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Research paper

Challenges, Teaching Practices, and Opportunities in Orthographic Projection: A Qualitative Study in Indonesian TVET

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ABSTRACT

Engineering drawing is fundamental to technical and vocational education and training (TVET), yet many students struggle with orthographic projection as a foundational skill. Despite ongoing efforts in vocational education reform, limited attention has been given to how orthographic projection is taught and experienced in classroom practice. This study investigates the challenges students face, current teaching practices, and perceived opportunities for improving engineering drawing instruction in Indonesian vocational high schools. Using a qualitative design, data were collected through semi-structured interviews with ten students and five teachers. Reflexive thematic analysis revealed consistent patterns of student difficulties in spatial visualization, understanding projection methods, drawing accuracy, and the use of computer-aided design (CAD). Teaching practices were found to rely primarily on paper-based instruction and manual sketching, with limited integration of digital tools. Participants identified several potential strategies, including expanded CAD practice, the use of 3D-printed models, industry-linked projects, and immersive tools such as augmented and virtual reality. These strategies were described as helpful for supporting visualization and engagement in learning. These findings reflect participants' perceptions of instructional needs rather than demonstrated effectiveness. The study contributes context-specific qualitative insights into learning bottlenecks and instructional practices in Indonesian TVET. It offers context-sensitive, tentative implications for instructional design and future research in vocational engineering drawing education.

Keywords: engineering drawing, orthographic projection, vocational education, spatial visualization, qualitative study, TVET

Technical and vocational education and training (TVET) play a critical role in preparing individuals with the technical competencies, practical skills, and knowledge required for employment and professional practice. TVET emphasizes practical skills, aligning educational outcomes directly with industry requirements to ensure students can transition efficiently from school to employment (Guile & Spinuzzi, 2024; Kryger & Qvortrup, 2025; Yang & Zheng, 2025). Across different countries, vocational education is increasingly viewed as a way to address skill shortages, support economic development, and reduce youth unemployment (Habibi et al., 2025; Øgård et al., 2025; Rausch et al., 2024). Engineering education within TVET specifically targets the development of technical skills crucial to advancing various industrial sectors. It integrates theoretical principles with practical applications (Wintersberg & Pittich, 2025). Engineering disciplines require well-designed instructional approaches that emphasize spatial reasoning and problem-solving (Sharma, 2023). Engineering drawing practice plays a significant role in developing foundational skills and supporting accurate technical communication.

The Indonesian government has strengthened vocational education through curriculum reform, industry collaboration, and investment in infrastructure and teacher development (Bruri Triyono & Hariyanto, 2024; Suharno et al., 2020). Despite these efforts, Indonesian vocational education institutions still face considerable challenges, including aligning curricula with industry needs, developing teachers' competencies, and limited educational resources (Helmy et al., 2021). According to the Indonesian National Labor Force Survey, vocational education increased employment in the manufacturing and accommodation sectors (BPS, 2024). Strong technological and engineering expertise is required to enhance the effectiveness of vocational education.

Orthographic projection is a fundamental component of engineering drawing and an essential skill in technology and engineering education (Khumaedi et al., 2021). Mastery of orthographic projection supports technical communication, spatial visualization, and accurate engineering documentation (Gummaluri, 2024). Overcoming instructional challenges, enhancing teaching practices, and adopting modern approaches offer great potential to improve engineering drawing education in TVET. Despite government policy and infrastructure investments, the digital and physical media for orthographic projection in Indonesian vocational high schools (VHS) are not adequately specified. This gap points to the need for closer examination of what happens at the classroom level. This study investigates the challenges students face, how teachers currently approach instruction, and what technology-enhanced opportunities may be feasible in this context. The research questions in this study are:

1. What challenges do VHS students face when learning orthographic projection engineering drawing?
2. How do VHS teachers currently teach orthographic projection engineering drawing?
3. What technology opportunities do teachers and students identify to improve learning?

LITERATURE REVIEW

Engineering drawing in education

Engineering drawing is widely regarded as a visual and technical communication tool for expressing design ideas, specifications, and spatial relationships in engineering and technical education (Baralić & Bjekić, 2024; Barr, 2004; Setiyawan et al., 2025). The teaching of engineering drawing is therefore closely tied to spatial cognition. In line with cognitive load theory (CLT), spatial ability plays a central role in understanding and producing technical graphics effectively (Marwa et al., 2020; Sorby, 1999). Despite this theoretical foundation, many students continue to struggle with the spatial reasoning required for orthographic projection.

Recent technological developments have introduced augmented reality (AR), virtual reality (VR), and computer-aided design (CAD) as tools to support visualization in engineering drawing education (Lukačević et al., 2023; Nipo et al., 2023; Setiyawan et al., 2021). These technologies can provide immersive and interactive learning environments that may help learners connect abstract 2D representations with 3D forms. However, their pedagogical value depends on how they are integrated into instruction rather than on the technology itself. These tools may support visualization when aligned with the spatial and representational demands of engineering drawing.

To maintain conceptual focus, this study emphasizes representation-based learning rather than broad technological adoption. The pedagogical value of digital tools depends on when and how they are used and integrated. Overreliance on digital drafting without strong manual foundations may limit students' ability to internalize projection concepts and spatial relationships. Traditional diagram-based instruction may support procedural accuracy, but it often does not sufficiently develop spatial cognition. Conversely, CAD-only approaches may shift attention to software operation rather than conceptual understanding. Therefore, a balanced instructional sequence—from manual sketching to physical or visual representation and finally to CAD-based drawing—has been suggested as a more effective approach to support spatial learning.

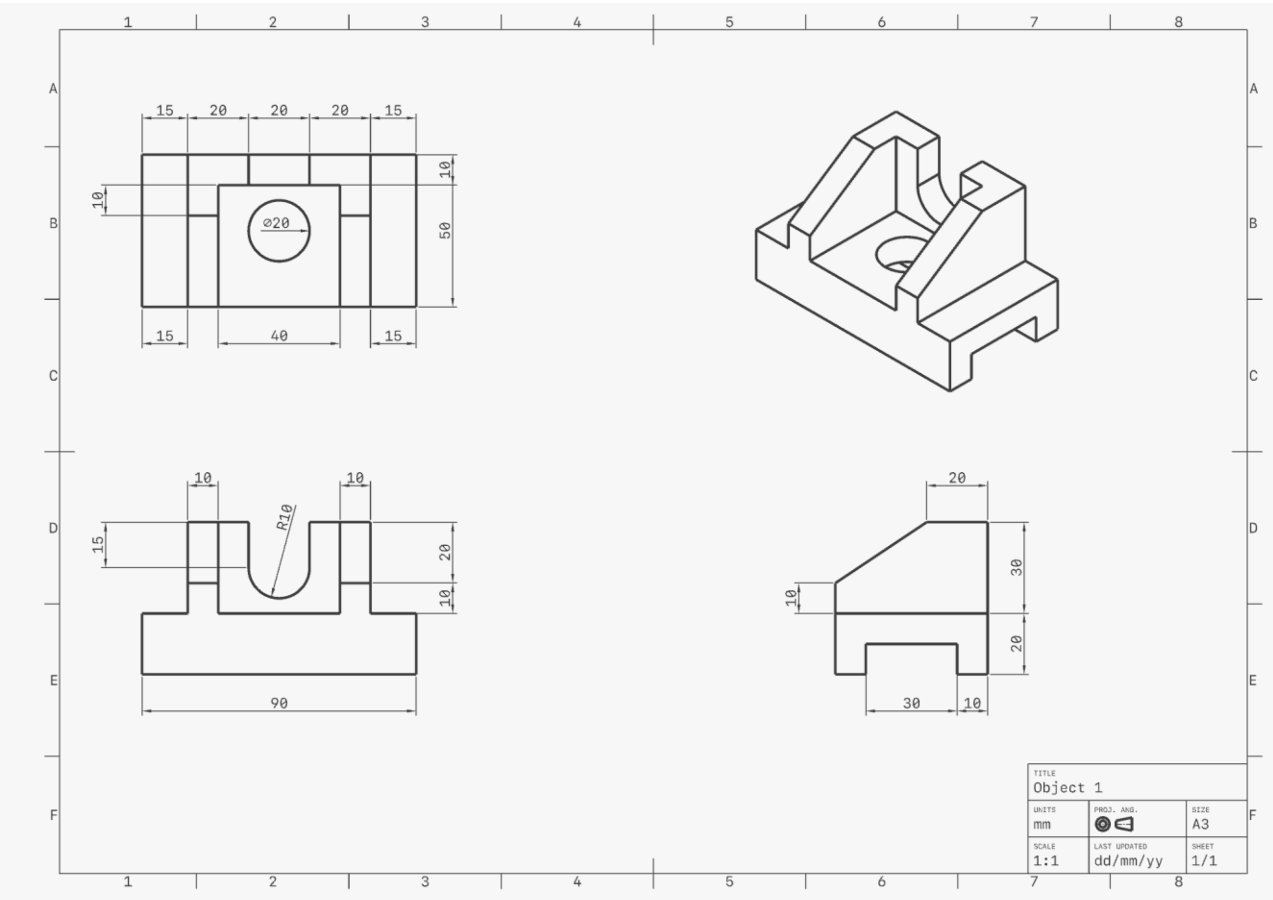
Orthographic projection

Orthographic projection operationalizes the translation from 3D form to a 2D representation and is thus the critical bottleneck in mastering engineering drawing. This technique plays a central role in technical communication across engineering disciplines, including mechanical, civil, and architectural engineering (Barr, 2004; Mursid et al., 2021). According to Sukandar et al. (2020), orthographic projection helps engineers visualize and interpret objects from top, front, and side views, forming the basis of design documentation and manufacturing communication.

Figure 1 presents a sample orthographic projection in an engineering drawing, illustrated by the authors using CAD software.

Figure 1

The authors illustrated the sample of orthographic projection in the engineering drawing task



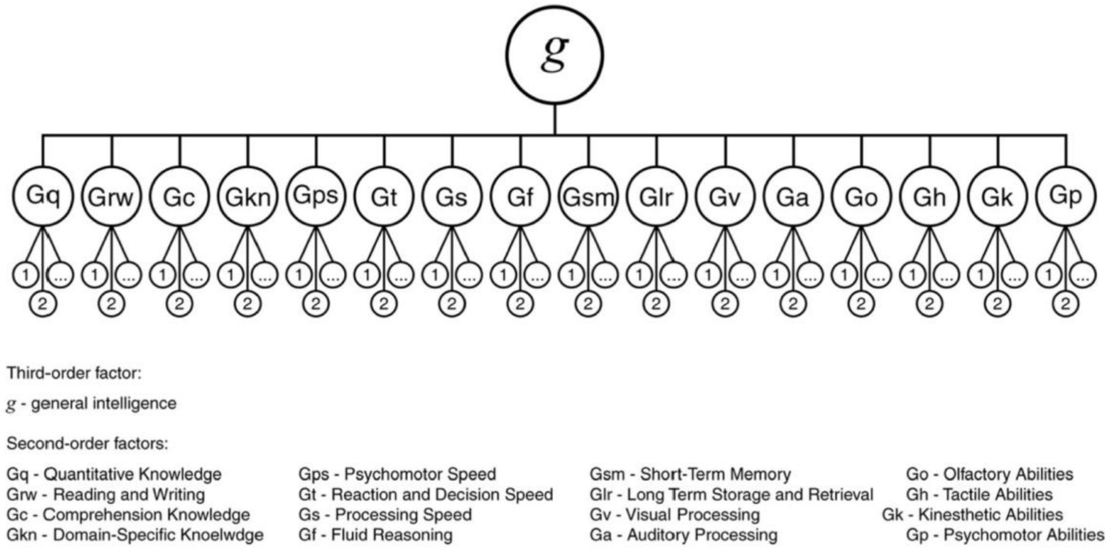
From a cognitive perspective, mastering orthographic tasks requires strong spatial visualization skills, which involve mentally manipulating and interpreting spatial information. Drawing on spatial intelligence theory, Marwa et al. (2020) and Awuor et al. (2022) both point to spatial reasoning difficulties as one of the more persistent obstacles engineering students face in developing conceptual understanding. This suggests that orthographic projection is not only a technical drawing skill but also a cognitively demanding process requiring the coordination of multiple spatial representations. Despite its central role in engineering education, many learners continue to struggle with these cognitive demands.

Spatial ability

The Cattell-Horn-Carroll (CHC) theory of intelligence integrates two earlier theories of cognitive abilities (Schneider & McGrew, 2012). The CHC theory structure is shown in Figure 2. From an educational standpoint, spatial ability refers to the capacity to mentally represent and manipulate spatial information. This capacity exists prior to formal training and distinguishes it from spatial skills, which are typically developed through instruction and practice (Sorby, 1999).

Figure 2

The CHC theory structure (Schneider & McGrew, 2012)



Spatial ability remains a strong predictor of learning and performance in engineering and technical education (McNea et al., 2025; Uttal et al., 2013). Additionally, spatial ability is a multidimensional construct including mental rotation, spatial visualization, and orientation across representations (Schenck & Nathan, 2024). In engineering drawing, these abilities are essential for interpreting orthographic projections and producing accurate technical representations.

From a pedagogical perspective, developing spatial ability in engineering drawing requires carefully integrating content knowledge, instructional strategies, and appropriate learning tools. Frameworks such as TPACK highlight the importance of aligning pedagogy and technology to support meaningful learning (Mishra & Koehler, 2006). In this study, the emphasis is on how different forms of representation can scaffold spatial understanding.

METHODS

Interview participants

Data were collected from students and teachers at three secondary-level vocational high schools (VHS) located in different regions of Indonesia. The sampling frame consisted of vocational high schools offering engineering drawing courses within the selected regions, from which schools meeting the inclusion criteria were identified and invited to participate. The schools were selected to represent variation in geographical and educational contexts, including a rural area (Sawit, Boyolali, Central Java), a town or suburban area (Tulungagung, East Java), and an urban area (Special Region of Yogyakarta). This variation was intended to capture differences in access to resources, technological infrastructure, and instructional practices across settings.

Participants were recruited through coordination with school administrators, who assisted in distributing study information to eligible teachers and students. School administrators assisted only in distributing study information, while all recruitment decisions and participant selection were managed independently by the research team. Participation was voluntary, and individuals who expressed interest were contacted directly by the research team. To minimize potential power relationships, teachers were not involved in selecting student participants, and all interviews were conducted outside of formal assessment contexts. This approach was intended to reduce institutional influence on participation and to ensure that responses reflected participants' perspectives rather than organizational expectations.

Purposive maximum-variation sampling was used to recruit 15 participants (10 students and five teachers) across the three schools. This approach aimed to capture diversity in participant roles, vocational programs (automotive and machining), teaching experience, and school environments. Inclusion criteria at the institutional level required that schools (1) provide vocational education, (2) implement the national curriculum, (3) hold a high accreditation status, and (4) have access to relevant technological resources during the data collection period. At the participant level, individuals were selected based on their direct experience in learning or teaching orthographic projection. No prior personal or professional relationship existed between the researchers and participants. The demographic characteristics of participants in this study are presented in **Table 1**.

Table 1
Demographic of participants

Variable	Category	Students (n)	Teachers (n)	Total (n)	Percentage (%)
Gender	Male	7	3	10	66.7
	Female	3	2	5	33.3
Age group	Under 20 years	10	-	10	67
	20 - 30 years	-	1	1	7
	31 - 40 years	-	2	2	13
	41 - 50 years	-	2	2	13
Teachers educational levels	Bachelor's degree	-	4	4	80
	Master's degree	-	1	1	20
Vocational Program	Automotive engineering	5	2	7	47
	Machining engineering	5	3	8	53
Teaching experience	< 5 years	-	2	2	40
	5 - 10 years	-	2	2	40
	> 10 years	-	1	1	20
Living place	Village	3	1	4	27
	Town	4	2	6	40
	City	3	2	5	33

The sample size was guided by the principle of information power, whereby a smaller sample is considered sufficient when the study's aim is focused and participants have relevant experience. Jumbe and Meyrick (2018) note that smaller, intentionally chosen groups often yield richer insights into participants' experiences. These details tend to get lost in larger samples. This method supports a more thorough grasp of the subtle aspects within participants' viewpoints and reactions. Data collection and analysis were conducted iteratively, and saturation was reached when similar patterns of challenges, practices, and opportunities recurred across participants.

Interview procedure and instruments

Data were collected between March and June 2024 through online semi-structured interviews conducted via Zoom. Each interview lasted approximately 45–60 minutes, was audio-recorded with participants' consent, and transcribed verbatim for analysis. All interviews were conducted in Bahasa Indonesia to allow participants to express their experiences in their first language. The quotations presented in this manuscript were translated into English by the research team and cross-checked through iterative review among the authors to preserve meaning and contextual accuracy. To further ensure translation accuracy, selected excerpts were reviewed multiple times in relation to the original transcripts to confirm semantic equivalence and contextual meaning.

Semi-structured interviews were selected because they allow participants to describe their experiences, perceptions, and suggestions in their own words while maintaining alignment with the research questions (Cohen et al., 2002). Separate interview protocols were developed for students and teachers and were reviewed and refined prior to data collection, including informal piloting, to ensure clarity, relevance, and alignment with the study aims. The interview focus for each participant group is summarized in Table 2.

Table 2
Interview protocol in this study

Participants	Focus area	Guiding question
Students	Learning challenges	What are the main challenges you face when learning orthographic projection in engineering drawing?
	Current support	What learning resources or teaching methods help you understand orthographic projection better?
	Improvement opportunities	What improvements or additional support would help improve your learning experience in orthographic projection?
Teachers	Student challenges	What are the common difficulties students encounter when learning orthographic projection?
	Current teaching practices	What teaching strategies or tools do you use to help students understand orthographic projection concepts?
	Improvement opportunities	What opportunities do you see for improving the teaching and learning of orthographic projection in vocational education?

Interviews were conducted by trained members of the research team using a consistent protocol. To minimize interviewer influence, a neutral, non-directive approach was adopted, with open-ended questions and follow-up prompts that supported participants' own perspectives without leading responses. Particular attention was given to the school-based context of the study to reduce potential power asymmetries, especially for student participants.

Data collection and analysis were conducted iteratively to assess the dataset's adequacy in relation to the research questions. After each interview, transcripts were reviewed to evaluate whether new insights were emerging. As data collection progressed, responses from both students and teachers showed increasing convergence. Recurring patterns emerged regarding spatial visualization difficulties, confusion about projection methods, drawing accuracy, and instructional practices. Students and teachers were treated as analytically distinct groups. Sufficient depth was reached within each group when similar patterns were consistently observed across participants. In the later interviews, no substantially new interpretive insights emerged. Data collection was concluded when patterns stabilized within and across participant groups, indicating sufficient information power for the study's focused scope.

To enhance trustworthiness by Nowell et al. (2017), several strategies were applied. Credibility was supported through the use of participants' first language and iterative review of translated data. Dependability was addressed through consistent interview procedures, verbatim transcription, and alignment between data collection and analysis. Confirmability was strengthened through collaborative review among researchers during data familiarization and interpretation. Transferability is supported by the detailed description of participants, settings, and procedures provided in this study.

Data analysis

The data analysis followed Braun and Clarke's (2006) using six-phase reflexive thematic analysis. All data interviews in audio format were transcribed verbatim and read repeatedly to support deep familiarization with the data. Coding was conducted in an inductive and iterative manner, focusing on participants' experiences and meanings rather than applying predefined categories. Two researchers initially engaged with a subset of transcripts to explore potential patterns and develop early interpretive codes. These initial codes were not treated as a fixed framework but as provisional and evolving analytic tools, which were continuously refined as analysis progressed across the full dataset. Coding involved repeated movement between individual extracts and the broader dataset, allowing patterns to be reinterpreted and reorganized throughout the process.

Theme development was a reflexive and interpretive process. Patterns were gradually clustered into subthemes and broader themes through ongoing discussion among the research team. Three authors reviewed and refined the developing themes in a cyclical manner, examining coherence within and between themes and ensuring alignment with representative data extracts.

In line with reflexive thematic analysis, the analytic process emphasized interpretation rather than consensus coding, and no inter-coder reliability measures were sought. Instead, analytic rigor was supported through iterative engagement with the data, reflective discussion among researchers, and the use of audit memos to document analytic decisions. The research team's disciplinary background in engineering education and technology-enhanced learning informed the interpretation of the data. In particular, attention to digital tools and emerging technologies reflects both participants' and the researchers' sensitivity to contemporary developments in vocational education. To mitigate potential bias, interpretations were continuously checked against participants, and alternative explanations were considered throughout the analytic process.

RESULTS

Three themes emerged from the analysis: the challenges students face when learning orthographic projection technical drawing, how teachers currently approach it, and what better teaching might look like going forward. Students are referred to as S1, S2, S3, and so on; teachers are referred to as T1 through T5. The labels protect confidentiality while also making it easier to follow individual voices across the findings.

Challenges in learning orthographic projection engineering drawing

The theme of student challenges comprised two subthemes: visualization problems and technical skill issues. Participants described four recurring difficulties: visualizing three-dimensional objects, distinguishing between projection methods, maintaining precision and accuracy, and adapting to CAD software. **Figure 3** presents an analytical map of this theme, showing the relationships among the subthemes and the illustrative codes. Additionally, representative quotations from both students and teachers are presented in **Table 3**.

Figure 3

Student challenges in orthographic projection engineering drawing

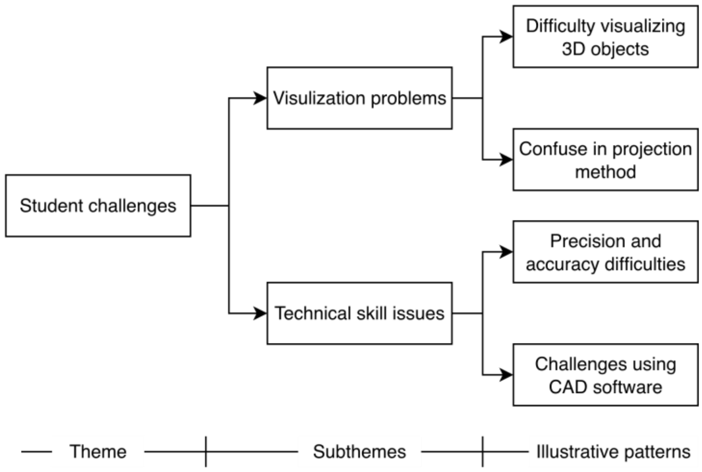


Table 3

Interpretive map of student challenges in orthographic projection learning

Subtheme	Illustrative patterns	Representative quotation
Visualization problems	Difficulty visualizing 3D objects	"One of the biggest challenges I face is visualizing 3D objects in 2D form. Sometimes, I struggle to imagine how different views, like the front, top, and side, are related" (S1).
		"Many students have difficulty imagining 3D objects in their minds, affecting their ability to draw orthographic projections correctly" (T1).
	Confusion in projection method	"I find it difficult to understand the rules of projection, like third-angle and first-angle projection. When I make mistakes, it takes a long time to realize where I went wrong" (S2).
		"A major issue is that students mix up projection methods. Some struggle to differentiate between first-angle and third-angle projection, leading to mistakes in their drawings" (T2).
Technical skill issues	Precision and accuracy difficulties	"The hardest part for me is drawing accurately with proper dimensions. Even though I understand the basic concepts, I often miscalculate proportions" (S3).
		"Students often lack patience and tend to rush through their drawings without checking for accuracy, resulting in misalignment between different views" (T3).
	Challenges using CAD software	"I find it hard to use CAD software for orthographic projection. The software tools have so many functions, and I don't always know which ones to use" (S7).
		"Some students struggle to transition from manual drawing to digital tools like CAD software" (T5).

Visualizing 3D objects was one of the most commonly cited difficulties, raised by both students and teachers. Orthographic projection is essentially a translation problem. A physical object must be mentally flattened into front, top, and side views, with each view accurate and consistent with the others. Such spatial reasoning does not develop naturally for many learners. Without it, students find themselves stuck at both ends, unable to read an orthographic drawing and equally unable to produce one.

Confusing first-angle and third-angle projection was not a one-off slip for many students; it came up repeatedly. What made it harder was students often could not tell where they had gone wrong. This was true even after an error had already crept into their drawing. Some of that comes down to how the two systems are typically introduced. When they are taught in sequence rather than placed directly side by side, the differences remain conceptual rather than visible. Students end up with two separate explanations in their heads and no clear way to compare them. Participants suggest that more explicit contrast between the two methods may support understanding.

Understanding orthographic projection and drawing it accurately are two different things. Students who could explain the concept clearly still made mistakes in dimensions and proportions when putting lines on paper. Some rushed through views without checking alignment, and small errors quickly compounded. Mastering orthographic projection requires both a solid mental model and careful, methodical attention, neither of which develops overnight. The conceptual side can be taught directly, but the precision needed for accurate drawing has to be built gradually through repeated practice.

Several participants highlighted difficulties in using CAD software for orthographic projection tasks. The large number of functions and commands can be overwhelming, particularly for beginners who are still developing a basic understanding of projection principles. Teachers also recognized this transition from manual drawing to digital tools as a significant challenge. Participants suggest that CAD may need to be introduced gradually and scaffolded to help students build confidence and digital competence. This ensures they develop technical fluency without losing focus on core conceptual understanding.

Current teaching practices in orthographic projection engineering drawing

Current teaching practices in orthographic projection were organized into two broad subthemes: conventional approaches and interactive approaches. Within these subthemes, participants described four recurring practices, namely paper-based teaching and presentations, step-by-step exercises, hands-on sketching before CAD, and group learning activities. Figure 4 presents an analytical map of this theme, showing the relationships among the subthemes and the illustrative codes. To provide a concise overview of the evidence, representative quotations from students and teachers are presented in Table 4, followed by interpretive explanations of each practice.

Figure 4

Current teaching strategies for orthographic projection and engineering drawing

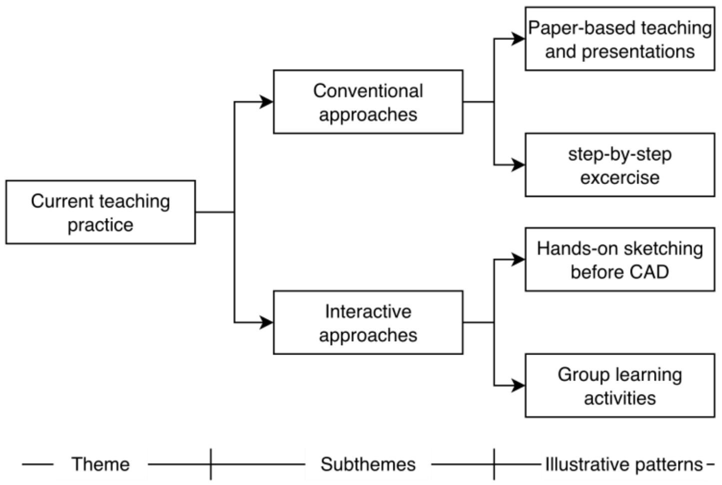


Table 4

Interpretive map of current teaching practice in orthographic projection learning.

Subtheme	Illustrative patterns	Representative quotation
Conventional approaches	Paper-based teaching and presentations	"Our teacher mainly explains the concepts using paper-based materials and presentation slides, and they give me examples on the whiteboards with some explanation" (S1).
		"I primarily use paper-based exercises and presentations to explain orthographic projection. These methods help students follow structured steps" (T1).
	Step-by-step exercises	"Our teacher gives us step-by-step exercises, starting from simple objects to more complex ones. This gradual approach helps me build confidence" (S2).
		"I provide step-by-step guidance and structured exercises to help students progress gradually" (T5).
Interactive approaches	Hands-on sketching before CAD	"We practice sketching by hand before using CAD software. This helps me grasp the basic concepts before moving on to digital tools" (S2).
		"I encourage students to start with freehand sketches before using drawing instruments or CAD software" (T2).
	Group learning activities	"Group activities help me because we can discuss and correct each other's mistakes. Sometimes, my classmates explain things better than the teacher" (S5).
		"I implement project-based learning and group activities, making the process more engaging" (T3).

Paper-based teaching and presentations remain foundational practices in orthographic projection instruction. Both students and teachers described these methods as a regular part of classroom delivery. These approaches play an important role in introducing concepts in a structured and accessible way, particularly for novice learners. Through this approach, teachers provide clear explanations, static visual references, and guided examples. Step-by-step exercises also emerged as a common instructional practice. Participants described a gradual progression from simple to more complex tasks. Moreover, teachers intentionally scaffold learning to build students' confidence and competence. This sequencing appears to help learners develop understanding incrementally and avoid being overwhelmed. The structured progression remains an important feature of effective teaching in this area.

Alongside these conventional approaches, participants also described more interactive strategies, particularly manual sketching, before the introduction of CAD software. Students and teachers viewed hand sketching as a useful preparatory stage. It helps learners grasp basic projection concepts before working with digital tools. Participants perceived this sequence as helpful for developing spatial awareness and conceptual understanding before engaging with digital tools.

Opportunities for future learning in orthographic projection engineering drawing

Opportunities for improving orthographic projection instruction were organized into two broad subthemes: physical learning media and digital and virtual learning environments. Within these subthemes, participants identified four possible improvements: the use of 3D-printed models, industry-based projects, increased CAD practice, and the integration of VR/AR tools. Figure 5 presents an analytical map of this theme, showing the relationships among the subthemes and the illustrative codes. Representative quotations from students and teachers are presented in Table 5, followed by interpretive explanations of each opportunity.

Figure 5

Analytic map of opportunities for enhancing orthographic projection instruction

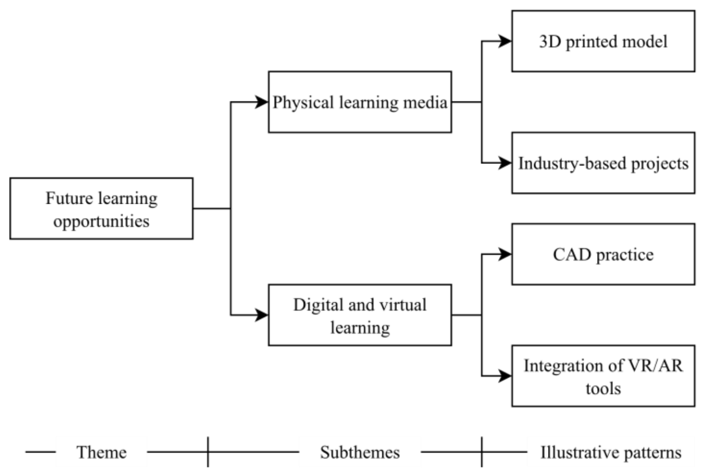


Table 5

Interpretive map of future learning in orthographic projection learning

Subtheme	Illustrative patterns	Representative quotation
Physical learning media	Use of 3D-printed models	"I think using 3D-printed models would help because they allow us to physically see and touch the object before drawing it" (S1).
		"Schools could invest in 3D-printed models to help students understand spatial relationships better" (T4).
	Industry-based projects	"I would love to see more industry-based projects where we work on real engineering drawings used in companies" (S3).
		"Integrating more real-world projects and collaborations with industries would give students hands-on experience" (T2).
Digital and virtual learning environments	Increased CAD practice	"More practice with CAD software would be helpful. Sometimes, we only get a little time to use it in class, and it's hard to master" (S7).
		"Expanding the use of digital tools like CAD software would better prepare students for future careers in engineering and design" (T5).
	Integration of VR/AR tools	"If we could use virtual reality (VR) or augmented reality (AR) applications, it would make it much easier to grasp 3D visualization" (S6).
		"Introducing gamified learning or interactive VR/AR exercises could make engineering drawing more engaging for students" (T4).

Participants perceived the use of 3D-printed models as a promising way to support spatial understanding. The participants viewed physical models as helpful because they allow learners to see, touch, and manipulate objects before translating them into orthographic views. These responses indicate that participants perceived tangible learning media as potentially helpful for bridging the gap between spatial perception and technical representation. This is particularly important for students who struggle to mentally imagine 3D forms.

Industry-based projects were also identified as a meaningful way to strengthen learning relevance. Students expressed interest in working with real engineering drawings, while teachers emphasized the value of collaboration with industry. These responses suggest that authentic projects can connect classroom learning with workplace practices. Additionally, it can increase student motivation and support the development of technical competence aligned with professional expectations.

Participants also highlighted the need for increased CAD practice. Students reported limited class time as a barrier to mastering CAD tools. Furthermore, teachers recognized stronger digital drawing skills as important for future careers in engineering and design. Participants emphasized the perceived need for more structured and sustained opportunities for CAD-based learning. Additionally, VR and AR were seen as potential tools to improve visualization and engagement. These findings reflect participants' perceptions of potentially useful approaches rather than demonstrated effectiveness. Further research using observational or experimental designs is needed to examine the impact of these tools on spatial reasoning, drawing accuracy, and learning outcomes.

DISCUSSION

This study examined three interconnected concerns in Indonesian TVET engineering drawing education: the challenges students face with orthographic projection, how teachers currently approach its instruction, and what technological opportunities exist to improve learning. These questions were driven by a persistent gap between curriculum expectations and students' actual ability to perform in practice. Rather than treating these issues separately, the findings point to a set of interrelated challenges related on spatial visualization, instructional sequencing, and contextual constraints. The findings are discussed below in relation to existing literature.

First, spatial visualization emerges as a central learning bottleneck in orthographic projection. Students often struggle to visualize 3D objects and translate them into 2D views. This difficulty reflects the importance of spatial visualization skills in engineering drawing. Sorby (1999) argues that spatial ability is essential for success in engineering graphics and design. When these skills are weak, students may find it difficult to understand object orientation. This finding is consistent with previous research showing students often struggle to reconstruct spatial models and projections due to limited spatial reasoning abilities (Marwa et al., 2020). Participants in this study reinforce the idea that orthographic projection is not only a technical skill but also a cognitively demanding translation process between 3D and 2D representations.

Orthographic projection also places a high cognitive demand on students. Lukačević et al. (2023) found orthographic tasks to elicit greater brain activity than isometric projection tasks. Students with weaker spatial ability experience more difficulty in interpreting and drawing orthographic views (Sorby, 1999; Van Den Einde et al., 2022; Muzaini et al., 2026). In line with participants' experiences, this suggests the need for instructional approaches that support visualization and reduce cognitive overload, rather than relying solely on abstract explanation.

Second, the findings highlight the limitations of conventional paper-based instruction when used in isolation. Traditional teaching methods, such as paper-based instruction and slide presentations, remain important in engineering drawing classrooms. These methods provide structure and help teachers introduce the basic principles of orthographic projection. Frey and Fisher (2010) emphasized the need to adapt instruction to different learning needs, while Abedi (2024) highlighted the value of integrating more interactive learning approaches. The present findings suggest that conventional instruction remains necessary but should be complemented with additional visual and interactive supports to address spatial difficulties.

Third, the findings point to the importance of carefully sequencing manual, physical, and digital representations in learning. Participants described manual sketching as a useful starting point before engaging with digital tools such as CAD. This progression supports conceptual understanding before introducing technical complexity. Rather than replacing traditional methods, participants' accounts suggest that combining manual sketching with physical or visual representations may provide a more effective learning pathway. For example, physical models, such as 3D-printed objects, were perceived as helpful for connecting abstract concepts with tangible forms. These findings suggest that learning may be strengthened when students move progressively from manual representation to more complex visual or digital environments.

Fourth, the findings reflect important contextual constraints on technology integration in Indonesian TVET. While participants identified tools such as CAD, 3D models, and immersive technologies as potentially useful, they also emphasized limitations related to access, time, and teacher readiness. This indicates that technology integration is not only a pedagogical issue but also a contextual one shaped by infrastructure and institutional conditions. As noted in vocational education research, effective implementation depends on aligning instructional innovation with available resources and teacher capacity (Billett, 2011; Dalle et al., 2024; Katz, 2026). Therefore, rather than assuming broad technological adoption, the findings highlight the need for context-sensitive and gradual integration strategies.

The findings also highlight the need to strengthen vocational teachers' professional capacity (Kalimullina et al., 2020). Students' difficulties with spatial visualization, projection methods, drawing accuracy, and CAD use reflect not only learning challenges but also the need for stronger pedagogical support (Hamilton et al., 2021). The TPACK framework provides a useful perspective, emphasizing the integration of content, pedagogy, and technology in teaching (Mishra & Koehler, 2006; Petko et al., 2024; Hahn et al., 2025). In this context, the key issue is not the adoption of multiple technologies, but how teachers can effectively use available tools to support spatial understanding and conceptual development.

References to advanced technologies such as VR, AR, 3D models, and possibly AI should therefore be interpreted cautiously. In this study, participants discussed these tools as potential or desirable supports rather than as empirically validated solutions. Their role is better understood as future-oriented possibilities that warrant further investigation, particularly regarding their feasibility and effectiveness in TVET contexts (Acar et al., 2025; Yıldırım et al., 2024).

Therefore, teacher professional development should focus not only on technical skills but also on instructional decision-making (Webb, 2026). Specifically, it should address how to sequence manual, physical, and digital representations to support spatial learning and reduce cognitive load. A more focused and context-aware approach to technology integration is likely to be more effective than broad adoption of multiple tools. Ongoing investment in teacher development, infrastructure, and instructional support remains essential for improving engineering drawing education in TVET.

Future recommendations

To improve orthographic projection instruction, teachers may combine established teaching practices with more visual and interactive approaches. Manual sketching should remain an important foundation. Participants in this study perceived that it can be strengthened through project-based tasks, multimedia support, and regular CAD practice. This combination may help students develop both foundational drawing skills and digital visualization skills. Teachers may also consider gradually introducing 3D modelling, 3D printing, AR, and VR, as these were identified by participants as potentially helpful for supporting visualization. These tools may give students opportunities to see and manipulate objects before translating them into orthographic views. However, these suggestions are based on participants' perceptions rather than tested instructional outcomes.

Schools may consider accessible 3D modelling and printing resources and industry partnerships to support more authentic learning experiences. At the same time, professional development is needed to help vocational teachers make informed decisions about when and how to use different tools in instruction. Rather than focusing on adopting multiple technologies, the findings suggest the importance of sequencing manual, physical, and digital representations to support spatial understanding. Sustained support for equipment, infrastructure, and teacher training remains important for enabling such practices.

Limitations and future research

This study provides insights into how orthographic projection is taught and learned in vocational engineering drawing. However, the findings should be interpreted with several concerns as limitations. The study involved ten students and five teachers from a specific regional context, which may limit the transferability of the findings to other settings. The data were based on interviews, which are appropriate for capturing participants' experiences but may be influenced by recall and self-report bias. In addition, the study did not include classroom observations, analysis of student drawings, or direct measures of spatial ability. As a result, the study does not provide evidence of instructional effectiveness or learning outcomes but rather reflects participants' perceptions of challenges and potential strategies. This limitation has implications for how the findings are interpreted across the manuscript.

Future research could examine orthographic projection instruction across broader vocational and educational contexts. Studies using mixed-methods, design-based research, or quasi-experimental approaches are needed to examine how the suggested instructional sequences operate in practice and whether they influence spatial reasoning and drawing accuracy. Further research may also explore how teacher professional development supports the integration of manual, physical, and digital representations in engineering drawing instruction. Such work would provide stronger empirical evidence for evaluating the effectiveness of the approaches identified in this study.

CONCLUSION

This study identifies key challenges students encounter in learning orthographic projection in vocational education, including difficulties with spatial visualization, confusion about projection methods, accuracy issues in engineering drawing, and challenges with adapting to CAD software. Current teaching practices predominantly emphasize traditional methods, such as paper-based instruction and step-by-step exercises, complemented by limited interactive approaches, such as manual sketching and group discussions. The findings also point to several opportunities to enhance student learning, particularly through the use of physical 3D-printed models, industry-linked projects, and wider use of CAD software and virtual reality tools. By identifying learning bottlenecks and outlining sequenced, technology-enhanced strategies, this study offers tentative, context-informed implications for improving VHS engineering drawing instruction.

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Ethical statement

The study received initial ethical approval from the Institutional Review Board (IRB) of the Faculty of Engineering, Semarang State University, Indonesia, initially granted in February 2024 (Approval No. B/3172/UN37.1.5/PT.01.05/2024), prior to data collection. In accordance with institutional policy, this approval was administratively updated in 2025 (Approval No. B/5181/UN37.1.5/KP.15/2025) to cover the ongoing doctoral study period. Written informed consent was obtained from all participants prior to the interviews. Participants were informed about the study's purpose, their voluntary participation, and their right to withdraw at any time. Parental or guardian consent was obtained for all participants under 18 years old in accordance with institutional ethical guidelines.

Competing interests

The authors declare no conflict of interest.

Author contributions

AS contributed to the research concept and design, data collection, data analysis and interpretation, drafting of the manuscript, critical revision, and final approval of the article. AY contributed to data analysis and interpretation, as well as to the critical revision of the article. SS contributed to data analysis and interpretation, manuscript drafting, critical revision, and final approval of the article. MBRW contributed to data collection, data analysis and interpretation, and critical revision of the article. WS contributed to data collection, manuscript drafting, and critical revision of the article. TTW contributed to data analysis and interpretation, critical revision, and final approval of the article. FA contributed to data analysis and interpretation, manuscript drafting, and critical revision of the article. APW contributed to the article's critical revision. TH contributed to the critical revision and final approval of the article. ZL contributed to data analysis and interpretation, critical revision, and final approval of the article. All authors read and approved the final manuscript.

Data availability

All data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI disclosure

The authors used ChatGPT (OpenAI, 2025) and Grammarly solely to assist with language editing, including grammar and wording refinement. The authors fully reviewed the manuscript and took full responsibility for its content, analysis, and conclusions. No generative artificial intelligence tools were used to generate the study data, conduct the analysis, or produce the scientific conclusions of this research.

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