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Research Article

Scientific Supervision and TPACK Competence on Teachers' Ability to Design IPAS Learning

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Abstract: This study aims to: (1) determine the effect of academic supervision on teachers' ability to design IPAS learning at elementary schools in Mandalle District; (2) examine the effect of TPACK competence on teachers' ability to design IPAS learning; and (3) analyze the simultaneous influence of academic supervision and TPACK competence on teachers' ability to design IPAS learning. The research was conducted in elementary schools across Mandalle District from September to October 2025 using a quantitative approach and a causal-comparative (ex post facto) design. A total of 51 teachers were selected through purposive sampling. Data were collected using a Likert-scale questionnaire and analyzed using PLS-SEM with the SmartPLS application. The results indicate that: (1) academic supervision has a positive and significant effect on teachers' ability to design IPAS learning ($\beta = 0.168$; T = 2.623; p = 0.009), although the effect size is categorized as small ($f^2 = 0.071$); (2) TPACK competence has a very strong and significant effect on teachers' ability to design IPAS learning ($\beta = 0.827$; T = 14.299; p = 0.000) with a very large effect size ($f^2 = 3.351$), making it the dominant factor influencing lesson design quality; and (3) jointly, academic supervision and TPACK competence explain 85.5% of the variance in teachers' ability to design IPAS learning, highlighting the importance of synergy between external guidance through supervision and internal teacher competence in mastering TPACK.

Keywords: Academic Supervision; Learning Design; School Teacher; Social Science Learning; TPACK Competencies

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1. Introduction

Education in the era of Society 5.0 faces increasingly complex global challenges, characterized by rapid technological disruption, dynamic social change, and growing demands for the development of critical and creative human resources. In this context, education can no longer be oriented solely toward academic content mastery, but must also foster adaptive competencies through collaborative and problem-solving approaches. This shift necessitates systemic transformation, ranging from curriculum policy to classroom practices. Consequently, improving the quality of learning has become a strategic agenda across educational levels as an effort to respond to global challenges and ensure the relevance of education to contemporary societal needs (M. Ali, 2019; M. I. Ali et al., 2025). At this juncture, teachers play a central role as agents of transformation who directly shape the quality of learning processes and outcomes.

At the elementary education level, the complexity of the teacher's role has intensified. Teachers are not only responsible for transmitting knowledge but are also expected to design contextual and meaningful learning experiences aligned with students' developmental characteristics (Lipiah et al., 2022). The ability to design learning is a critical indicator of teacher professionalism, as effective planning determines the achievement of learning objectives in a systematic and sustainable manner. Professional teachers are required to integrate learning objectives, methods, media, and assessment in a reflective and coherent way to create transformative learning experiences (Hikmah, 2024). Therefore, strengthening teachers' capacity in learning design constitutes a fundamental foundation for improving the quality of elementary education.

The implementation of the Merdeka Curriculum further reinforces these demands through the introduction of IPAS (Natural and Social Sciences) as an integrated interdisciplinary subject at the elementary school level. IPAS learning is designed to foster scientific and social literacy thematically, enabling students to connect academic concepts with real-life contexts (Desstya et al., 2024). Within this framework, teachers are required to design IPAS learning holistically, encompassing the formulation of learning objectives, the selection of inquiry-based strategies and methods, and the development of authentic assessments that reflect the integration of science and social perspectives. The success of IPAS implementation is highly dependent on teachers' ability to design learning that is contextual, reflective, and aligned with the principles of the Merdeka Curriculum (Surul & Septiliana, 2023).

However, empirical realities at the elementary school level indicate a gap between curriculum demands and classroom practices. Data from the even semester report documents of the 2024/2025 academic year in several elementary schools in Mandalle District reveal that the average IPAS scores of fourth- and fifth-grade students range from 68 to 72, which remains below the Minimum Learning Achievement Criteria (KKTP) established by schools at 75. Furthermore, approximately 42% of students achieved scores below the KKTP in IPAS. These findings indicate that students' IPAS learning outcomes have not yet met expected targets and reflect suboptimal learning processes. This condition is further supported by an analysis of teachers' instructional materials, which shows that around 60% of teachers still use adapted teaching modules from previous years without substantial contextual adjustments to the Merdeka Curriculum. Teachers' difficulties are particularly evident in formulating learning outcomes, designing authentic assessments, and selecting inquiry-based and scientific approach learning activities (Robi'ah, 2025).

One factor presumed to contribute to this condition is the practice of academic supervision in schools, which tends to remain administrative and formalistic. Preliminary interviews with teachers and school principals in elementary schools in Mandalle District indicate that supervision is typically conducted once or twice per semester and primarily focuses on checking the completeness of instructional documents, without being followed by reflective dialogue or substantive pedagogical feedback. In fact, supervision should function as a professional development process that encourages reflection, competence development, and improvement in teaching quality (Glickman et al., 2014). When supervision does not address substantive aspects such as learning design, teachers lose essential reflective spaces needed to enhance the quality of their instructional planning (Aulia, 2019; Marais, 2022).

In addition, teachers' Technological Pedagogical Content Knowledge (TPACK) competence remains a critical challenge in IPAS learning. Preliminary data show that only approximately 35% of teachers consistently utilize digital technologies in planning and implementing IPAS learning, such as interactive media, simulations, or online learning platforms. The majority of teachers still rely on conventional methods and printed materials, resulting in learning experiences that are less interactive and less aligned with the characteristics of learners in the digital era. In fact, mastery of TPACK enables teachers to integrate content, pedagogy, and technology harmoniously to create more meaningful and contextual learning experiences ((Galunggung et al., 2024). Limited use of technology in learning design has implications for student engagement and the overall quality of IPAS instruction.

These phenomena indicate a close relationship between teachers' limited ability to design IPAS learning, weak implementation of scientific supervision, and underdeveloped TPACK competence. Scientific supervision is conceptualized as a professional development approach that emphasizes the use of objective data, reflective dialogue, and collaboration between supervisors and teachers in improving instructional quality (Ulfah, 2024). Several studies have demonstrated that scientific supervision contributes positively to improving instructional quality and teacher professionalism (Maharani, 2024; Royani et al., 2024), while TPACK competence has been shown to influence teachers' ability to develop lesson plans effectively (Sholihah et al., 2016). Nevertheless, these studies have not specifically examined the combined effects of scientific supervision and TPACK competence on teachers' ability to design IPAS learning at the elementary school level, particularly within the local context of schools in Mandalle District.

Based on this research gap, the present study has both academic and practical significance in providing contextual empirical evidence regarding the influence of scientific supervision and TPACK competence on teachers' ability to design IPAS learning. Theoretically, this study contributes to the advancement of scholarship on scientific supervision and TPACK within the context of integrated IPAS learning at the elementary level. Practically, the findings are expected to inform the development of more effective and sustainable teacher professional development strategies. Accordingly, the objectives of this study are to examine the effect of scientific supervision on teachers' ability to design IPAS learning, to analyze the effect of TPACK competence on this ability, and to investigate the simultaneous effects of scientific supervision and TPACK competence on teachers' ability to design IPAS learning in elementary schools in Mandalle District.

2. Literature review

Scientific Supervision

Scientific supervision is increasingly framed as a form of professional support grounded in systematic observation, objectivity, and evidence-based decision making, aimed at improving instructional quality through sustained teacher development. Rather than functioning as an administrative checklist, scientific supervision emphasizes deeper engagement with classroom practice by relying on systematic observation, data analysis, critical reflection, and professionally accountable feedback cycles (Septiani, 2019; Zai, 2020). This orientation positions teachers as active professional partners in improvement processes, not merely as objects of evaluation. In line with this view, scientific supervision also prioritizes the development of teachers' scientific thinking and professional reasoning, enabling them to respond to classroom challenges through rational, data-informed problem solving (Sanduleac, 2023). The emphasis on systematic observation and evidence analysis further reinforces supervision as a structured mechanism for improving teachers' planning, implementation, and evaluation capacities (Akpan, 2008).

From a developmental standpoint, scientific supervision is designed to enhance teaching competencies, particularly in instructional planning, delivery, and assessment, through educational and data-driven guidance (Lumbanbatu & Sihotang, 2022). It is not limited to identifying weaknesses but is intended to cultivate reflective and metacognitive teaching habits through constructive feedback that strengthens teachers' capacity to evaluate and refine their practice (Sanduleac, 2023). In science-oriented instruction, Stoner (Yang, Yunfei, Lijun Xie, 2022) highlights the role of scientific supervision in improving the accuracy of evaluating teaching methods and learning outcomes, thereby increasing the precision of instructional improvement. Moreover, a responsive and adaptive supervision approach can strengthen teacher professionalism while simultaneously supporting overall school learning quality

(Ristiyani et al., 2022). These perspectives collectively suggest that scientific supervision becomes meaningful when it influences substantive instructional decisions—especially those related to lesson design and assessment coherence—rather than focusing primarily on documentation compliance.

Principles and procedures within scientific supervision further illustrate its inquiry-based and dialogic character. The OQEAC principle—observing, questioning, experimenting, associating, communicating—indicates that supervision can operate as a professional inquiry cycle: collecting classroom evidence, interrogating practice through reflective questions, testing improvements, linking findings to standards and pedagogical theory, and communicating results as part of sustained professional growth (Rokhman et al., 2024). Complementing this, the principles of being systematic, objective, and instrument-based underscore that supervision should rely on observable evidence and structured tools rather than subjective impressions (Jabbar et al., 2024). The Scientific Supervision Model (SSM) also provides a structured developmental pathway, including teacher and classroom profiling, evaluation of content and pedagogical competence, direct observation, reflective discussion, long-term development planning, and structured feedback (Avwiri & Okey, 2022). A directive approach through school action cycles similarly demonstrates that supervision can be deliberately designed to close identified teaching-skill gaps in a planned and measurable manner (Lumbanbatu & Sihotang, 2022). However, despite these conceptual and procedural strengths, empirical clarity remains limited regarding the extent to which scientific supervision directly contributes to teachers' capacity to design integrated learning in specific subjects such as IPAS.

TPACK Competence

The TPACK framework asserts that effective teaching in digital contexts cannot be explained solely by content knowledge (CK) and pedagogical knowledge (PK), but also depends on teachers' ability to integrate technological knowledge (TK) meaningfully into instructional decision making. TPACK is conceptualized as the dynamic interaction among CK, PK, and TK, where technology is not an add-on but an integral element embedded in pedagogical strategies and content representation (Schmid & Petko, 2020; Warr & Mishra, 2022). When teachers can integrate these knowledge domains effectively, learning experiences become more engaging, relevant, and instructionally efficient, particularly when technological choices align with learning goals and student characteristics (Maknun, 2022). Importantly, TPACK is also positioned as a practical guide that supports teachers in selecting appropriate technologies to strengthen instructional quality and student learning outcomes (MY et al., 2025; Padmavathi, 2017).

Conceptually, TPACK consists of seven interacting components—CK, PK, TK, TPK, TCK, PCK, and TPACK—which together form an integrative competence for 21st-century teaching (Somantri & Putri, 2023). CK serves as the foundational requirement for accurate instruction and preventing misconceptions (Kusaini et al., 2022), while PK guides teachers' strategic choices in classroom management, instruction, and evaluation (Niess, 2015). TK expands teachers' capacity to employ digital tools, learning applications, and interactive media (Somantri & Putri, 2023). The hybrid domains of TPK and TCK reinforce that technology use must be pedagogically and content-appropriate to enhance conceptual understanding rather than merely modernize presentation (Inayati et al., 2024). Meanwhile, PCK remains crucial for translating complex concepts into accessible learning experiences through well-chosen representations and methods (Niess, 2015). Taken together, the framework implies that teachers' lesson-design quality is strongly associated with their ability to coordinate content, pedagogy, and technology in coherent instructional plans.

In IPAS learning, TPACK offers a pathway for improving conceptual clarity and student engagement by enabling the visualization of abstract ideas, contextual inquiry, and interactive learning experiences. Technology-supported instruction can increase students' understanding of abstract scientific concepts through more interactive approaches (Herwanto et al., 2024). Similarly, technology-assisted discovery learning can strengthen contextual learning and make instruction more relevant to real-world settings (Galunggung et al., 2024). Research also highlights the motivational benefits of augmented reality and other interactive media, which can enhance students' engagement and learning experiences (Rahmawati, 2023). Nevertheless, TPACK implementation frequently encounters persistent barriers, including limited technological knowledge and integration skills, insufficient training, inadequate ICT devices and infrastructure, unstable internet connectivity, time constraints, and curriculum rigidity that restrict instructional innovation. These challenges suggest that the relationship between teachers' TPACK competence and lesson-design quality is context-sensitive and warrants empirical testing within specific local settings.

Teachers' Ability to Design Instruction

Teachers' instructional design ability represents a core professional competence that positions teachers as designers of learning experiences rather than mere implementers of curricular documents. Instructional design is understood as a systematic process integrating learning objectives, content, methods, media, and learner characteristics into a coherent plan that enables meaningful and goal-directed learning (Kurniawati, 2021). From a broader learning-design perspective, planning is shaped by values and assumptions and is influenced by social and technological developments; therefore, instructional design is not neutral but embedded in social, political, and economic contexts (Carvalho & Yeoman, 2023). The Understanding by Design approach strengthens this emphasis by prioritizing desired learning outcomes, followed by assessment design and then the development of learning activities aligned with those outcomes (Dewi, 2023; Namus et al., 2024). Consequently, instructional design quality can be judged by coherence among objectives, assessment, and learning activities, as well as by the design's responsiveness to learner context.

Effective instructional design also requires structured components that support implementation and evaluation. In a teaching module, elements such as objectives, content, conclusions, evaluation, assessment guidance, key terms, and references reflect the need for clarity of direction, content precision, and measurable achievement (Chairunnisa et al., 2022). Teaching modules may also include general information, core instructional components (objectives, key concepts, prompting questions, learning steps, assessments, enrichment and remediation, and reflection), and appendices that provide supporting instruments (Triandini et al., 2023). In the Merdeka Curriculum context, lesson planning is expected to be reflective and flexible, attentive to curriculum characteristics and learner diversity, supportive of a conducive learning environment, oriented toward active student participation, and strengthened through collaboration with parents and the community (Lisdawati, 2024). These perspectives indicate that instructional design quality extends beyond document completeness and depends on teachers' capacity to orchestrate coherent, contextual, and impactful learning processes.

Multiple factors shape instructional design quality, combining individual and institutional determinants. School principal supervision and teacher professional competence are highlighted as important influences on the quality of instructional planning (Solihah, 2023). In technology-enhanced learning settings, design quality is also associated with course structure, visual design, interactivity, and the availability of technical and pedagogical support that affects student engagement and satisfaction (Konstantinidis et al., 2023). At the same time, content quality remains the strongest determinant, followed by usability, interaction, and visual design (Aisyah, 2023). Collectively, these findings suggest that teachers' ability to design instruction is an intersection point where professional development mechanisms (such as scientific supervision) and integrative technology competence (TPACK) may jointly shape the quality of instructional planning.

IPAS (Natural and Social Sciences) in Elementary Schools

IPAS, as a Merdeka Curriculum innovation, integrates natural sciences and social sciences into thematic, contextual, and transdisciplinary learning intended to form students' holistic understanding of natural and social realities. IPAS is designed to make learning more engaging, practical, and enjoyable, including through the use of digital teaching materials appropriate for elementary students' characteristics (Fanani et al., 2022). It also aims to equip students with the capacity to manage natural and social environments wisely through gradual and integrated learning processes, with inquiry serving as a core approach that encourages learning through direct experience, questioning, investigation, and independent conclusion-making (Wulandari et al., 2023). Accordingly, IPAS requires high-quality instructional design that balances scientific reasoning and social sensitivity while maintaining contextual relevance.

Instructional strategies in IPAS typically begin with analyzing learning outcomes and conducting diagnostic assessments, followed by developing structured teaching modules and designing core activities that include observing, questioning, exploring, and communicating, supported by relevant formative and summative assessment (Surul & Septiliana, 2023). Differentiated instruction is also emphasized to address variations in students' learning styles—visual, auditory, and kinesthetic—thereby strengthening engagement and optimizing individual achievement (Lestari et al., 2024). In assessment, authentic assessment is recommended for measuring competencies holistically across cognitive, affective, and psychomotor domains in alignment with the Pancasila Student Profile (Cholifah et al., 2024). As a result, IPAS increases the demand for teachers' instructional design capacity, particularly in producing coherent, contextual, differentiated, and assessment-sensitive learning plans.

Despite its curricular promise, IPAS implementation faces multidimensional challenges spanning pedagogy, technology, management, and infrastructure. Teachers may struggle to guide multiple student groups evenly in problem-based learning environments, while limited internet access and weak group-management skills hinder effective multimedia use (Ariawan & Kadek, 2024). Challenges also arise in the need to integrate technology effectively for improving conceptual understanding and interdisciplinary skills, while teachers often experience difficulties matching technology use to diverse student needs (Maladerita et al., 2024). Furthermore, implementing the Merdeka Curriculum within IPAS requires adequate teacher training, a more flexible curriculum environment, and supportive learning infrastructure; without these, adaptive and contextual learning becomes difficult to achieve (Ramadhani & Erviastiwi, 2023). This synthesis indicates that although prior studies have established the importance of scientific supervision and TPACK and have mapped IPAS implementation challenges, empirical evidence remains limited regarding how scientific supervision and TPACK competence—both individually and jointly—relate to teachers' capacity to design IPAS learning in the specific local context of elementary schools. This theoretical and empirical gap positions the present study to test the extent to which evidence-based professional development (scientific supervision) and integrative technology competence (TPACK) contribute to teachers' IPAS instructional design capability.

H1: There is a significant effect of scientific supervision on teachers' ability to design IPAS learning in elementary schools in Mandalle District.

H2: There is a significant effect of TPACK competence on teachers' ability to design IPAS learning in elementary schools in Mandalle District.

H3: There is a significant simultaneous effect of scientific supervision and TPACK competence on teachers' ability to design IPAS learning in elementary schools in Mandalle District.

3. Proposed Method

Research Design and Approach

This study employed a quantitative research approach with a causal-comparative (ex post facto) design to examine the effects of scientific supervision and teachers' TPACK competence on their ability to design IPAS (Natural and Social Sciences) learning. The ex post facto design was selected because the independent variables—scientific supervision and TPACK competence—already existed naturally in the school context and were not manipulated by the researcher. This approach enabled the objective examination of causal relationships among variables through numerical data and statistical modeling. The research was conducted in elementary schools located in Mandalle District, Pangkajene and Islands Regency, South Sulawesi Province, Indonesia, from September to October 2025.

Population and Sample

The population consisted of all elementary school teachers teaching Grades III to VI in Mandalle District who had implemented IPAS learning under the Merdeka Curriculum. This population was defined based on the curriculum structure, as IPAS is formally taught at these grade levels. According to 2025 Dapodik data, the population comprised 51 teachers (44 female and 7 male). Given the relatively small population size, a total sampling technique was applied, whereby all 51 teachers were included as research participants. This approach was used to obtain a comprehensive and accurate representation of the relationships among the studied variables.

Data Collection Procedures

Data were collected using questionnaires as the primary method, supported by document analysis. The questionnaires were designed to measure scientific supervision, TPACK competence, and teachers' ability to design IPAS learning. Each questionnaire consisted of statements rated on a five-point Likert scale ranging from strongly disagree to strongly agree, including both positively and negatively worded items to control for response consistency (Sugiyono, 2019). The scientific supervision questionnaire focused on systematic classroom observation, constructive feedback, reflective dialogue, and continuous improvement facilitated by principals or supervisors. The TPACK competence questionnaire assessed teachers' ability to integrate content knowledge, pedagogical strategies, and technology in lesson design. The instructional design questionnaire measured teachers' competencies in formulating learning objectives, organizing learning activities, selecting appropriate methods and media, and designing authentic assessments aligned with the Merdeka Curriculum. Document analysis was used as a supporting technique to obtain factual data related to school profiles, supervision records, and teachers' IPAS instructional documents, such as teaching modules, lesson plans, and assessment tools, to support data triangulation.

Instruments and Measures

All constructs were measured using self-administered questionnaires developed based on the operational definitions of each variable. Scientific supervision was operationalized as a systematic professional development process grounded in scientific principles aimed at improving teachers' instructional planning competence. TPACK competence was defined as teachers' ability to integrate content, pedagogy, and technology coherently in IPAS lesson design. Teachers' ability to design IPAS learning was operationalized through indicators covering learning objectives, instructional activities, assessment alignment, and the appropriateness of models, approaches, and instructional media. Responses were scored using a five-point Likert scale, with higher scores indicating stronger competence or more effective supervision practices.

Data Analysis Techniques

Data analysis was conducted using partial least squares structural equation modeling (PLS-SEM) with SmartPLS software. The analysis followed two main stages: evaluation of the measurement model (outer model) and evaluation of the structural model (inner model).

Measurement model assessment included convergent validity, discriminant validity, and reliability testing. Convergent validity was established when outer loading values exceeded 0.70, with values between 0.60 and 0.70 considered acceptable for exploratory research, and when Average Variance Extracted (AVE) values exceeded 0.50. Discriminant validity was assessed using the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT), with HTMT values required to be below 0.85–0.90. Reliability was evaluated using Cronbach's alpha and composite reliability, with threshold values of 0.70 or higher.

Structural model evaluation involved assessing collinearity through variance inflation factor (VIF) values, which were required to be below 5 to indicate the absence of multicollinearity. The coefficient of determination (R^2 and adjusted R^2) was used to determine the proportion of variance in teachers' instructional design ability explained by scientific supervision and TPACK competence, following the interpretation guidelines of Hair et al. (2019). Predictive relevance was examined using the Q^2 value obtained through blindfolding procedures, with values greater than zero indicating acceptable predictive capability. Effect size (f^2) was calculated to assess the relative contribution of each independent variable, with values of 0.02, 0.15, and 0.35 indicating small, medium, and large effects, respectively. Hypothesis testing was conducted using the bootstrapping procedure in SmartPLS, generating path coefficients, t-statistics, and p-values. Hypotheses were accepted when p-values were below 0.05 or t-statistics exceeded 1.96.

4. Results and Discussion

Results

Data analysis was conducted using Partial Least Squares–Structural Equation Modeling (PLS-SEM) and comprised measurement model (outer model) evaluation, structural model (inner model) evaluation, and hypothesis testing.

Measurement Model Evaluation (Outer Model)

Convergent Validity

Convergent validity was first assessed using indicator outer loadings. Indicators were considered valid if their outer loading values were ≥ 0.70 (Ravand & Baghaei, 2016; Hair et al., 2019).

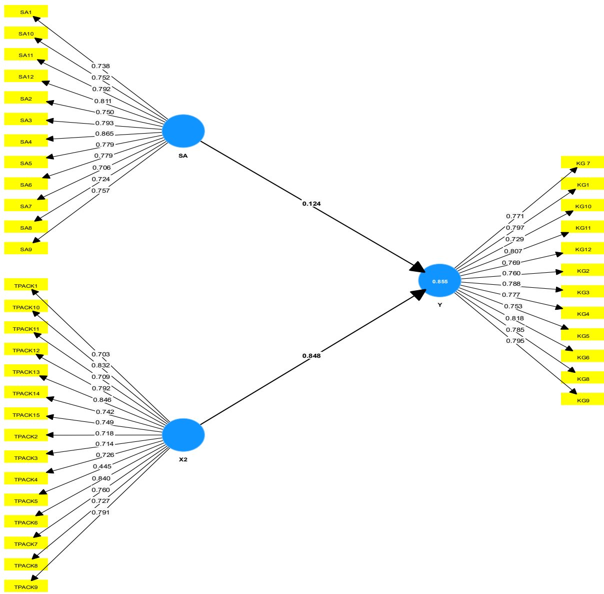

Figure 1. PLS-SEM Structural Model with Outer Loadings.

All indicators for Scientific Supervision (X1) and Instructional Design Ability (Y) met the minimum threshold. One TPACK indicator (X2.5) showed an outer loading below 0.70

and was therefore removed from the model.

Source: SmartPLS Output (2025)

Convergent validity was further confirmed through Average Variance Extracted (AVE).

Table 1. Average Variance Extracted (AVE).

Construct	AVE
Scientific Supervision (X1)	0.59
TPACK (X2)	0.52
Instructional Design Ability (Y)	0.60

Source: SmartPLS Output (2025).

All AVE values exceeded the recommended threshold of 0.50, indicating adequate convergent validity.

Discriminant Validity

Discriminant validity was examined using Heterotrait–Monotrait Ratio (HTMT).

Table 2. HTMT Ratio.

Construct	X1	X2	Y
X1	—	0.608	0.644
X2	0.608	—	0.792
Y	0.644	0.792	—

Source: SmartPLS Output (2025).

All HTMT values were below 0.90, indicating satisfactory discriminant validity (Hair et al., 2019).

Construct Reliability

Construct reliability was evaluated using Cronbach's alpha and composite reliability.

Table 3. Construct Reliability.

Construct	Cronbach's Alpha	Composite Reliability	AVE
Scientific Supervision (X1)	0.938	0.946	0.596
TPACK (X2)	0.941	0.949	0.556
Instructional Design Ability (Y)	0.941	0.949	0.608

Source: SmartPLS Output (2025).

All constructs demonstrated excellent reliability and validity.

Structural Model Evaluation (Inner Model)

Coefficient of Determination (R^2)

Table 4. R-Square Values

Endogenous Variable	R^2	Adjusted R^2
Instructional Design Ability (Y)	0.855	0.849

Source: SmartPLS Output (2025).

Scientific supervision and TPACK jointly explained 85.5% of the variance in teachers' instructional design ability, indicating a strong model.

Effect Size (f^2)

Table 5. Effect Size (f^2).

Relationship	f^2	Interpretation
Scientific Supervision → Instructional Design Ability	0.071	Small
TPACK → Instructional Design Ability	3.351	Very Large

Source: SmartPLS Output (2025).

TPACK demonstrated a dominant contribution to instructional design ability.

Hypothesis Testing

Table 6. Path Coefficients and Hypothesis Testing.

Path	β	t-value	p-value
Scientific Supervision → Instructional Design Ability	0.168	2.623	0.009
TPACK → Instructional Design Ability	0.827	14.299	0.000

Source: SmartPLS Output (2025).

Both direct effects were positive and statistically significant.

Predictive Relevance (Q^2)

Table 9. Predictive Relevance (Q^2_predict).

Endogenous Variable	Q^2_predict	RMSE	MAE
Instructional Design Ability (Y)	0.832	0.436	0.346

Source: SmartPLS Output (2025).

The model demonstrated very high predictive relevance. Overall, the measurement and structural models met all recommended criteria for validity, reliability, explanatory power, and predictive relevance. Scientific supervision and TPACK competence jointly exerted a substantial influence on teachers' ability to design IPAS learning, with TPACK emerging as the dominant predictor and scientific supervision providing a statistically significant supportive effect.

Discussion

Effect of Scientific Supervision on Teachers' Ability to Design IPAS Learning

The PLS-SEM results indicate that scientific supervision has a positive and statistically significant effect on teachers' ability to design IPAS learning. This relationship is evidenced by a path coefficient of 0.168, a t-value of 2.623, and a p-value of 0.009. Although the effect size is relatively small ($f^2 = 0.071$), the finding confirms that scientific supervision contributes meaningfully to improving teachers' instructional planning.

From a theoretical perspective, this result aligns with academic supervision theory, which conceptualizes supervision as a professional development process rather than administrative control. Glickman et al. (2017) emphasize that effective supervision involves systematic planning, classroom observation, reflective dialogue, and follow-up actions. In this study, scientific supervision appears to support teachers in refining learning objectives, selecting instructional strategies, and designing authentic assessments for IPAS learning through reflective and data-informed guidance.

This finding is consistent with prior studies demonstrating the role of supervision in enhancing teachers' instructional competence. Ipa (2024) reported that routine supervision enabled teachers to develop instructional innovations, while Lumuan (2023) found substantial improvements in lesson planning quality following sustained supervisory cycles. Similarly, Prasetiyo & Muhes (2025) and Simbolon (2022) highlighted that observation-based supervision and reflective feedback significantly improved teachers' ability to design instructional materials. Collectively, these studies reinforce the conclusion that scientific supervision consistently supports improvements in instructional planning, including in the context of IPAS learning. However, the relatively small effect size suggests that scientific supervision alone is insufficient to substantially enhance teachers' instructional design capacity. Its effectiveness depends largely on the quality of pedagogical interaction, the competence of supervisors, and the extent to which feedback is translated into practice. Thus, supervision should be strengthened through contextualized mentoring, reflective dialogue, and individualized professional support.

Effect of TPACK Competence on Teachers' Ability to Design IPAS Learning

The findings demonstrate that TPACK competence exerts a very strong and significant influence on teachers' ability to design IPAS learning. This is reflected in a path coefficient of 0.827, a t-value of 14.299, and a p-value below 0.001. The exceptionally large effect size ($f^2 = 3.351$) confirms that TPACK is the dominant predictor of instructional design ability in this study. This result is theoretically grounded in the TPACK framework, which posits that effective instructional planning depends on teachers' ability to integrate content knowledge, pedagogical strategies, and technology in a coherent and contextual manner. IPAS learning, which emphasizes inquiry, integration of scientific and social concepts, and contextual exploration, inherently requires such integration. Therefore, teachers with strong TPACK competence are better positioned to design meaningful and effective IPAS learning experiences.

The findings are consistent with previous research highlighting the critical role of TPACK in lesson planning. Masfuah et al (2024) found that TPK and TCK significantly improved instructional planning quality, while Pramesti and Sari (2025) reported that weaknesses in technological mastery limited the effectiveness of IPAS lesson design. This study extends prior research by empirically demonstrating that when TPACK competence develops comprehensively, its impact on instructional design becomes substantial and decisive. Practically, these results indicate that TPACK is not an auxiliary skill but a core professional competence for teachers in the digital era. In the Mandalle context, teachers' ability to design IPAS learning is strongly shaped by their capacity to integrate digital tools, inquiry-based pedagogy, and interdisciplinary content. Emerging technologies, including AI-based instructional planning tools, further strengthen the technological dimension of TPACK; however, their effectiveness remains contingent on teachers' pedagogical judgment and content understanding.

Combined Effect of Scientific Supervision and TPACK Competence to Design IPAS Learning

The simultaneous analysis shows that scientific supervision and TPACK competence jointly exert a very strong influence on teachers' ability to design IPAS learning. The R^2 value of 0.855 indicates that 85.5% of the variance in instructional design ability is explained by the two predictors, reflecting a highly robust explanatory model. This finding supports a systems-oriented view of teacher professional development, in which instructional quality emerges from the interaction between external support mechanisms and internal teacher competencies. TPACK represents an internal capacity that directly shapes instructional planning, while scientific supervision functions as an external facilitator that promotes reflection, feedback, and continuous improvement. Prior research by Singerin (2022) similarly suggests that supervision becomes more effective when mediated by teachers' TPACK competence, highlighting the complementary nature of both factors.

The dominance of TPACK over supervision can be explained by its direct application in every stage of lesson design, whereas supervision plays a more indirect, facilitative role. In IPAS learning, which demands visualization, inquiry activities, and digital integration, TPACK becomes a prerequisite for translating supervisory feedback into concrete instructional improvements. Without adequate TPACK competence, supervision risks remaining procedural rather than transformative. Overall, these findings imply that improving IPAS instructional quality requires an integrative strategy that combines reflective and dialogic scientific supervision with systematic development of teachers' TPACK competence. Educational improvement efforts should therefore move beyond administrative supervision and invest in sustained capacity-building initiatives that enable teachers to meaningfully integrate technology, pedagogy, and content in instructional design.

6. Conclusions

This study concludes that teachers' ability to design IPAS learning at the elementary school level is significantly influenced by scientific supervision and TPACK competence, both individually and simultaneously. Scientific supervision contributes positively by supporting reflective professional development, while TPACK competence emerges as the strongest internal factor shaping the quality of instructional planning. When considered together, these variables explain a substantial proportion of teachers' instructional design capability, indicating that effective IPAS lesson planning results from the interaction between external professional support and teachers' integrated pedagogical, content, and technological capacities.

From a theoretical perspective, these findings reinforce professional development frameworks that conceptualize instructional quality as a synergistic outcome of academic supervision and TPACK competence. This study contributes empirically by positioning TPACK as a central determinant in the context of integrative IPAS learning, which requires inquiry-based approaches and pedagogically grounded technology use. From a managerial and practical standpoint, the results highlight the importance of strengthening scientific supervision oriented toward professional coaching rather than administrative compliance, alongside systematic efforts to enhance teachers' TPACK competence. Teachers are encouraged to use supervision as a reflective tool for improving instructional planning, while school principals and supervisors should design dialogic and context-sensitive supervision practices to support the effective implementation of the Merdeka Curriculum.

Despite these contributions, this study is limited by its restricted geographical scope, reliance on self-reported questionnaire data, and focus on only two independent variables. Future research is therefore recommended to expand the research context across regions or educational levels, employ mixed-method approaches to deepen empirical insights, and incorporate additional variables such as instructional leadership, school culture, or teachers' digital literacy. Further studies may also explore the mediating or moderating role of TPACK in the relationship between scientific supervision and instructional quality, thereby providing a more comprehensive understanding of strategies for improving learning design in elementary education.

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