

## Pre-service teachers' conceptual understanding and challenges in isometric drawing: Implications for teaching engineering graphics and design

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### Abstract

This qualitative study explored pre-service teachers' conceptual understanding of isometric drawing (ID) and the challenges they encounter when engaging with it. This enquiry was necessitated by the persistence of poor performance in ID, which constitutes a significant portion of engineering graphics and design (EGD) grade 12 examination paper two. This study was conducted to examine pre-service teachers' understanding of ID, challenges experienced in conceptualizing ID, and the strategies they employ when engaging in ID. This may alleviate poor performance and enhance how pre-service teachers conceptualize ID. With constructivist learning theory by Vygotsky underpinning this study, 40 EGD first-year pre-service teachers were purposively selected to participate in this study. Data was collected through focus group interviews and analyzed using the six-step thematic analysis by Braun and Clarke (2006) to identify patterns and trends in pre-service teachers' responses. The findings suggest that pre-service teachers possess a sound conceptual understanding that ID involves translating two-dimensional orthographic views into a three-dimensional figure. The findings further revealed that pre-service teachers favor the box method, which provides a geometric framework for students to work more effectively, especially those with developing spatial visualization skills. The emerging findings underscore the need for scaffolding approaches such as the box method to be employed, as it demonstrated efficacy for students with lower baseline spatial abilities.

**Keywords:** isometric drawing, box method, pre-service teachers, scaffolding, spatial visualization, technology-enhanced learning

### INTRODUCTION

Engineering graphics and design (EGD) is a technical subject introduced in the further education and training band (i.e., grade 10-grade 12). EGD uses graphical illustrations as the primary method of communication, a gateway subject to engineering fields. The main topics covered in EGD include general drawing principles for all technological drawings, free-hand drawing, first-and third-angle orthographic projects, descriptive and solid geometry, mechanical working drawing, civil working drawing, isometric drawing (ID), perspective drawing, electrical diagrams, interpenetrations and developments, loci of helices, cams and mechanisms, design process and computer-aided drawing or design (CAD) (Department of Basic Education, 2011).

The importance of EGD in engineering education cannot be overstated. However, there are significant challenges in this field. The skills shortages in the engineering sector and the poor performance of first-year engineering students have been linked to deficiencies in the schooling system (Kraak, 2008; Mtshali, 2023; Sotsaka, 2019). These scholars highlight the failure of schools and teachers to develop, through subjects like EGD, the fundamental skills required in engineering courses. These skills include the ability to communicate graphically, apply spatial reasoning (also referred to as visual spatiality), and the ability to read and interpret graphical text.

This study explored how first-year EGD pre-service teachers conceptualize and approach ID. By focusing on these future educators, the research addressed a crucial

### Contribution to the literature

- This paper contributes to the paucity of studies done in isometric drawing and shape how EGD teachers can best teach this section that has been challenging for quite some time. ,
- By exposing challenges and pre-service teachers conceptual understanding of isometric drawing opens a door for an improved pedagogical method to be adopted by teachers responding to the challenges presented in this paper.
- This paper further informs curriculum reforms that can be implemented to govern how isometric drawing is taught.

link in the educational chain, potentially influencing how ID is taught and understood in classrooms for years to come.

Several factors underscored the significance of this study:

1. The consistent poor performance in ID tasks, as highlighted in national senior certificate examiners' and moderators' reports.
2. The critical role of spatial visualization skills in engineering education and profession.
3. The potential impact on students' overall performance in EGD and their prospects for admission to engineering courses.

The findings of this study make a valuable contribution to practice-led research in EGD education. By providing insights into pre-service teachers' challenges when engaging in IDs and strategies they employ that can enhance their spatial visualization skills, this study can significantly impact the training of pre-service EGD teachers. Ultimately, this could improve the teaching of ID at school level, better-preparing students for future studies and careers in engineering fields. As mentioned above, this study's main aim was to explore pre-service teachers' perspectives on why they conceptualize ID in the way they do. The main research question guided this study: Why do pre-service teachers conceptualize ID in a particular way?

The above main research question was guided by the following sub-questions:

1. How do pre-service teachers conceptualize and understand ID?
2. What challenges do pre-service teachers face when engaging in ID, and what strategies do they employ to overcome them?

## LITERATURE REVIEW

### Spatial Ability

The importance of spatial ability in engineering courses has been extensively documented over the past decade. Numerous scholars have emphasized that success in engineering disciplines requires students to possess spatial ability to comprehend complex technical

concepts. Research literature consistently identifies spatial ability as a cornerstone of engineering education, with many students struggling in these courses due to deficiencies in this critical skill (Khoza, 2013, 2018).

Zorn et al. (2021) define spatial ability as "the human brain's ability to manipulate, produce, retain and retrieve three-dimensional (3D) models." This cognitive capacity is particularly vital for EGD students, as the subject inherently requires mental manipulation of various objects. Pictorial topics such as ID, assembly drawing, solids geometry, and perspective drawing present significant challenges to students who lack these fundamental spatial skills.

In solid geometry, for instance, students must often visualize portions of drawings that have been cut away or are not directly represented. Successfully accomplishing this mental task requires well-developed spatial visualization abilities (Khoza, 2013, 2018). Similarly, Sotsaka and Singh-Pillay (2020) identified that pre-service teachers struggle with assembly drawing primarily due to insufficient spatial ability. These observations highlight that spatial ability constitutes an essential skill for all EGD students to effectively engage with and understand the subject content.

### Impact on Academic and Professional Success

The implications of underdeveloped spatial ability extend beyond classroom performance. Zorn et al. (2021) argue that students who lack spatial ability will experience negative effects on both their academic grades and subsequent professional careers, as they enter the workforce without the crucial ability to mentally manipulate objects. Mulligan (2015) further characterizes spatial ability as the mental capacity to manipulate objects in space to solve specific problems – a cognitive ability that develops throughout various life stages.

To understand this developmental aspect, Piaget (1971) cognitive development theory provides a useful framework. According to Piaget (1971), children (and, by extension, students) develop their cognitive abilities through four sequential stages:

- (1) sensorimotor intelligence,
- (2) preoperational thinking,
- (3) concrete operational thinking, and

(4) formal operational thinking.

During the final stage, students become capable of applying abstract logic and reasoning, though some continue to experience difficulties. This theoretical perspective suggests that spatial ability can be cultivated through targeted training and by engaging students in tasks specifically designed to enhance their spatial cognition.

### Developmental Nature of Spatial Skills

Research consistently demonstrates that spatial visualization abilities develop throughout an individual's lifetime and can be significantly improved through participation in appropriate spatial activities (Bayaga & Kok, 2019). Tumkor and de Vries (2015) support this view, noting that carefully constructed exercises can effectively enhance spatial ability skills. Recognizing this developmental potential, our study explored how pre-service teachers conceptualize and approach ID, with the goal of implementing effective interventions to strengthen their spatial abilities.

Spatial visualization has been identified as key to students' understanding of ID. Khoza (2013) emphasizes that the process of imagining absent components can only be successfully accomplished by learners who possess spatial visualization ability. Importantly, Omar and Farzeeha (2016) point out that spatial visualization skills are not uniformly distributed across the population but rather exist along a spectrum from low to moderate to high proficiency levels. Given that most educational systems prioritize written text in both instruction and assessment, it is unsurprising that many learners demonstrate deficiencies in spatial visualization skills. This widespread limitation contributes significantly to poor performance in topics such as ID, perspective drawing, and assembly drawing—all of which require well-developed spatial visualization skills for success.

### Malleability of Spatial Ability

Students with high spatial ability typically find concepts like two-dimensional (2D)-to-3D conversion relatively straightforward, as they already possess the crucial skills required in EGD. However, many students lack these advanced spatial ability skills, resulting in difficulties in understanding topics such as ID, assembly drawing, and perspective drawing—all of which demand sophisticated spatial reasoning. As noted by Kok (2020), numerous students struggle with 2D-to-3D translation precisely because they lack fundamental spatial skills.

An important distinction exists in the literature regarding terminology. Milkova and Pekarkova (2023) differentiate between "spatial ability" and "spatial skills," characterizing the latter as a set of capabilities that can be developed through training, whereas the

former is sometimes viewed as an innate capacity that cannot be substantially improved through practice. Sorby (1999, as cited in Sotsaka (2019)) echoes this distinction, asserting that spatial ability cannot be learned, while spatial skills can be developed and refined through practice. However, Piaget (1971) offers a contrasting perspective, suggesting that spatial ability itself can be developed through the four cognitive developmental stages from childhood to adulthood.

This conceptual tension leads to the concept of "malleability of spatial skill"—a term describing how spatial abilities can be shaped and enhanced through various activities and interventions. Milkova and Pekarkova (2023) note that numerous studies have investigated this malleability, with findings consistently indicating that spatial skills can indeed be improved through specific training and targeted tasks. This position is supported by research from multiple scholars (Gecu-Parmaksiz & Delialioğlu, 2020; Miller et al., 2016; Newcombe & Frick, 2010; Sorby, 2009)

### Interventions for Developing Spatial Skills

The malleability of spatial skills depends significantly on the specific activities and training to which students are exposed. Our study subjected pre-service teachers to AutoCAD training and simulation-based teaching methodologies to enhance their spatial skills. This approach was informed by extensive literature demonstrating that spatial skills can be effectively developed through exposure to AutoCAD (Etelä & Eniekenemi, 2016; Khabia & Khabia, 2012; Kösa & Karakuş, 2018; Pando Cerra et al., 2014; Reffold, 1998; Yue & Chen, 2001) and simulation-based learning environments (Aebersold, 2018; Campos et al., 2020; Froyd et al., 2012; Koh et al., 2010).

Strong spatial skills translate directly to improved achievement in engineering courses, as these skills constitute core competencies in engineering disciplines (Uttal et al., 2013). Consequently, educational emphasis should be placed on ensuring students receive thorough training to develop these essential skills. As Uttal et al. (2013) assert, investing in the development of students' spatial skills will yield substantial dividends by producing more capable mathematicians and engineers. This perspective is reinforced by recent studies (İleri et al., 2023; Khine, 2017), which reveal that enhanced spatial skills reliably predict student success across science, technology, engineering, arts, and mathematics fields.

Given the critical importance of spatial skills in EGD, Khine (2017) emphasizes that these skills are malleable and can be improved through specific interventions. Supporting this claim, Sorby et al. (2013) demonstrated that targeted interventions with first-year students significantly improved their performance on tasks requiring spatial visualization skills. These findings

collectively underscore the value of implementing structured interventions to develop the spatial abilities of engineering students, particularly pre-service teachers who will eventually be responsible for cultivating these same skills in future generations of learners.

### **Theoretical Framework**

At the core of our theoretical approach lies constructivism, a learning theory positing that learners actively construct their knowledge and meaning from experience. In constructivist learning environments, activities are characterized by active engagement, hands-on experiences, enquiry, problem-solving, investigations, experimental design, and collaboration (Brau, 2018). These characteristics align closely with the nature of EGD, making constructivism a particularly apt framework for our study.

While there are various forms of constructivism, we focused on two primary types: cognitive constructivism and social constructivism. These approaches provide complementary perspectives on how learners develop understanding, particularly in spatial visualization and ID skills central to EGD.

Both cognitive and social constructivism share several key principles that are particularly relevant to EGD education. These principles form the foundation for effective learning strategies and teaching methodologies in the field:

1. **Active construction of knowledge:** Learning is an active process where students engage with content rather than passively receiving information (Backes et al., 2023). In this paradigm, lecturers assume the role of facilitators in a self-directed learning environment, placing students at the center of knowledge construction.

In EGD education, this principle manifests when students are given ID tasks to enhance their conceptualization of 3D representation. The lecturer acts as a guide, providing resources and support while allowing students to explore and discover concepts independently. This approach fosters critical thinking and problem-solving skills, which are crucial in EGD.

2. **Social participation and cooperation:** Students learn through interaction with peers and more knowledgeable others, emphasizing the social nature of learning. Breed (2016) argues that cooperative learning involves students working together and accepting responsibility for one another's learning, which aligns with the principles of self-directed learning.

In EGD education, this principle can be applied by encouraging students to tackle ID tasks collaboratively. Group projects, peer reviews, and

team-based problem-solving exercises can significantly enhance students' understanding of complex spatial concepts. This collaborative approach not only improves conceptualization skills but also develops communication and teamwork abilities, which are valuable in professional engineering environments.

## **RESEARCH DESIGN AND METHODOLOGY**

### **Research Approach**

To gather rich data to respond to the objectives of this study, a qualitative research approach was adopted. This approach was employed for its ability to gather in-depth insight from the participants to respond to the phenomena under investigation, which, in the context of this study, explored pre-service teachers' perspectives on conceptualizing and approaching ID. The above aligns closely with Morgan (2022) and Smit and Onwuegbuzie (2018) articulations that the qualitative approach involves gathering data through methods such as interviews, observations, focus groups, and analysis of documents or artefacts. These methods allow researchers to collect detailed, descriptive information about participants' perspectives and experiences.

### **Data Collection and Analysis**

This study adopted a pure qualitative stance; hence, data was collected through focus group interviews with the sampled 40 pre-service teachers. The choice for this data collection was mainly because the aim was to gather pre-service teachers' perspectives on the conceptualization of ID, and one of the advantages of focus group interviews is that it allows a researcher to get in-depth, rich data from the participants.

Data collected was subjected to Braun and Clarke (2006) six steps of thematic analysis to look for patterns and trends from the pre-service teachers' responses in how they conceptualize ID and the approaches they employ. From the analysis, six themes emerged, which formed the basis of discussion in the next section.

### **Participants and Sampling**

This study sampled 40 EGD first-year pre-service teachers to participate in this study. These participants were selected using a purposive sampling technique. At MP University of Technology where this study was conducted, there are over 400 students across four levels of study, and the reason for purposive sampling was to select participants who meet the criteria required for this study. Building up from the above, Taherdoost (2016) asserts that purposive sampling is the technique used by researchers to deliberately select individuals with certain qualities to gather information that cannot be obtained

from other choices. The above definition provides justification for the sampling technique used.

This study further employed a convenience sampling technique to select a site for this study. This study was conducted at the MP University of Technology where the leader author is employed. Access to the university and students was effortless and cheap, which are some advantages of convenience sampling. Convenience sampling was used because participants can be accessed quickly and readily available. Convenience sampling was also used because it overcomes many limitations, as it is very cheap and easy to use compared to other techniques (Taherdoost, 2016). Additionally, Mulisa (2022) posits that convenience sampling is used because participants are easy to select, and the participants selected are not intended to be representative of the entire population.

### Research Rigor and Trustworthiness

This study adopted a pure qualitative approach, with data collected through four focus group interviews involving forty pre-service teachers (ten participants per group which lasted for 20 minutes each lesson). The sessions were repeated only once due to the length of the data collection process for the main PhD study which had 4 data phases of data collection. The focus group interview schedule underwent expert validation by specialists in technology education and qualitative research to ensure clarity, relevance, and alignment with the study objectives.

To ensure consistency in the coding process, an interrater reliability check was conducted. An independent qualitative researcher coded a subset of the data, and discrepancies were resolved through discussion and consensus. Peer debriefing further supported the credibility and dependability of the analysis.

### Ethics and Gaining Access

Ethical clearance was sought from the ethics committee affiliated with the authors, after which permission was granted to carry out the research within acceptable ethical boundaries. The study and its procedure were approved by the Research Ethics Committee at University of KwaZulu-Natal (HSSREC/00007769/2024). The participants of which were forty preservice teachers were notified of the procedure on how the study will be conducted and they were issued with informed consent letters. Participants were further advised that only those who consented will form part of the study and that their true identities will be concealed through pseudonyms. In the following section (results and discussion) participants were addressed using pseudonyms. Using pseudonyms ensured confidentiality and anonymity for the participants.

## RESULTS AND DISCUSSION

Data was collected from 40 first-year pre-service teachers through focus group interviews to respond to the research questions that guided this study as articulated above.

The responses from the focus group interview stemmed from the free-hand sketching task they were subjected to. From the resulting focus group discussion, six themes emerged that formed the basis for discussion in this paper. This paper was underpinned by two research questions as outlined below:

1. How do pre-service teachers conceptualize and understand ID?
2. What challenges do pre-service teachers face when engaging in ID, and what strategies do they employ to overcome them?

The above research questions were central in responding to the main objectives of this study which were to explore how first year EGD pre-service teachers conceptualize and approach the complex sections of ID. Below is the section that responds to research question 1: How do pre-service teachers conceptualize and understand ID? Three main themes emerged which are discussed in length below.

### Theme 1. Conceptual Understanding of ID

The focus group interviews revealed that pre-service teachers have developed a solid conceptual foundation regarding ID. When asked to articulate their understanding, participants consistently emphasized the dimensional transformation involved in the process.

When **Simuthandile Mbili** was asked about her understanding of ID, she responded:

My understanding of isometric drawing is that I must use the different views. Top, side and front view to combine them into a 3D solid.

**Simuthandile Mbili** highlighted the need to integrate different views (top, side, and front) to create a 3D representation. This perspective was reinforced by **Dimpho Mokoena**, who emphasized the transformational aspect of ID:

What I understand about isometric drawing is that it is a drawing that is given in three views that you need to combine in order to complete or produce one solid figure.

**Dimpho Mokoena** characterized ID as a process that combines three distinct views to produce a unified solid figure. Adding further nuance, **Zakewu Tsotetsi** highlighted the integrative nature of the process:

Isometric drawing is a form of drawing whereby we combine different shapes to become one whole object.

**Zakewu Tsotetsi** described it as an integrative process of combining different shapes into a cohesive whole object.

**Thabani Mthethwa** noted:

My understanding regarding isometric drawing is that you draw an object or shape in 3D using given views.

Besides, **Hleloluhle Dlamini** mentioned that

I understand that in isometric, you move from orthographic projection to isometric.

**Thabani Mthethwa** offered additional technical insights, with **Thabani Mthethwa** focusing on the dimensional transformation aspect, while **Hleloluhle Dlamini** situated the process within the broader context of technical drawing by referencing the shift from orthographic projection to isometric representation.

The collective responses from these focus group interviews demonstrate that pre-service teachers have developed a robust understanding of the fundamental concept of ID. Their articulations align closely with established definitions in literature. For instance, the participants' understanding resonates with Mlambo (2024, p. 362) definition that "isometric drawing is usually given in 2D views, and learners are expected to convert the given 2D drawing to a 3D drawing." Similarly, Gagnier et al. (2017) describe ID as a process involving translation from 2D to 3D representations, requiring students to encode information from 2D views to construct a coherent 3D image. This alignment between pre-service teachers' conceptualization and scholarly definitions suggests a promising foundation for their future teaching practice. The responses from the participants show that students have a clear understanding of what ID is. This shows that students, if students understand what ID is, but still struggle with application, the issue may lie in pedagogy rather than content knowledge. This helps refine teacher training approaches.

## **Theme 2. Spatial Visualization Key to Understanding ID**

Building upon pre-service teachers' foundational understanding of ID discussed previously, we explored their awareness of the crucial cognitive skills that underpin success in this area. Spatial visualization emerged as the predominant skill identified by participants, revealing their metacognitive awareness of the cognitive processes involved in technical drawing tasks.

When asked about the critical skills needed to understand ID, **Zama Duma** emphasized the fundamental role of spatial visualization:

Spatial visualization skill is very important in understanding isometric drawing because when lacking that skill, it will be challenging to start drawing.

Reinforcing this perspective, **Mlondi Mvelase** asserted that spatial visualization constitutes the cognitive foundation necessary for isometric comprehension:

Spatial visualization is very important because you cannot draw nor understand isometric drawing without visualization skill.

Elaborating on the mental processes involved, **Hleloluhle Dlamini** articulated the sequential nature of visualization before execution:

The spatial visualization skill is very important because before drawing, you must be able to form mental images of it and that can only be done through visualizing the given 2D views.

**Palesa Ntuli** extended this concept to include predictive visualization and planning:

I think it is very important because you need to know what the outcome of the drawing would be like before you even draw it.

This theme of mental transformation was further reinforced by **Jessica Ndlovu**, who highlighted the synthetic nature of the visualization process:

I think special visualization skills are important because in understanding isometric drawing.

These findings highlight the pre-service teachers' sophisticated understanding of spatial visualization as the cognitive cornerstone of successful ID. Their insights align with established theoretical frameworks in spatial cognition research. For instance, the literature review highlighted that spatial visualization ability encompasses the brain's capacity to manipulate, produce, retain, and retrieve 3D mental models, which is crucial for pictorial topics like isometric and assembly drawing (Zorn et al., 2021). This consensus among participants reflects the current understanding of cognitive psychology, where spatial visualization is recognized as a complex cognitive skill comprising multiple components. According to Uttal et al. (2013), spatial visualization involves intricate mental processes, including mental rotation, spatial relations, and spatial working memory. The pre-service teachers' responses demonstrate an intuitive grasp of these components, particularly the mental transformation processes

described by Newcombe and Shipley (2014) as essential for STEM learning. The findings underscore the significance of spatial visualization skills in EGD as outlined by the participants. Identifying spatial visualization as central to understanding ID advances teacher education research by connecting cognitive development to disciplinary competence and instructional effectiveness.

### Theme 3. Building Confidence Through Practice in ID

Building up from the themes discussed above, the pre-service teachers were prompted about the support they need to improve the way they conceptualize ID, as most pre-service teachers performed poorly in the pre-test, which necessitated the need for scaffolding. Their responses revealed two major themes related to support: technology-enhanced visualization and deliberate practice.

#### Sub-theme 3.1. Technology-enhanced learning

**Jay Matthews** put forth that one way they can be assisted to conceptualize ID better is through improving their spatial ability:

The form of intervention I would appreciate is improving my spatial visualization ability through technologies such as AutoCAD, which my high school teacher used very late, but it had that impact.

This sentiment was echoed by **Ziyanda Mzizi**, who elaborated on the importance of infusing technology in the teaching of ID:

I think the support I need to better understand isometric drawing is doing online tutorials on YouTube and other social media platforms where I'm going to watch videos because I learn best through watching videos.

Similarly, **Steve Rogers** noted that the core issue lies in his ability to visualize the outcome of a drawing, which can be improved immensely through using technology when teaching ID:

AutoCAD and watching videos on YouTube will improve the way I do isometric drawing.

#### Sub-theme 3.2. Practice-based approaches

The responses from the pre-service teachers suggest that a technology-based pedagogy plays a crucial role in scaffolding their learning. However, several pre-service teachers also emphasized that consistent and intensive practice is essential for improving their performance in ID.

For instance, **Deon Carter Mthembu** maintains that he can be assisted through more practice exercises in ID:

Providing us with more problems than we can solve can be beneficial, as it encourages deeper learning. Additionally, collaborating in groups can help students gain new perspectives and discover concepts they may not have encountered before.

Adding to this, **Michael Armstrong** emphasized the importance of consistent and intensive practice:

More isometric questions as practice will help the way I attempt isometric drawing, which, in turn, will improve my performance.

**Palisa Ntuli** further highlighted the need for practice to improve the way she does ID:

More practice would definitely improve my performance in isometric drawing.

These findings highlight the need for scaffolding to enhance the way pre-service teachers conceptualize ID. The responses reveal two primary pathways for intervention: technology-infused pedagogy, which aids in improving spatial ability, and structured practice opportunities, which build competence through repetition.

The emphasis on technology integration aligns with Mlambo and Mkhwanazi (2024) assertions that technology can help students convert abstract concepts into concrete concepts. Similarly, Cheng et al. (2018) and Cheng and Mix (2014) state that traditional teaching methods fail to stimulate students' spatial imagination capabilities, explaining why many struggle to understand ID. The importance of technology-infused teaching in EGD is further echoed by Rikza et al. (2024), who argue that technology forms an integral part of spatial ability training and should be used to improve students' spatial ability.

Katsioloudis and Jones (2018) provide additional support for this approach, finding that 3D modelling software significantly improves spatial visualization skills in engineering design students. Their research demonstrated that students who used CAD tools like AutoCAD specifically mentioned by **Jay Matthews** and **Steve Rogers** showed greater improvement in spatial rotation and visualization tasks compared to those who used only traditional drawing methods. Likewise, Sorby et al. (2018) documented substantial gains in spatial ability among engineering students who received computer-aided instruction, particularly benefiting those with initially weak visualization skills. As mentioned by authors above that EGD is both practical and abstract in nature therefore the integration of technology aid in bringing abstract concept to concrete form for better conceptualization. This contributes to the practice of teaching EGD that all teachers across the

globe should adopt to enhance teaching and learning in EGD classrooms.

The above presentation of findings was used to respond to research question 1: How do pre-service teachers conceptualize and understand ID? The following section will present findings aimed at responding to research question 2: What challenges do pre-service teachers face when engaging in ID, and what strategies do they employ to overcome them? This main aim of this research question was to investigate the challenges preservice teachers are faced with when engaging with ID and what are the strategies they employ to better understand the concept. Three main themes emerged from the findings which aided in responding to research question 2 as outlined above.

#### **Theme 4. Impact of Spatial Visualization on Student Performance in ID**

Building upon the established importance of spatial visualization skills in ID, this theme explores the direct relationship between these cognitive abilities and pre-service teachers' actual performance on drawing tasks. The participants' reflections on their pretest results reveal a compelling pattern that reinforces the critical nature of visualization capabilities in technical drawing outcomes.

**Sanele Mwelase** explicitly connected his poor performance on the pretest (previously discussed) to specific difficulties with mental visualization:

My performance was poor. The reason behind my poor performance is that I fail to visualize drawing or to have a clear picture of how to draw. On how the drawing is supposed to be drawn.

This self-assessment was echoed by **Dimpho Mokoena**, who similarly identified the inability to form mental images as the root cause of her struggles:

The performance in this test was bad. The reason behind this is that I cannot visualize the drawing because you cannot draw an isometric without visualizing or having a clue where to start.

In striking contrast, **Nozomi Kugisaki** attributed her excellent performance to her innate visualization capabilities:

My pre-test performance was good because I'm naturally talented in visual perception, and I have learnt that to succeed in engineering graphics and design, you need to be able to visualize.

**Mlondi Mvelase** corroborated this positive correlation between visualization ability and performance success:

My performance was good. The reason is because I was creating a picture in my mind before my drawing.

These first-hand accounts establish a clear pattern: participants who self-reported stronger spatial visualization abilities performed better on ID tasks, while those who acknowledged visualization difficulties experienced poorer outcomes. This pattern aligns with established research on the relationship between spatial cognition and technical drawing performance.

The critical role of spatial visualization in ID performance extends beyond the current study. Zorn et al. (2021) conducted a comprehensive study of engineering graphics students and found that spatial visualization ability was the strongest predictor of success in technical drawing tasks, accounting for approximately 40% of the variance in student performance. Similarly, Ha and Fang (2018) demonstrated through regression analysis that spatial visualization skills were more predictive of ID performance than prior academic achievement or general intelligence measures.

The challenges reported by struggling participants reflect broader patterns in technical education. In a longitudinal study of engineering students, Sorby (2012) found that those with underdeveloped spatial skills were 2.3 times more likely to fail graphics-heavy courses than peers with stronger visualization abilities. This finding is particularly relevant to teacher preparation, as noted by Branoff and Dobelis (2012), who found that pre-service teachers' spatial visualization abilities directly predicted their future effectiveness in teaching technical drawing concepts. This contributes to EGD practices which makes teachers aware of the fundamental component that should not be overlooked by teachers. These findings set precedence for the EGD community at large to prioritize the visualization skills as they predict success.

The following presentation and discussion of findings respond to the second part of research question 2, which looks at the different strategies pre-service teachers employ to better tackle ID questions. Below is how they responded:

#### **Theme 5. A Box Method Strategy**

Building upon the established relationship between spatial visualization abilities and ID performance, the investigation naturally progressed to examining the specific methodological strategies pre-service teachers employ when constructing IDs. The findings revealed two predominant approaches: the structured "box method" emerged as the primary technique, while a smaller subset of participants favored free-hand sketching as their initial approach. These strategic preferences reveal important insights into cognitive approaches to 3D representation tasks.

Most participants expressed a clear preference for the box method, a systematic approach that provides structural scaffolding for complex isometric constructions. **Yolanda Duma** articulated her step-by-step implementation of this technique:

I first drew the isometric box, then lightly sketched the views on all sides as they appeared. Finally, I connected all the necessary lines.

This methodical approach was echoed by **Nozomi Kugisaki**, who also prioritized the box method as her preferred strategy:

I primarily rely on the box method. Normally, I start by creating a 3D box and then construct the shapes from it using the given views.

Similarly, **Ziyanda Mzizi** confirmed her reliance on the box method while noting its efficiency benefits:

I began with an isometric box before creating the final drawing. Sometimes, I do a rough sketch to the side before using a box method, which helps in saving time.

**Jay Matthews** succinctly summarized the essence of this approach:

To first draw a box then fill in the drawing each side.

The widespread preference for the box method among pre-service teachers reflects established practices within the broader professional community. This alignment is evidenced in Mlambo (2024) investigation of teachers' pedagogical content knowledge in teaching ID, where a participant emphasized that:

the basic principle of isometric drawing is to understand the box technique which I always encourage my learners to use.

This convergence suggests a continuity of practice from pre-service preparation through to professional teaching methodologies. This also sets guidelines for attempting to ID as learners learn best if there is a set of steps/guidelines to follow. The box method adds to the pedagogical methods employed by teachers when teaching ID.

The prevalence of the box method aligns with cognitive load theory, as articulated by Sweller et al. (2019), who propose that structured approaches reduce extraneous cognitive load during complex spatial tasks. By providing a geometric framework, the box method offers what Tversky (2019) describes as "spatial chunking" allowing the drawer to organize complex spatial information into manageable components. This structured approach appears particularly beneficial for those with developing spatial visualization skills, as

noted by Sorby and Hungwe (2018), who found that scaffolded approaches like the box method showed efficacy for students with lower baseline spatial abilities.

From an instructional design perspective, the box method represents what Van Merriënboer and Kirschner (2017) term a "supportive scaffold" an intermediate representation that bridges the gap between 2D orthographic projections and fully realized 3D visualization. Empirical studies by Akasah and Alias (2010) demonstrated that students who employed the box method showed 27% higher accuracy in ID tasks compared to those using unstructured approaches.

## Theme 6. Free-Hand Sketching

While the box method dominated, a notable subset of participants reported alternative strategies centered on free-hand sketching. **Chris Gumede** described his approach:

I usually draw a free-hand rough sketch or demo on the side to visualize the drawing before actually drawing it with instruments.

Similarly, **Palisa Ntuli** emphasized her reliance on preliminary sketching:

I first analyze the drawing, then create a free-hand sketch on the side, which makes it easier to complete the isometric drawing using instruments.

These alternative approaches align with the contemporary understanding of free-hand sketching as a cognitive tool. As Xu et al. (2022) observe, free-hand sketching functions as a universal communication tool for engineers, facilitating the translation of abstract concepts into concrete representations. The cognitive benefits of this approach are elaborated by Peters (2020), who characterizes free-hand sketching as an externalization of the thinking process that reduces cognitive load and stimulates design creativity.

The value of free-hand sketching in ID has specifically been documented in several studies. Ferguson (2021) research on engineering education demonstrated that preliminary sketching activates different neural pathways than formal drawing, engaging what he terms "visual thinking" rather than "procedural drawing." This distinction may explain why some individuals with strong spatial visualization abilities gravitate towards sketching approaches. Goldschmidt (2017) further argues that sketching serves as an interactive dialogue between mind and paper, facilitating what she terms "visual reasoning" a process particularly relevant to the transformation from 2D to 3D representation required in ID. The findings above provide a new direction on how pre-service teachers can attempt ID through free hand sketching which is a fundamental skill in EGD that is taught in Grade 10.

These findings further shed light on new practices for EGD, that skills taught in early grades in high school are fundamental in EGD success.

### Limitations

While this study employed a comprehensive focus group interview with forty pre-service teachers, several limitations must be acknowledged. First, reliance on a single data collection method without a follow-up interview limits our ability to fully understand the cognitive processes underlying students' conceptualization of ID. Secondly, this study was confined to a single university of technology, with data collected exclusively from EGD pre-service teachers to ensure its manageability. As a result, the findings cannot be generalized to all universities across South Africa but apply specifically to this institution. This limitation highlights the need for future research in other universities of technology, incorporating data from pre-service teachers to provide a more comprehensive and unbiased perspective. Future research should incorporate qualitative methods such as think-aloud protocols during task completion and post-task interviews to gain deeper insights into students' spatial reasoning processes and conceptual understanding.

### CONCLUSION AND RECOMMENDATIONS

The findings from the focus group interviews revealed several important insights. Firstly, most pre-service teachers share a common conceptual understanding that ID fundamentally involves the process of converting 2D orthographic views into a 3D representation. This understanding, while technically correct, varies in depth and application across participants.

Secondly, the findings clearly established that pre-service teachers recognize spatial visualization ability as a critical foundation for their conceptualization of ID. Many participants identified limitations in their spatial reasoning as a key barrier to successful ID performance. Furthermore, the analysis uncovered two primary pathways through which pre-service teachers believe their conceptualization could be improved: technology-enhanced visualization tools and structured practice opportunities.

The findings above uncovered a lack of spatial visualization skills among pre-service teachers, which, according to the literature above, is a strong predictor of success across various engineering disciplines and technical fields. The findings underscore the importance of spatial visualization skills in the conceptualization of ID. As a result, this study recommends scaffolding intervention to be embedded in pedagogical practices such as technology-enhanced learning and practice-

based approaches, which tie in well with the concept of self-directed learning.

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