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Pedagogical Orientation, Pedagogical Practices, and Digital Pedagogical Competencies among Pre-Service Chemistry Teachers in Islamic Universities

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Abstract

The growing demand for digitally competent science teachers has positioned digital pedagogy as an important component of contemporary chemistry teacher education. In chemistry learning, digital technologies play an important role in helping students understand abstract concepts, molecular representations, and symbolic processes. However, previous studies focus on digital skills, with limited attention to pedagogy in chemistry teacher education. This study aimed to examine the predictive relationships among pedagogical orientation, pedagogical practices, and digital pedagogical competencies among pre-service chemistry teachers in Islamic universities in Indonesia. A survey was conducted with 158 pre-service chemistry teachers from seven Islamic universities, and the data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The findings revealed that pedagogical orientation significantly influenced pedagogical practices ($t = 28.761$) and digital pedagogical competencies ($t = 2.399$), while pedagogical practices also significantly affected digital pedagogical competencies ($t = 8.390$). The structural model explained 69.1% of the variance in digital pedagogical competencies ($R^2 = 0.691$), indicating a substantial predictive effect. Among the examined variables, pedagogical orientation emerged as the strongest predictor of digital pedagogy. Practically, the findings suggest that chemistry teacher education programs should strengthen pedagogically meaningful uses of digital technologies, including visualization tools, simulations, and interactive learning platforms.

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Introduction

The rapid development of digital technology has significantly transformed educational practices, including teaching methods, learning resources, and classroom interaction (Arabboy Ibroxim og‘li, 2025; Haleem et al., 2022). In science education, particularly chemistry education, digital technology plays an important role in supporting students’ understanding of abstract concepts, molecular representations, and symbolic processes that are often difficult to visualise through conventional instruction alone (Avargil et al., 2012; Chen & Wei, 2015; Krause et al., 2017). Various digital tools, such as molecular visualisation software, simulations, and online learning platforms, enable students to engage more actively with chemistry content and improve conceptual understanding. As educational environments become increasingly technology-driven, teachers are expected not only to master digital tools technically but also to integrate them pedagogically into meaningful learning processes.

The growing integration of digital technology into education requires teachers and pre-service teachers to adapt continuously to technological changes (Edwards & Nuttall, 2015; Sharma et al., 2024). Pre-service teachers need sufficient knowledge and pedagogical understanding to utilise digital technology effectively in classroom teaching and learning (Schmidt et al., 2009). In chemistry education, this issue becomes particularly important because learning in chemistry involves multiple levels of representation, including macroscopic, microscopic, and symbolic dimensions, which often require digital support to facilitate student understanding (Permatasari et al., 2022; Widarti, 2021). Therefore, the ability of pre-service chemistry teachers to integrate digital technology meaningfully into instruction has become an essential component of contemporary teacher education (Abdixalilovna, 2025; Bekbenova et al., 2026; Cetin-Dindar et al., 2018; Hoai, 2026).

Within this context, the concept of digital pedagogy has gained increasing attention. Digital pedagogy generally refers to the pedagogically meaningful use of digital technologies to support teaching and learning processes (Istrate, 2022; Kivunja, 2013). Digital pedagogy is not merely concerned with the presence of technology in the classroom, but with how teachers design learning experiences that encourage student engagement, collaboration, interaction, and reflective learning. Väätäjä and Ruokamo (2021) conceptualised digital pedagogy into three interrelated dimensions: pedagogical orientation, pedagogical practices, and digital pedagogical competencies.

Pedagogical orientation refers to teachers' beliefs and perspectives regarding how students learn and how teaching should be conducted (Väätäjä & Ruokamo, 2021). Pedagogical practices refer to instructional strategies and classroom practices implemented during teaching and learning activities, while digital pedagogical competencies refer to teachers' abilities to integrate digital technology effectively into instructional processes (Cabanero et al., 2022; Väätäjä & Ruokamo, 2021). These dimensions are particularly relevant in chemistry education because effective use of digital technology requires not only technical competence but also pedagogically appropriate instructional decisions for teaching abstract scientific concepts.

Previous studies have widely discussed digital competence and technology integration among pre-service teachers (Krause et al., 2017; Schmidt et al., 2009). However, most studies have focused primarily on technical competence or general technology use rather than examining the interrelationships among pedagogical orientation, pedagogical practices, and digital pedagogical competencies. In addition, studies specifically situated within chemistry teacher education remain limited, particularly in Islamic teacher education institutions (PTKI) in Indonesia. PTKI institutions have distinct characteristics because they integrate teacher education with Islamic institutional values and operate within different educational ecosystems under the Ministry of Religious Affairs. Despite the growing use of digital technology in Indonesian higher education, limited research has examined how pedagogical orientation and practices shape digital pedagogical competencies among pre-service chemistry teachers in this context.

Several previous studies show that pre-service teachers generally tend to utilize digital technology mainly for purposes such as presenting information, reinforcing content, or providing visualizations, rather than using it to support deeper conceptual understanding and interactive learning processes (Kaminskiene et al., 2022; Nurfidah, 2021; Polly et al., 2023; Sholihah et al., 2016). This pattern indicates that the integration of technology in chemistry education is still largely focused on technical and surface-level applications instead of being embedded in more pedagogically meaningful ways that actively enhance student thinking and engagement. Consequently, it becomes increasingly important to examine how pedagogical orientation and pedagogical practices are related to the development of digital pedagogical competencies among pre-service chemistry teachers, as this understanding is essential for strengthening and improving chemistry teacher education programs in the digital era.

This study aims to examine in greater depth the relationships among pedagogical orientation, pedagogical practices, and digital pedagogical competencies among pre-service chemistry teachers enrolled in Islamic universities in Indonesia, with a particular focus on how these interrelated factors collectively shape the quality of technology integration in chemistry education. The findings are expected to make a meaningful contribution to chemistry teacher education by providing a more comprehensive understanding of the key factors that influence the development of effective and pedagogically grounded digital teaching practices, thereby supporting the advancement of meaningful digital pedagogy in chemistry learning within the context of higher education.

The hypotheses proposed in this study are as follows:

H1: Pedagogical orientation significantly affects digital pedagogical competencies among pre-service chemistry teachers.

H2: Pedagogical orientation significantly affects pedagogical practices among pre-service chemistry teachers.

H3: Pedagogical practices significantly affect digital pedagogical competencies among pre-service chemistry teachers.

Method

A survey design was employed to examine the digital pedagogy of pre-service chemistry teachers. Survey research was considered appropriate because it enables the investigation of relationships among sociological and psychological variables within a specific population. The study population consisted of pre-service chemistry teachers enrolled in Islamic teacher education institutions (PTKI) in Indonesia. Among the fourteen PTKIs offering Chemistry Education programs, seven universities were selected using random sampling. Respondents from each university were then selected via convenience sampling, with the heads of study programs serving as institutional gatekeepers.

Convenience sampling was employed because the respondents were geographically dispersed across multiple universities in different regions of Indonesia, and participant accessibility depended on institutional approval and voluntary participation. This technique was therefore considered appropriate for efficient data collection within the scope and timeframe of the study. The demographic characteristics of the respondents are presented in Table 1.

Table 1. Respondent Demographics

Category	Frequency (N)	Percentage (%)
1. University		
a. UIN Walisongo	35	22.15%
b. UIN Sultan Syarif Kasim	34	21.52%
c. UIN Sunan Kalijaga	26	16.45%
d. UIN Sunan Gunung Djati	26	16.45%
e. UIN Mahmud Yunus	14	8.87%
f. UIN Ar-Raniry	13	8.23%
g. UIN Syarif Hidayatullah	10	6.33%
Total	158	100%
2. Gender		
a. Female	134	84.81%
b. Male	24	15.19%
Total	158	100%
3. GPA		
a. 3,51 – 4,00	108	68.35%
b. 3,01 – 3,50	47	29.75%
c. 2,51 – 3,00	3	1.90%
d. 2,01 – 2,50	0	-
Total	158	100%
4. Software used		
a. >6 software	44	27.85%
b. 4-6 software	60	37.97%
c. <4 software	54	34.18%
Total	158	100%

Respondents completed a closed-ended questionnaire distributed through the heads of study programs over a four-month period. Participation in the study was voluntary, and respondents were informed that all responses would be treated anonymously and confidentially. No personally identifiable information was collected during the survey process. Before data collection, the questionnaire underwent expert judgment to assess content validity and instrument feasibility. Three experts in chemistry education, educational technology, and teacher education evaluated the clarity, relevance, and representativeness of the instrument items. The validation process focused on aligning the questionnaire items with the conceptual dimensions of digital pedagogy. Revisions were made based on the experts' suggestions before the instrument was administered to respondents. In addition, an initial reliability test showed that the instrument had satisfactory internal consistency, with Cronbach's alpha values exceeding the recommended threshold of 0.70.

The questionnaire was developed based on the three dimensions of digital pedagogy proposed by Väätäjä and Ruokamo (2021): pedagogical orientation, pedagogical practices, and digital pedagogical competencies. In total, the instrument consisted of 30 self-assessment items:

five items measuring pedagogical orientation, ten items measuring pedagogical practices, and fifteen items measuring digital pedagogical competencies. Because the present study focuses on the predictive relationships among latent constructs rather than on item-level descriptive profiling, the instrument is presented in construct-level summary form (see Table 2). The complete item structure was retained for the PLS-SEM analysis, and indicators with insufficient outer loadings were removed during measurement model evaluation.

Table 2. Construct-Level Summary of The Questionnaire

Construct	Number of initial items	Conceptual coverage	Example indicator
Pedagogical Orientation	5	Self-perceived readiness related to learning objective formulation, learner diversity, student engagement, classroom climate, and responsiveness to students' learning difficulties.	Ability to design learning objectives that consider students' diverse learning needs.
Pedagogical Practices	10	Instructional decision-making and classroom enactment, including the selection of teaching approaches, learning models, instructional strategies, student-centred activities, online learning methods, software use, and learning tasks.	Ability to select appropriate instructional strategies according to learning objectives, subject matter, and students' needs.
Digital Pedagogical Competencies	15	Self-perceived competence in designing technology-supported learning, solving technical problems, facilitating online interaction, using learning management and communication tools, conducting online assessment, and managing learning data.	Ability to design technology-supported learning activities that enable students to construct new knowledge and skills.

All items were measured using a five-point Likert-type scale ranging from Poor (1) to Excellent (5), with higher scores indicating stronger self-perceived pedagogical and digital pedagogical ability. Before structural model testing, the measurement model was evaluated through outer loading, composite reliability, average variance extracted, and discriminant validity procedures.

The survey data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) with SmartPLS software version 3.2.8. PLS-SEM was selected because it is suitable for examining predictive relationships among latent constructs and can simultaneously evaluate measurement and structural models (Ghozali & Latan, 2015). Compared with covariance-based SEM, PLS-SEM is considered more flexible for exploratory and prediction-oriented studies involving complex relationships among variables.

The PLS-SEM analysis consisted of three stages: measurement model analysis (outer model), structural model analysis (inner model), and hypothesis testing. The outer model analysis evaluated the validity and reliability of the measurement model, while the inner model analysis assessed the structural relationships among constructs.

Several criteria were used in evaluating the model (Setiaman, 2020). Convergent validity was assessed using factor loading values, where standardised loadings above 0.70 were considered acceptable. Discriminant validity was evaluated through cross-loading values to determine whether indicators loaded more strongly on their respective constructs than on other constructs. Reliability was assessed using Composite Reliability values greater than 0.70 and Average Variance Extracted (AVE) values above 0.50. The coefficient of determination (R^2) was used to examine the predictive accuracy of endogenous constructs, with values of 0.75, 0.50, and 0.25 indicating substantial, moderate, and weak explanatory power, respectively.

Hypothesis testing was conducted using the bootstrapping procedure in SmartPLS. The significance of the structural relationships was determined using t- and p-values at $\alpha = 0.05$. Relationships with t-values greater than 1.96 were considered statistically significant (Ghozali & Latan, 2015).

Results and Discussion

Results

Inferential Analysis

The inferential analysis in this study consisted of three stages: measurement model analysis (outer model), structural model analysis (inner model), and hypothesis testing using Partial Least Squares Structural Equation Modelling (PLS-SEM).

a. Measurement Model Analysis (Outer Model)

1) Convergent Validity

Convergent validity was assessed using factor loading values. Indicators with loading values above 0.70 were considered acceptable (Setiaman, 2020). Prior to the final estimation, several indicators with loading values below the recommended threshold were removed from the model to improve construct validity. The final outer loading results are presented in Table 3.

Table 3. Outer Loadings (Measurement Model)

Indicators	**DPC (Y)**	**PO (X1)**	**PP (X2)**
DPC1	0.757		
DPC2	0.711		
DPC3	0.736		
DPC5	0.734		
DPC6	0.737		
DPC9	0.748		
DPC10	0.798		
DPC11	0.791		
DPC12	0.837		
DPC13	0.826		
DPC14	0.807		

DPC15	0.796
PO1	0.776
PO2	0.773
PO3	0.781
PO4	0.814
PO5	0.774
PP1	0.826
PP2	0.833
PP3	0.834
PP4	0.828
PP5	0.772
PP6	0.833
PP10	0.774

Note:

DPC = Digital Pedagogical Competencies, PO = Pedagogical Orientation, PP = Pedagogical Practices

Table 3 shows that all retained indicators had loading values above 0.70, indicating that the measurement model satisfied the requirements for convergent validity.

2) Discriminant Validity

Discriminant validity was evaluated using cross-loading values. Cross-loading analysis was conducted to determine whether each indicator loaded more strongly on its intended construct than on other constructs (Fornell & Larcker, 1981). The results are presented in Table 4.

Table 4. Discriminant Validity (Cross Loading)

Indicators	DPC (Y)	PO (X1)	PP (X2)
DPC1	0.757	0.706	0.770
DPC2	0.711	0.492	0.609
DPC3	0.736	0.560	0.627
DPC5	0.734	0.434	0.452
DPC6	0.737	0.481	0.542
DPC9	0.748	0.575	0.656
DPC10	0.798	0.653	0.683
DPC11	0.791	0.609	0.644
DPC12	0.837	0.547	0.661
DPC13	0.826	0.599	0.671
DPC14	0.807	0.602	0.630
DPC15	0.796	0.569	0.593
PO1	0.605	0.776	0.587
PO2	0.576	0.773	0.623
PO3	0.568	0.781	0.680
PO4	0.605	0.814	0.638
PO5	0.564	0.774	0.672
PP1	0.658	0.675	0.826
PP2	0.664	0.663	0.833
PP3	0.665	0.676	0.834

PP4	0.630	0.663	0.828
PP5	0.666	0.691	0.772
PP6	0.698	0.692	0.833
PP10	0.702	0.595	0.774

Most indicators demonstrated satisfactory discriminant validity, as their loadings were higher on their respective constructs than on other constructs. However, one indicator (DPC1) showed a slightly higher cross-loading on Pedagogical Practices (0.770) than on Digital Pedagogical Competencies (0.757). This finding indicates a conceptual overlap between pedagogical practices and digital pedagogical competencies, particularly because technology integration in teaching is closely related to instructional implementation. Nevertheless, the difference between the loading values was relatively small, and the indicator remained theoretically relevant to the construct; therefore, the item was retained in the final model.

3) Reliability and Average Variance Extracted (AVE)

Reliability and convergent validity were further evaluated using Composite Reliability and Average Variance Extracted (AVE). Composite Reliability values above 0.70 and AVE values above 0.50 indicate acceptable reliability and validity (Setiaman, 2020).

Table 5. Composite Reliability and Average Variance Extracted

Variables	Composite Reliability	AVE
Digital Pedagogical Competencies (Y)	0.947	0.599
Pedagogical Orientation (X1)	0.889	0.615
Pedagogical Practices (X2)	0.933	0.664

Table 5 shows that all constructs met the recommended reliability and validity criteria, as all Composite Reliability values exceeded 0.70 and all AVE values exceeded 0.50.

b. Structural Model Analysis (Inner Model)

Structural model analysis was conducted to examine the relationships among constructs and evaluate the predictive accuracy of the proposed model.

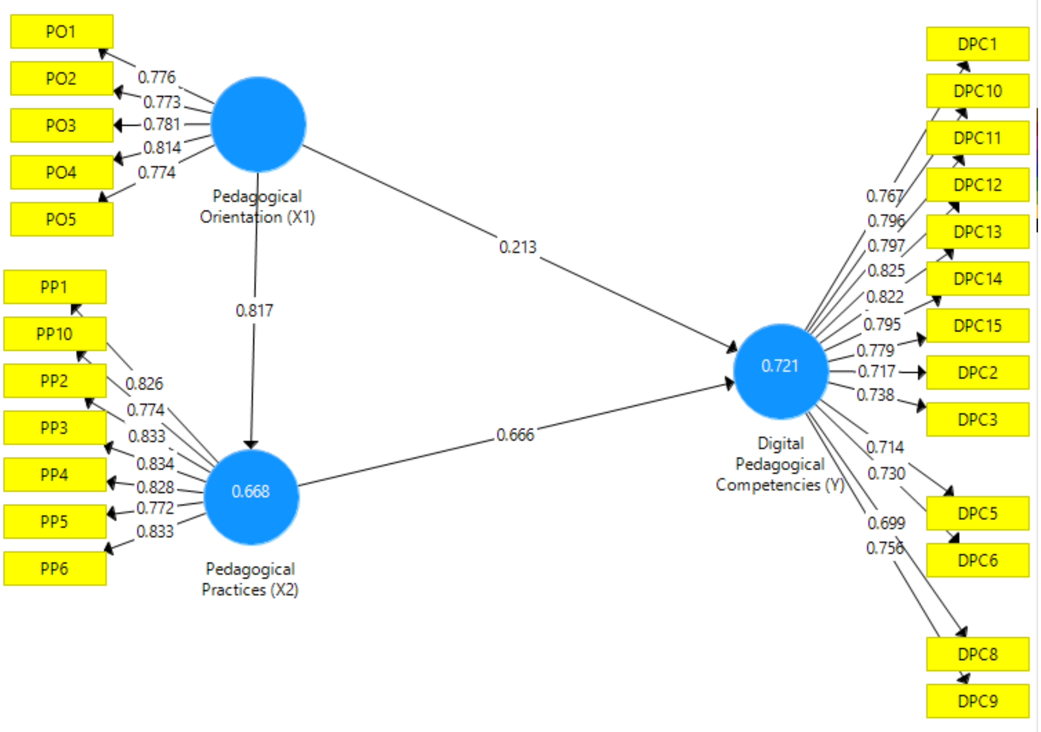

Figure 1. Structural Model Results

Figure 1 shows that all indicators satisfied the validity and reliability requirements and that the proposed structural model could be used for hypothesis testing.

c. Coefficient of Determination (R^2)'

Table 6. R^2 of Endogenous Constructs

Variables	R Square	R Square Adjusted
Digital Pedagogical Competencies (Y)	0.721	0.717
Pedagogical Practices (X2)	0.668	0.665

The R^2 value for Digital Pedagogical Competencies was 0.721, indicating that Pedagogical Orientation and Pedagogical Practices jointly explained 72.1% of the variance in Digital Pedagogical Competencies. Meanwhile, the R^2 value for Pedagogical Practices was 0.668, indicating that Pedagogical Orientation explained 66.8% of the variance in Pedagogical Practices. These findings suggest that the structural model had moderate to substantial explanatory power.

d. Hypothesis Testing

Hypothesis testing was conducted using the bootstrapping procedure in SmartPLS. The significance of the structural relationships was evaluated using path coefficients (β), t-values, and p-values.

Table 7. Structural Model Results

Hypothesis	Path	β	t-value	p-value	Decision
H1	Pedagogical Orientation → Digital Pedagogical Competencies	0.213	2.399	< .05	Supported
H2	Pedagogical Orientation → Pedagogical Practices	0.817	28.761	< .001	Supported
H3	Pedagogical Practices → Digital Pedagogical Competencies	0.666	8.390	< .001	Supported

The results indicate that all hypothesised relationships were positive and statistically significant. Pedagogical Orientation significantly affected Digital Pedagogical Competencies ($\beta = 0.213$, $t = 2.399$, $p < .05$), indicating that stronger pedagogical orientation is associated with higher digital pedagogical competencies among pre-service chemistry teachers. Pedagogical Orientation also showed a significant positive effect on Pedagogical Practices ($\beta = 0.817$, $t = 28.761$, $p < .001$), suggesting that teachers' beliefs and perspectives regarding learning strongly influence their instructional practices.

In addition, Pedagogical Practices significantly affected Digital Pedagogical Competencies ($\beta = 0.666$, $t = 8.390$, $p < .001$), indicating that instructional practices substantially contribute to the development of digital pedagogical competencies among pre-service chemistry teachers.

Discussion

This study examined the relationships among pedagogical orientation, pedagogical practices, and digital pedagogical competencies among pre-service chemistry teachers in Islamic universities in Indonesia. The findings indicate that all proposed relationships were positive and statistically significant. More specifically, pedagogical orientation significantly influenced both pedagogical practices and digital pedagogical competencies, while pedagogical practices also significantly affected digital pedagogical competencies. The structural model further demonstrated that pedagogical orientation and pedagogical practices jointly explained a substantial proportion of the variance in digital pedagogical competencies. These findings suggest that the development of digital pedagogy among pre-service chemistry teachers is shaped not only by technical abilities but also by pedagogical beliefs and instructional practices. In other words, digital pedagogy appears to develop through a pedagogically mediated process rather than through technological exposure alone.

The findings show that pedagogical orientation contributes significantly to digital pedagogical competencies among pre-service chemistry teachers. This indicates that pre-service teachers' beliefs about teaching, learning, student engagement, and classroom interaction influence how they integrate digital technology into instructional processes. In chemistry education, this relationship is particularly important because chemistry learning frequently involves abstract concepts, molecular representations, symbolic reasoning, and invisible scientific processes that are often difficult to understand through conventional instruction alone. Consequently, digital technology in chemistry education is not simply an instructional supplement but an important pedagogical tool for supporting conceptual visualisation, inquiry activities, and interactive learning experiences.

This finding supports previous studies emphasising the importance of pedagogical beliefs in shaping technology integration practices (Abraukhova et al., 2020; Sakharova et al., 2021; Zhao et al., 2021). However, the present study also extends previous research by showing that digital pedagogical competence is not merely a matter of technical digital literacy. Previous studies on digital competence have often emphasised technical mastery, operational skills, or digital literacy readiness as the central dimensions of teacher competence. In contrast, the present findings suggest that pedagogical orientation functions as an underlying instructional framework that shapes how technology is enacted within chemistry learning contexts. This finding reinforces the argument that meaningful technology integration depends not only on teachers' ability to operate digital tools but also on how they conceptualise learning, student participation, and knowledge construction.

The findings also demonstrate a strong relationship between pedagogical orientation and pedagogical practices. The large path coefficient between these variables indicates that pre-service teachers' beliefs about learning substantially shape their instructional decision-making and classroom practices. This finding reinforces the argument that pedagogical orientation functions as a cognitive and instructional foundation guiding how teachers organise learning activities, select teaching strategies, facilitate interaction, and integrate digital technology into classroom instruction. In this context, pedagogical practices do not emerge independently from technical competence alone but are closely linked to teachers' beliefs about how learning should occur.

This finding is consistent with previous studies showing that pedagogical orientation influences curriculum implementation, instructional strategies, and classroom roles (Devins et al., 2015; Erdem, 2021; Handal & Herrington, 2003; Law, 2009). Nevertheless, the present study further demonstrates that the relationship between pedagogical orientation and pedagogical practices is strongly associated with the development of digital pedagogy among pre-service chemistry teachers. This finding is particularly relevant in chemistry education because integrating digital technology frequently requires teachers to make pedagogical decisions about simulations, molecular visualisation, virtual laboratory activities, and inquiry-oriented learning environments. Teachers who emphasise student-centred learning and collaborative knowledge construction may therefore be more likely to implement digital technology interactively rather than using it only for one-way information delivery.

Furthermore, pedagogical practices significantly influenced digital pedagogical competencies and exerted the strongest direct effect in the structural model. This finding suggests that digital pedagogical competence develops primarily through instructional enactment and teaching practice rather than through technological exposure alone. Pre-service teachers who actively engage in designing student-centred instruction, online learning activities, classroom management, technology-supported assessment, and collaborative learning environments are more likely to develop stronger digital pedagogical competencies.

This finding aligns with studies emphasising that digital competence should be understood as an instructional and pedagogical capability rather than merely technical proficiency (Mariscal et al., 2023; Prestridge, 2012; Sachan & Dwivedi, 2023; Voogt et al., 2013). However, the present findings also refine these perspectives by showing that pedagogical practices become the most immediate mechanism through which digital pedagogy is enacted in chemistry learning. In other words, technology integration appears to depend less on isolated technological skill and more on how teachers operationalise pedagogy through classroom practice. This finding is particularly important in chemistry education because digital technologies are frequently used to support simulations, virtual experiments, molecular visualisation, and inquiry-based scientific learning. Without pedagogically meaningful classroom practices, digital technology may remain limited to presentation-oriented instruction rather than supporting deeper conceptual understanding and scientific reasoning.

An important finding of this study is that pedagogical orientation plays a foundational role in shaping digital pedagogy indirectly through pedagogical practices. Although pedagogical orientation directly influenced digital pedagogical competencies, its strongest relationship was found with pedagogical practices. This suggests that pedagogical beliefs influence digital pedagogy primarily by shaping how pre-service teachers enact teaching and learning processes in classroom practice. The findings therefore indicate that digital pedagogy among pre-service chemistry teachers develops through a pedagogically mediated pathway in which instructional beliefs shape pedagogical practices, which, in turn, contribute to digital pedagogical competencies. This finding challenges technology-centred perspectives that position digital competence primarily as technical mastery or technological readiness. Instead, the findings support a more pedagogically grounded understanding of digital pedagogy in which instructional beliefs, classroom interaction, and teaching practices become central components of meaningful technology integration. This theoretical perspective is particularly relevant for chemistry education because effective technology integration requires the alignment of pedagogy, scientific representation, and digital tools within meaningful learning contexts.

The contextual setting of PTKI institutions in Indonesia also provides an important contribution to the literature. Previous studies on digital pedagogy have predominantly been conducted in general teacher education or Western higher education contexts, while limited attention has been given to Islamic teacher education institutions. PTKI institutions operate within distinctive institutional, curricular, and cultural environments that integrate teacher education with Islamic educational values. Therefore, the present findings contribute to expanding the discussion of digital pedagogy into more diverse educational contexts, particularly within developing-country higher education systems undergoing digital transformation.

The findings of this study have several practical implications for chemistry teacher education programs, particularly within Islamic universities and teacher education institutions in Indonesia. *First*, digital pedagogy training should move beyond technical workshops that focus only on operating software or digital platforms. Teacher education programs need to strengthen pedagogically meaningful uses of digital technology, especially for teaching abstract chemistry concepts through simulations, molecular visualisation tools, virtual laboratories, and inquiry-oriented digital learning. *Second*, teacher education curricula should integrate digital pedagogy across instructional practice courses rather than positioning technology as a separate technical competency. *Third*, teacher educators should provide pre-service teachers with opportunities to experience collaborative, student-centred digital learning environments that model effective pedagogical practices for chemistry instruction.

The findings also contribute to the theoretical literature on digital pedagogy by reinforcing the view that digital pedagogical competence is closely connected to pedagogical orientation and instructional practice. While previous studies often conceptualised digital competence primarily in terms of technical skill or digital literacy, the present findings suggest that digital pedagogical competencies are deeply rooted in teachers' pedagogical beliefs and classroom enactment. This perspective is particularly important for science and chemistry education because effective technology integration requires aligning content knowledge, pedagogy, scientific representation, and digital technology within meaningful instructional contexts.

Despite these contributions, this study has several limitations. The study relied on self-reported questionnaire data, which may reflect perceived competencies rather than actual classroom performance. In addition, the cross-sectional design limits the ability to examine changes in digital pedagogical competencies over time. The study was also conducted within PTKI institutions in Indonesia; therefore, the findings may not be directly generalizable to other teacher education contexts with different institutional cultures or technological infrastructures. Future research may incorporate classroom observation, teaching performance assessment, or longitudinal approaches to examine how digital pedagogy develops across teacher education programs.

Conclusion

This study investigated the relationships among pedagogical orientation, pedagogical practices, and digital pedagogical competencies of pre-service chemistry teachers at Islamic universities in Indonesia. The findings revealed that pedagogical orientation significantly affects both pedagogical practices and digital pedagogical competencies, and that pedagogical practices also play a significant role in fostering these competencies. These results suggest that the development of digital pedagogy occurs through a pedagogically mediated process in which instructional beliefs shape teaching practices, which in turn influence the meaningful integration of digital technologies into learning. The study highlights that digital pedagogical competence extends beyond technical proficiency and is rooted in pedagogical beliefs, instructional decision-making, and classroom practices. In chemistry education, where students encounter abstract concepts, molecular representations, symbolic reasoning, and inquiry-based learning, digital technologies are most effective when integrated into appropriate pedagogical approaches rather than used solely for content delivery. Furthermore, this research enriches the literature by providing empirical evidence from Islamic teacher education institutions (PTKI) in Indonesia and reinforcing the interconnectedness of pedagogical orientation, pedagogical practices, and digital pedagogical competencies. Practically, the findings underscore the importance of shifting teacher education programs from technology-focused training toward pedagogy-driven digital integration through strategies such as molecular visualization, virtual laboratories, simulation-based learning, inquiry-oriented instruction, and collaborative learning practices. Nevertheless, the study is limited by its reliance on self-reported data and its specific institutional context, underscoring the need for future research that employs classroom observations, longitudinal approaches, and cross-institutional comparisons.

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Credit Authorship Contribution Statement

Safira Afifah Sabrina: Conceptualisation, Software, Visualisation, Formal analysis, Writing the original draft, Project administration. **Jamil Suprihatiningrum**: Conceptualisation, Methodology, Formal analysis, Resources, Writing, review & editing, Supervision.

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