manual drawing on the whiteboard and distributed worksheets for immediate practice.
Technological Knowledge (TK)	Demonstrated competence in using the entire EGD lab environment, including 28 computers, a mounted projector, a whiteboard, and AutoCAD installed on the school laptop. The teacher effectively integrated these tools to answer clarification questions and enhance visualisation.

Table 4: Teacher D: High TPACK Integration

Component	Observation Findings
Content Knowledge (CK)	Teacher D demonstrated a deep understanding of orthographic principles and methods, using the whiteboard, projector, AutoCAD video, and laptop. The teacher's ability to scaffold the context by breaking it into manageable parts indicated a high level of CK.
Pedagogical Knowledge (PK)	The presentation involved an AutoCAD video followed by demonstrations of drawing order (top, front, left views) on the whiteboard with high accuracy. The lesson was well-structured, including clear learning objectives and a relevant worksheet. High learner engagement was observed, with most learners completing the assessment task/worksheet within 25 minutes.
Technological Knowledge (TK)	Exhibited a high level of understanding and confidence in operating all chosen tools (AutoCAD video, laptop, projector, whiteboard), which were specifically relevant to orthographic projection.

Table 5: Teacher E: Low TPACK Integration / Resource Constraint

Component	Observation Findings
Content Knowledge (CK)	The execution of CK by Teacher E was deemed unsatisfactory. Observation revealed critical deficiencies in the foundational phase of instruction, specifically the failure to conduct a necessary prior knowledge check and, more significantly, the omission of explanations regarding the key principles and projection techniques fundamental to orthographic projections. In addition, the teacher failed to check prior knowledge and omitted explanations of essential orthographic projection principles and techniques, despite using the CAPS document. This suggested a lack of CK in the specific area of orthographic projection principles.
Pedagogical Knowledge (PK)	The lesson used the approved textbook and a cardboard box to check prior knowledge. The teacher demonstrated high accuracy in manual drawing on the

	whiteboard using a clutch pencil and set squares. However, due to the high volume of struggling learners.
Technological Knowledge (TK)	The teacher was confident and effective in using the <i>available</i> school technology (installed whiteboard, projector, and Optima visualiser). However, the teacher did not use CAD due to limited resources. This constraint led many learners to fail to demonstrate understanding of orthographic projections.

Table 6: Teacher F: Low TPACK Integration / Resource Constraint

Component	Observation Findings
Content Knowledge (CK)	Teacher F demonstrated an average level of CK, using the chalkboard and chalk to explain orthographic principles and methods step-by-step. The instruction was clear but limited by the available media.
Pedagogical Knowledge (PK)	The lesson used a physical model (3D prism) and the approved textbook. Instruction involved drawing sketches on the chalkboard with high accuracy. Limited individual assistance was provided, and only a few learners could draw without help.
Technological Knowledge (TK)	Teacher F used the traditional method (chalk and chalkboard) exclusively, reporting that the only accessible technological tool was a 3-in-1 photocopy machine. The lack of ICT resources prevented the use of CAD or any visualisation technology, resulting in the majority of learners not understanding orthographic projection.

Table 7: Teacher G: Low TPACK Integration / Resource Inaccessibility

Component	Observation Findings
Content Knowledge (CK)	The execution of CK by Teacher E was deemed unsatisfactory. The teacher did not explain the key principles of orthographic projections, instead beginning with front-view drawing. This approach suggested a fundamental gap in foundational content delivery.
Pedagogical Knowledge (PK)	The lesson used the approved textbook, demonstrating high accuracy and competence in drawing sketches on the chalkboard using set squares and coloured chalks. The teacher was responsive to clarification questions, but most learners ultimately did not show understanding of orthographic projections.
Technological Knowledge (TK)	The teacher used the traditional method (chalk and chalkboard) because available technological tools (laptop, projector, digital whiteboard) were locked in a storeroom and inaccessible. This resource inaccessibility resulted in most learners not showing understanding of orthographic projections.

Table 8: Teacher H: Low TPACK Integration / Resource Constraint

Component	Observation Findings
Content Knowledge (CK)	Teacher H demonstrated intensive CK on orthographic projection, meticulously aligning instructional preparation with CAPS and ATP documents. This high level of expertise was evidenced by the ability to effectively articulate the complex relationship between orthographic views, dimensioning, and annotation, confirming that the teacher met basic expectations for content delivery in this domain. The teacher met basic expectations for content delivery.
Pedagogical Knowledge (PK)	The lesson relied solely on the approved textbook, with sketches drawn on the chalkboard with high accuracy. The attempt to assess understanding through a distributed worksheet was unsuccessful, as most of the learners struggled to visualise the object and failed to complete the drawing as expected.

Technological Knowledge (TK)	The classroom contained only a chalkboard and chalk, forcing the exclusive use of the traditional method due to the complete lack of ICT tools. Consequently, most learners did not show understanding of orthographic projection.
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Table 9: Teacher I: Low TPACK Integration / Skills Deficit

Component	Observation Findings
Content Knowledge (CK)	Teacher I demonstrated an average level of CK, aligning lesson aims with CAPS and foregrounding dimensioning and pictorial views. Prior knowledge was checked using simple verbal questions about everyday shapes.
Pedagogical Knowledge (PK)	The lesson was presented using a chalkboard and coloured chalk, employing a step-by-step demonstration and guided practice. Despite clear structuring, most learners became stuck and required individual attention, indicating that the instructional method was insufficient for effective visualisation and understanding.
Technological Knowledge (TK)	Although the school possessed significant, advanced technological tools (installed projector, laptop, interactive LED whiteboard, and a locked computer room with 22 computers), the teacher exclusively used the traditional method due to a self-reported lack of basic ICT knowledge.

DISCUSSION

Pedagogical Knowledge (PK)

How do you use CAD to show the application of orthographic projections in real-world scenarios?

The study established that teachers employ a broad spectrum of resources, ranging from advanced technological tools (AutoCAD, JPEG videos) to tactile resources (cardboard boxes, physical models) and finally to traditional methods (textbooks and chalkboards). During the interview, most participants reported leveraging CAD software, such as AutoCAD, and specialised PGegd video tutorials to demonstrate the practical use of projections. Complementing this digital approach, several teachers detailed the use of tangible instructional aids, including simple cardboard constructions and physical three-dimensional models, to facilitate learners' ability to differentiate between various multi-view projections. The use of advanced audio-visual media is considered an effective strategy for enhancing teaching and learning, as it allows instructional content to be accessed and replayed.³⁰ Furthermore, it provides a more engaging, flexible, and visually enriched learning experience. Furthermore, audio-visual resources support learners during revision and assessment by aiding memory recall and reinforcing understanding of difficult concepts.³¹

How do you feel about the application of CAD to teach and demonstrate EGD?

Teachers view CAD integration as essential for improving learners' comprehension of complex graphical concepts, boosting spatial skills, and leading to improved academic performance. During the interview, teachers perceive CAD as a valuable tool for improving teaching and learning for EGD, particularly in improving quality results and preparing learners for the demands of the 4th industrial revolution. CAD is an important tool that equips learners with skills directly transferable to a modern, digitised workplace, thereby enabling them to become assets to their community.³² This consensus on CAD's necessity, despite resource limitations, indicates a significant readiness among teachers to embrace digital pedagogical practices, contingent upon addressing infrastructure and training barriers.

³⁰ Jennifer L Hill and Amanda Nelson, "New Technology, New Pedagogy? Employing Video Podcasts in Learning and Teaching about Exotic Ecosystems," *Environmental Education Research* 17, no. 3 (2011): 393–408.

³¹ Thokozani Isaac Mtshali, "Challenges Faced by Civil Technology Teachers in Preparing and Presenting Theory and Practical Lesson in South African Schools: A Case of Five Schools in Ekurhuleni Districts.," 2018.

³² Jason Ravitz et al., "Using Project Based Learning to Teach 21st Century Skills: Findings from a Statewide Initiative," in *American Educational Research Association Conference*, vol. 16 (Vancouver, Canada, 2012), 1–9.

When presenting orthographic projection, what teaching methods and strategies did you employ, and why?

The selection of teaching methods and strategies to present orthographic projection is directly influenced by resource availability, ICT competence, and pedagogical orientation. During the interview, teachers indicated that they use constructivist and learner-centred approaches to teach orthographic projections; however, due to limited ICT resources and training, they often resort to traditional teaching methods. The reliance of the majority on traditional methods highlights a systemic challenge related to resource constraints. This finding underscores the importance of a professional teacher's ability to prepare lessons that meet all learner needs using available equipment.³³ Furthermore, effective practice requires robust PK and skills concerning instructional techniques, audience analysis, and effective evaluation strategies.³⁴ The findings highlight an urgent need for professional development and ICT resource provision to facilitate a pedagogical shift toward interactive and digitally aligned instruction.

Technological Knowledge (TK)

What potential does CAD have for orthographic projection education and learning?

Teachers unanimously recognise CAD as a powerful tool with significant potential for orthographic projection education. During the interview, teachers recognise the potential of CAD to facilitate visualisation skills, improve learners' understanding, and promote problem-solving abilities. CAD helps to facilitate visualisation, supports the development of spatial skills, and generally enhances learners' understanding of difficult concepts.³⁵ However, the pervasive lack of resources and inadequate teacher training severely hinders this potential. ICT teachers must be completely competent in using the program, which requires continuous support and training.³⁶

What is the impact of CAD on the quality of teaching and learning orthographic projections?

During the interview, teachers recognise the potential benefits of CAD for teaching and learning orthographic projections. Teachers reflected on CAD's ability to transform abstract concepts into simpler, more accessible concepts.³⁷ The integration of ICT/CAD makes abstract concepts in EGD more easily understood by the learners.³⁸ Although CAD demonstrably offers significant pedagogical advantages, systemic constraints, particularly the lack of ICT resources, severely limit its practical impact on teaching quality.³⁹ Therefore, to realise the full potential of CAD in improving outcomes in orthographic projection, targeted investment in ICT resources and training by the DoE is essential.

Classroom Observation Discussions

CK Domain: During the observation process, teachers showed good CK in orthographic projections, crucial for clear and detailed explanations. However, a few teachers exhibited deficiencies in explaining core principles (e.g., projection techniques and interpretation), underscoring the necessity for continuous professional development in CK.

³³ Mtshali, "Challenges Faced by Civil Technology Teachers in Preparing and Presenting Theory and Practical Lesson in South African Schools: A Case of Five Schools in Ekurhuleni Districts."

³⁴ Sotsaka, "An Exploration of the Interface between Grade 11 Engineering Graphics and Design Teachers' Understanding of Assembly Drawing and Their Practice: A Case Study of the UThukela District, KwaZulu-Natal."

³⁵ Ruhizan M Yasin, Lilia Halim, and Azaman Ishar, "Effects of Problem-Solving Strategies in the Teaching and Learning of Engineering Drawing Subject," *Asian Social Science* 8, no. 16 (2012): 65.

³⁶ Md Shahadat Hossain Khan, Mahbub Hasan, and Che Kum Clement, "Barriers to the Introduction of ICT into Education in Developing Countries: The Example of Bangladesh," *International Journal of Instruction* 5, no. 2 (2012).

³⁷ Khoza, "Difficulties in Sectional Drawing: A Case of Student Teachers at a University Based in the Eastern Cape."

³⁸ Rodriguez and Rodriguez-Velazquez, "Spatial Visualization Skills in Courses with Graphics or Solid Modeling Content."

³⁹ Alharbi, "A Review of the Internal and External Factors Affecting Teachers' ICT Use in Classroom."

PK Domain: During observation, teachers demonstrated high levels of PK, demonstrating mastery of various instructional strategies, effective classroom management, lesson plan development, and assessment techniques aligned with CAPS.⁴⁰

TK Domain: The observation revealed that the application of TK was severely limited by resource constraints and inaccessibility. The classroom observations provided clear evidence of systemic infrastructural barriers; specifically, the researcher noted instances where available ICT tools were locked away in a storeroom, effectively rendering them inaccessible for instructional purposes and consequently denying learners essential skills development necessary for competence in the digital era.⁴¹ This practice highlights a critical discrepancy between resource provision and use, directly limiting the effective integration of TK into the curriculum. Conversely, observations of CAD/ICT integration showed that learners' visualisation was developed, resulting in outstanding drawings characterised by neatness and accuracy.

RECOMMENDATIONS

The study recommends that DoE should prioritise infrastructure development. The DoE should allocate sufficient budget and resources to equip all secondary schools offering EGD in Limpopo Province with the necessary, fully functional ICT infrastructure, including computers capable of running CAD software, projection equipment, and reliable internet access. To establish a maintenance plan to ensure the sustainability and functionality of ICT resources, the DoE must implement a proactive maintenance and support system to promptly repair or replace broken and stolen equipment. A mandate and funding for comprehensive ICT/CAD training should be developed, and mandatory, ongoing professional development programmes focusing specifically on the pedagogical application of CAD software (such as AutoCAD or JPegd) within the EGD curriculum should be implemented.

CONCLUSION

This study explored teachers' perspectives in the application of CAD in teaching orthographic projections to Grade 10 secondary school learners in Limpopo Province. The findings, consistent with existing literature, indicate that many teachers predominantly employ traditional teaching methods for orthographic projections due to a lack of ICT resources and inadequate training in CAD software use. The literature suggests that for technology integration to be successful, schools must be equipped with the necessary ICT infrastructure, and teachers must receive professional development training to confidently infuse these tools into their lessons. The two data sources unanimously affirm the substantial benefits of integrating CAD for teaching orthographic projection. Firstly, the study examined the teachers' perspectives towards the application of CAD in teaching orthographic projections. The findings of this study align with this perspective, confirming a widespread lack of ICT resources in many schools and a stated need for professional ICT training among teachers. Teachers have an overwhelmingly positive perspective, recognising that CAD is a transformative tool that enhances visualisation and simplifies abstract concepts, leading to improved comprehension. Observations confirmed that in classrooms where CAD was successfully integrated, it had a discernible positive impact on learner visualisation and understanding. Secondly, the study identified the ways teachers use technology when teaching orthographic projections lessons in the EGD classrooms. Despite the acknowledged benefits, all sections converge on the finding that widespread technological and resource deficits are the primary impediments to effective CAD integration. Teachers cite the pervasive lack of ICT resources, limited software, poor maintenance, and reliance on traditional methods due to systemic failures (e.g., stolen or broken equipment).

⁴⁰ Valerian F Gabdulchakov, "Pedagogical Skills of the Teacher and the Degree of Creative Self-Realization of a Student in Conditions of University Educational Space," *Procedia-Social and Behavioral Sciences* 146 (2014): 426–31; Jacob Filgona et al., "Motivation in Learning," *Asian Journal of Education and Social Studies* 10, no. 4 (2020): 16–37.

⁴¹ R. Minty and E. U. Pather, "The Integration of ICTs in the Teaching and Learning of Mathematical Literacy: A Study Conducted in Eight Schools in Gauteng, South Africa," *International Journal of Science Commerce and Humanities* 2, no. 1 (2014): 47–60.

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ABOUT AUTHOR(S)

Dorries Machabedi Mphahlele is a postgraduate student and a master’s candidate at the Department of Technology and Vocational Education at Tshwane University of Technology, South Africa.

Dr.Ramongwane Daniel Sephokgole is a lecturer in agricultural science and technology in the Department of Technology and Vocational Education at Tshwane University of Technology, South Africa.

Dr.Thokozani Izaac Mtshali is a senior lecturer and research chair in the Department of Technology and Vocational Education at Tshwane University of Technology, South Africa.