# Determinants of Elementary Teachers' Digital Competence: Examining Mediating and Moderating Effects through SEM and Network Analysis

Yeni Erita[1,*], Ade Herdian Putra[2], Yulia Septi Wahyuni[1], Risda Amini[1], Delfi Eliza[3], and Mutia Yollanda[4]

[1]Department of Elementary School Teacher Education, Faculty of Education, Universitas Negeri Padang, Padang, Indonesia
[2]Department of Guidance and Counseling, Faculty of Education, Universitas Negeri Padang, Padang, Indonesia
[3]Departement of Early Childhood Teacher Education, Faculty of Education, Universitas Negeri Padang, Padang, Indonesia
[4]Department of Mathematics and Data Science, Faculty of Mathematics and Natural Sciences, Universitas Andalas, Padang, Indonesia
Email: yenierita@fip.unp.ac.id (Y.E.); adeherdian@unp.ac.id (A.H.P.); ayusepti341@gmail.com (Y.S.W.); risda.amini@fip.unp.ac.id (R.A.); delfieliza@fip.unp.ac.id (D.E.); mutia.yollanda@sci.unand.ac.id (M.Y.)
*Corresponding author

Manuscript received August 27, 2025; revised October 26, 2025; accepted December 22, 2025; published May 22, 2026

***Abstract*—The integration of digital technology in basic education increasingly requires teachers to have adequate digital competencies. However, in various regions of Indonesia, especially at the elementary school level, teachers' digital competencies remain a serious challenge that impacts the low quality of interactive digital learning. This study aims to analyze the influence of digital literacy, collaborative culture, and institutional support on teachers' digital competencies, considering the role of digital self-efficacy as a mediator and institutional support as a moderator. This study uses a quantitative approach with Partial Least Squares Structural Equation Modeling analysis technique. Data were obtained from 330 elementary school teachers in West Sumatra Indonesia through direct and online surveys using the SurveyMonkey platform. The entire research process obtained ethical approval from Padang State University and was accompanied by informed consent from respondents. The results indicate that digital literacy, collaborative culture, and institutional support significantly influence teachers' digital competence. Digital self-efficacy did not show a significant mediating effect, but its role as a direct predictor and theoretical construct remains conceptually central. Institutional support strengthens the effect of digital literacy on digital competence while it weakens the effect of collaborative culture on digital competence. The novelty of this study lies in the integration of individual and institutional factors into a single analytical framework to explain digital competence in an emerging educational context. This study suggests that teacher development programs should not only focus on technical training but also on strengthening self-efficacy, collaborative culture in schools, and consistent institutional support. Further research is recommended to explore long term interventions with a cross level educational approach.**

***Keywords*—digital competence, digital literacy, collaborative culture, institutional support, digital self-efficacy, structural equation modeling, elementary school**

## I. Introduction

In the midst of the rumbling digital transformation that penetrates almost all aspects of life, the world of education has not escaped the flow of change. Schools, including primary education, are expected to be able to adapt to technological advances, not only as passive users, but also as managers and utilizers of technology for meaningful learning processes [1–3]. However, these expectations are not always in line with the reality on the ground. In Indonesia, many elementary school teachers still have difficulties in implementing digital-based learning optimally [4–6]. Digital competencies, which should be the foundation in delivering 21st century learning, are not fully possessed by many teachers at the primary level.

When we talk about digital competencies, we do not just mean the ability to use electronic devices, but a complex set of skills such as managing information, making ethical and critical use of digital media, creating interactive digital learning content, and communicating and collaborating through online platforms [7–9]. Unfortunately, previous studies and various national reports show that these competencies are still low among elementary school teachers in Indonesia [10–12]. In many cases, technology is only used as a supplement, not as a pedagogical tool that changes the way teachers teach and students learn [13].

Teachers' lack of digital competence is not without consequences. Amid global efforts to narrow the digital divide and promote inclusive and adaptive education, teachers who are not digitally proficient will be left behind [14, 15]. Moreover, students under their guidance will miss out on opportunities to thrive in learning environments that foster creativity, independence and critical thinking skills. This situation can lead to inequality in the quality of education, especially between schools that have access to technology and digitally competent teachers and those that are still technologically challenged [16–18].

The question that then arises is: what influences the digital competence of elementary school teachers? Why are some teachers able to demonstrate a high level of mastery of technology, while others are left far behind? Starting from this reflection, this research tries to dig deeper into the factors that are thought to play an important role in shaping the digital competence of teachers at the primary level.

In this study, digital literacy and digital competence are treated as related but conceptually distinct constructs. Digital literacy refers to foundational skills that enable individuals to access, understand, and use digital technologies effectively. Digital competence, on the other hand, represents a broader applied construct that integrates digital literacy with pedagogical, ethical, and collaborative dimensions relevant to educational practice. This distinction provides conceptual clarity for positioning digital literacy as an antecedent and digital competence as the outcome variable in this study.

There are four main factors that are theoretically and empirically predicted to influence teachers' digital competence: digital literacy [19], collaborative culture [20], digital self-efficacy [21] and institutional support [22]. These four variables are presented not merely as a list of causal factors, but as a reflection of the interrelated personal and structural aspects in the process of teacher adaptation to technology.

Digital literacy reflects the extent to which teachers have basic to advanced skills in using and understanding digital technologies [23–26]. Meanwhile, collaborative culture reflects the social ecosystem in the school environment that allows teachers to share good practices, discuss and learn together regarding technology integration in learning [27, 28]. These two factors show that digital competence is not only shaped by individual abilities, but also influenced by collective culture.

On the other hand, there is digital self-efficacy - the extent to which teachers believe in their own ability to use technology effectively. This is a psychological aspect that is often key to whether teachers will move forward to try new things or choose to stay in their comfort zone [29–31]. Teachers with high levels of digital self-efficacy tend to be more willing to experiment with new platforms, seek technological solutions to classroom problems, and innovate in their delivery.

However, these factors certainly do not stand alone. Institutional support plays a role that cannot be ignored. When principals make space for technology experimentation, provide training, and establish policies that support Information and Communication Technology (ICT) integration, teachers have a greater chance of growth. Institutional support can be an accelerator or the opposite-a hindrance [32, 33].

Furthermore, in the framework of this study, digital self-efficacy is thought to not only act as a direct predictor of digital competence, but also as a mediator [34, 35]. That is, the influence of digital literacy, collaborative culture, and institutional support on teachers' digital competence is likely to flow through their perceived self-efficacy. Teachers who feel technologically capable are more likely to actualize their knowledge and collaborative culture into real competencies.

Not only that, institutional support is also predicted to act as a moderator, which strengthens or weakens the relationship between digital literacy, collaborative culture, and digital self-efficacy with digital competence [36]. This suggests that how much impact these factors have cannot be separated from the context of support available in the school environment. Teachers with high literacy and confidence in technology, but no institutional support, may still struggle to realize effective digital learning.

Recent international studies have increasingly highlighted the importance of digital literacy, institutional support, and teacher self-efficacy in strengthening digital competence in primary education settings in various countries such as Europe, China, and Australia [37, 38]. However, most of these studies focus on contexts with advanced digital infrastructure and stable institutional support systems. This study addresses this gap by situating the analysis in the Indonesian context, where digital transformation is still uneven and institutional support varies significantly across schools. The novelty of this study lies in integrating individual and institutional factors into a single framework and testing their direct, moderating, and mediating effects using PLS SEM in a developing educational system. This contextual contribution extends the international discourse on digital competence by providing empirical evidence from a different sociotechnical environment.

By understanding this complex pattern of relationships, we can formulate strategies for developing teachers' digital competencies that not only target technical skills but also touch on psychological and structural aspects. This research, conducted in West Sumatra Indonesia, attempts to offer a full picture of how these four factors interact and influence the quality of digitization of basic learning in Indonesia.

This study contributes theoretically by expanding the existing digital competence model through the integration of digital literacy, collaborative culture, digital self-efficacy, and institutional support as key predictive constructs. While previous studies have primarily examined these variables separately in Western or global contexts, this research situates the model within the Indonesian educational landscape, where digital transformation in schools is still uneven. By testing this integrated model in Indonesia, this study provides evidence that contextual factors such as school culture and institutional readiness play an important role in shaping teachers' digital competence. This contextual expansion enriches the theoretical understanding of digital competence development in emerging education systems.

## II. Literature Review

Recent theoretical and empirical developments emphasize that the relationships among digital literacy, institutional support, and digital competence are often shaped by mediating and moderating mechanisms [39]. Digital self-efficacy has been conceptualized as a central mediating construct that explains how teachers translate digital knowledge into effective classroom practices. Institutional support, in turn, has been shown to act as a contextual moderator that can strengthen or weaken these relationships [40]. Building on these recent advances, this study examines both mediation and moderation simultaneously, providing a more comprehensive understanding of digital competence development.

### *A. Digital Competencies of Elementary School Teachers*

Digital competence is an individual's ability to use information and communication technology effectively and responsibly in work and social contexts [41, 42]. In the world of basic education, teacher digital competence is the main foundation in the implementation of technology-based learning. According to Ferrari [43], digital competencies include skills in accessing, assessing, producing and disseminating digital information in creative and ethical ways. For elementary school teachers, this competency is not only related to technical skills, but also pedagogical skills in integrating technology into learning.

Unfortunately, studies in Indonesia still show that most elementary school teachers have not reached an adequate level of digital competence [10]. This has an impact on the low effectiveness of using digital media in learning and limited innovation in material delivery. Therefore,

identifying factors that influence digital competence is important to formulate appropriate interventions.

### B. Digital Literacy

Digital literacy is defined as a set of abilities that enable individuals to access, evaluate, use and create information using digital technologies [44]. Teachers who have high digital literacy will be better able to select relevant tools and media, understand digital content governance, and be more adaptive to new technological developments. According to Ilomäki *et al*. [45], digital literacy includes not only technical skills, but also the cognitive and social dimensions of technology use.

In the context of basic education, digital literacy serves as an important prerequisite in developing digital competencies. Teachers who do not have good digital literacy will find it difficult to navigate online learning resources, develop digital teaching materials and communicate effectively through digital media.

### C. Collaborative Culture

Collaborative culture in schools refers to the openness among teachers to share practices, support each other and build active professional learning communities. According to Vangrieken *et al.* [46], a collaborative culture creates an environment conducive to the collective exchange of ideas, pedagogical experimentation and capacity building of teachers. In a collaborative environment, teachers tend to adopt technology more easily due to social support and access to good practices.

In previous studies, it was found that the existence of a collaborative culture promotes stronger technology integration [47]. Teachers who actively discuss and share their experiences of using technology will be more confident and encouraged to improve their digital competence.

### D. Digital Self-Efficacy

Digital self-efficacy refers to an individual's belief in their ability to use digital technology for specific purposes. The concept is rooted in Bandura's [48] social cognitive theory, which states that perceptions of one's own abilities (self-efficacy) strongly influence decisions to act, how much effort to exert and perseverance in the face of challenges. In the context of teachers, digital self-efficacy determines how confident the teacher can utilize technology in learning

Research shows that digital self-efficacy is positively correlated with teachers' digital competence [49]. Teachers who have high self-efficacy are more likely to experiment with technology, take training, and implement new approaches to teaching. In this research framework, digital self-efficacy is positioned as a mediator variable that bridges the influence of digital literacy, collaborative culture, and institutional support on teachers' digital competence.

### E. Institutional Support

Institutional support includes any form of facilitation from the school environment or educational institution, including the provision of ICT infrastructure, management policies, professional training, as well as moral support from the principal or peers. moral support from the principal or peers. According to Ertmer and Ottenbreit-Leftwich [50], institutional support is an important factor in promoting successful technology integration in schools. Without adequate support, even motivated and skilled teachers will experience barriers.

In this study, institutional support not only acts as a direct predictor of digital competence, but also as a moderator variable that can strengthen or weaken the relationship between other factors (digital literacy, collaborative culture, self-efficacy) and digital competence. This means that institutional support is a key element that determines how effectively the other factors work in improving teachers' digital capacity.

### F. Conceptual Model and Research Hypothesis

This study develops a conceptual model that links the influence of digital literacy, collaborative culture, and institutional support on the digital competence of elementary school teachers, with digital self-efficacy as a mediating variable and institutional support also acting as a moderating variable. This model is based on the assumption that digital competence is not only influenced by knowledge and social environment factors, but also by confidence in using technology and institutional support that allows teachers to develop optimal digital learning practices.

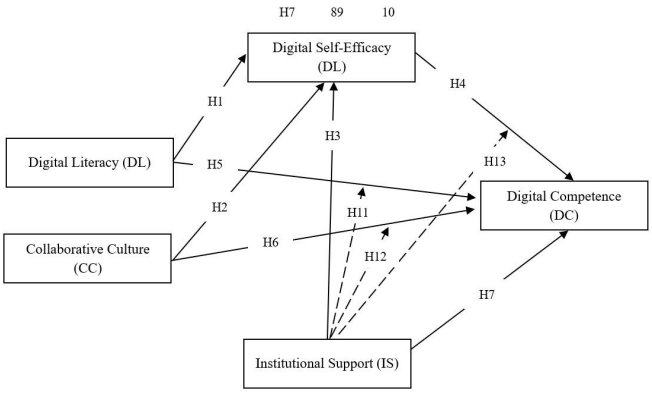



Fig. 1. Conceptual model.

Based on the conceptual model illustrated in Fig. 1, the research hypothesis proposed is as follows:

H1: There is a positive and significant correlation between digital literacy and digital self-efficacy.

H2: There is a positive and significant correlation between collaborative culture and digital self-efficacy.

H3: There is a positive and significant correlation between institutional support and digital self-efficacy.

H4: There is a positive and significant correlation between digital self-efficacy and digital competence.

H5: There is a positive and significant correlation between digital literacy and digital competence.

H6: There is a positive and significant correlation between collaborative culture and digital competence.

H7: There is a positive and significant correlation between institutional support and digital competence.

H8: Digital self-efficacy significantly mediates the correlation between digital literacy and digital competence.

H9: Digital self-efficacy significantly mediates the correlation between collaborative culture and digital competence.

H10: Digital self-efficacy significantly mediates the correlation between institutional support and digital competence.

H11: Institutional support significantly moderates the correlation between digital literacy and digital competence.

H12: Institutional support significantly moderates the correlation between collaborative culture and digital competence.

H13: Institutional Support significantly moderates between digital self-efficacy and digital competence.

All constructs in this study are specified as reflective. Each construct is measured through multiple indicators that are assumed to reflect the underlying latent variable. Changes in the latent construct are expected to be manifested in changes across the indicators, and the indicators are assumed to be interchangeable and correlated. This specification is consistent with previous studies on digital literacy, collaborative culture, digital self-efficacy, institutional support, and digital competence that conceptualize these variables as reflective constructs.

## III. Materials and Methods

### A. Research Design

This study uses a quantitative approach with a confirmatory research design based on Partial Least Squares-Structural Equation Modeling (PLS-SEM). This design was chosen to empirically test the conceptual model developed from existing theories, such as theories of digital literacy, self-efficacy, and institutional support [51–53]. With this approach, the research aims to confirm the causal relationship between the variables in the previously formulated theoretical framework, especially in the context of developing digital competencies of elementary school teachers.

The choice of this design also considers the nature of the variables studied, which are psychosocial constructs and require indicator-based analysis. The PLS-SEM model allows researchers to estimate the strength of direct and indirect effects, as well as test reliability and construct validity [54]. Thus, this design is able to provide a comprehensive picture of the factors that influence the digital competence of elementary school teachers in the context of interactive digital learning in West Sumatra Indonesia.

### B. Population and Sample

The population in this study is all elementary school teachers in West Sumatra Indonesia who are actively teaching and have experience in using digital devices for learning purposes. The selection of West Sumatra Indonesia as the research location is based on the consideration that this region has a variety of school characteristics, both public and private, and the level of adoption of educational technology still varies. This provides a more comprehensive picture of the condition of digital competence of elementary school teachers in the area.

Table 1. Demographic characteristics of research respondents

| Demographics | | Frequency | Percentage (%) |
|---|---|---|---|
| Gender | Female | 174 | 52.73% |
| | Male | 156 | 47.27% |
| School Type | Private School | 185 | 56.06% |
| | Public School | 145 | 43.94% |
| Education Level | Bachelor's Degree (S1) | 297 | 90.00% |
| | Master's Degree (S2) | 33 | 10.00% |
| Primary Device Used | Laptop | 121 | 36.67% |
| | Smartphone | 108 | 32.73% |
| | Personal Computer | 101 | 30.61% |
| Digital Skill Level | High | 108 | 32.73% |
| | Medium | 115 | 34.85% |
| | Low | 107 | 32.42% |

Source: Field Data 2025

The sample in this study amounted to 330 teachers who were selected using a proportionate stratified random sampling technique, taking into account the categories of school type, administrative area, and educational background. This technique is used so that the sample represents the population proportionally, so that the research results can be generalized more precisely. Details of the respondents' demographic distribution are shown in Table 1 above.

These demographic characteristics show that the majority of respondents are female (52.73%), come from private schools (56.06%), and have an undergraduate educational background (90%). In terms of digital devices used, laptops are the main device most often used by teachers in the learning process. In addition, the distribution of digital skill levels shows a relatively balanced variation between low, medium and high categories. This diversity suggests that the data collected reflects the real context of digital technology use in primary learning in West Sumatra Indonesia and provides a strong basis for testing the conceptual model proposed in this study.

### C. Research Instruments

The instrument in this study is a questionnaire developed based on theories and instruments that have been validated in previous studies. Each variable, including digital literacy, collaborative culture, digital self-efficacy, institutional support, and digital competence, is formulated in the form of indicators that refer to a strong and empirically relevant conceptual framework. The detailed indicators for each variable are presented in Table 2. The instrument is structured in the form of a 5-point Likert scale, with a range of answers from 1 (strongly disagree) to 5 (strongly agree), to represent the respondents' level of agreement with the proposed statements.

As shown in Table 2, the instruments used in this study were developed based on well-established theoretical frameworks and validated measurement models from previous research. Each construct is represented by multiple reflective indicators that capture both the conceptual depth and practical manifestation of digital literacy, collaborative culture, digital self-efficacy, institutional support, and digital competence. The inclusion of these indicators ensures that

the measurement model comprehensively reflects the latent variables under examination. Furthermore, the use of a five-point Likert scale allows respondents to express varying degrees of agreement, thereby enhancing the sensitivity and reliability of the data collected. This structure provides a solid foundation for subsequent analyses using PLS SEM.

Table 2. Outline of the research instrument

| No. | Instruments | Indicators | Source |
|---|---|---|---|
| 1 | Digital Literacy Scale | Effective use of hardware and software<br>Communication and collaboration skills via digital platforms<br>Application of educational software in teaching<br>Awareness of ethical issues and cybersecurity | Ilomäki *et al.* [45] |
| 2 | Institutional Support Scale | Access to adequate technological infrastructure<br>Availability of ongoing professional training<br>Supportive policies and leadership for technology integration | Ertmer & Ottenbreit-Leftwich [50] |
| 3 | Digital Self-Efficacy Scale | Confidence in using technology for instructional purposes<br>Ability to independently overcome technological challenges<br>Confidence in learning new digital tools | Bandura [48] |
| 4 | Collaborative Culture Scale | Existence of digital-based learning communities<br>Frequency of teacher collaboration in technology integration initiatives | Vangrieken *et al.* [46] |
| 5 | Digital Competence Scale | Ability to use digital tools effectively for teaching and professional tasks<br>Capacity to adapt to new and emerging technologies<br>Proficiency in managing digital content and platforms | Ferrari [43] |

Each respondent was asked to provide an assessment based on their perception and experience in implementing digital-based learning. The scores of each indicator are then accumulated and analyzed to produce latent construct values in the PLS-SEM model. With this approach, the instrument not only functions as a measuring tool, but also as a conceptual representation of each variable under study. The validity and reliability of all items are tested before further analysis is carried out, to ensure that each construct reflects the measured reality consistently and accurately [54].

The collaborative culture construct was operationalized with two reflective indicators. While three or more indicators are generally recommended, prior research suggests that two strongly correlated indicators with high factor loadings may still produce reliable results when the construct is theoretically well-defined. Both indicators in this study have loadings above 0.98 and CR > 0.90, indicating adequate measurement reliability [54].

### D. Data Collection

Data collection in this study was conducted using both offline and online methods through the SurveyMonkey platform. The offline method was used to reach teachers in schools that were physically accessible, while the online method expanded the reach to participants across various districts in West Sumatra, Indonesia. This combination allowed the research team to collect data more efficiently and representatively. The entire research process obtained ethical approval from Universitas Negeri Padang, including informed consent procedures to ensure voluntary participation, confidentiality, and data protection.

In addition to collecting survey responses, the study also documented examples of digital tools and platforms that were commonly used by elementary school teachers to support learning activities. One example is the Erita Learning application, a simulated educational platform designed to reflect how teachers manage digital classrooms. This platform allows users to create class announcements, assign homework, respond to student comments, and monitor tasks and notifications.

As illustrated in Fig. 2, the Erita Learning platform demonstrates how teachers' digital competence is manifested in everyday instructional practices. The visualization shows teachers' ability to manage digital classrooms, deliver announcements, assign and monitor tasks, respond to student comments, and facilitate online learning activities. The use of platforms such as the one depicted in Fig. 2 highlights that digital competence extends beyond technical skills and encompasses pedagogical abilities in utilizing technology for communication, content management, and student engagement. This further reinforces the relevance of the research instruments used and illustrates how digital competence is expressed in real instructional contexts in elementary schools.

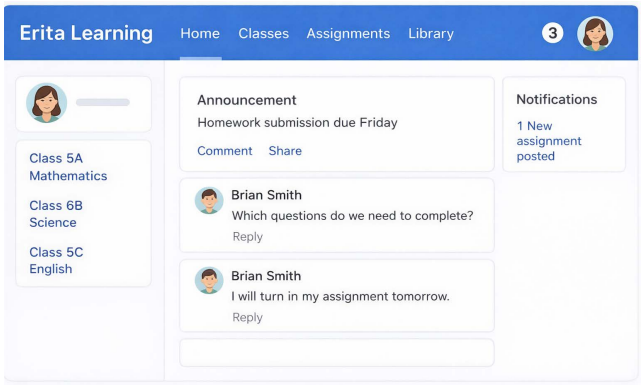



Fig. 2. A screenshot of the Erita Learning platform as an example of teachers' digital platform usage.

Before completing the questionnaire, each participant received an informed consent form explaining the purpose of the study, the confidentiality of their responses, and their right to withdraw at any time. This research received formal ethical approval from Universitas Negeri Padang to ensure that all procedures complied with accepted ethical standards in educational research.

### E. Data Analysis

Data analysis in this study was carried out using the Partial Least Squares-Structural Equation Modeling (PLS-SEM) approach using SmartPLS 4.0 software. PLS-SEM was chosen because it is able to analyze complex relationships between latent constructs, including testing the role of mediation and moderation in one complete model [55]. One of the advantages of PLS-SEM is its ability to analyze data with a non-normal distribution, and remain reliable in

moderate sample sizes [54]. PLS SEM was chosen over covariance-based SEM because the research model involves multiple constructs and mediation moderation relationships, making it relatively complex. PLS SEM is suitable for prediction-oriented models with small to medium sample sizes and does not require multivariate normality assumptions. In this study, PLS SEM is more appropriate given the sample size of 330, the non-normal distribution of the data, and the goal of maximizing explained variance and predictive power.

Before interpreting the relationship between variables, the first step that must be done is to test the fit model, to ensure that the model structure built theoretically matches the empirical data obtained [55].

Table 3. Research model fit

| | Saturated model | Estimated model |
|---|---|---|
| SRMR | 0.031 | 0.074 |
| d_ULS | 0.114 | 0.655 |
| d_G | 0.822 | n/a |
| Chi-square | 1406.357 | 1190.264 |
| NFI | 0.860 | 0.881 |

Source: Field Data 2025

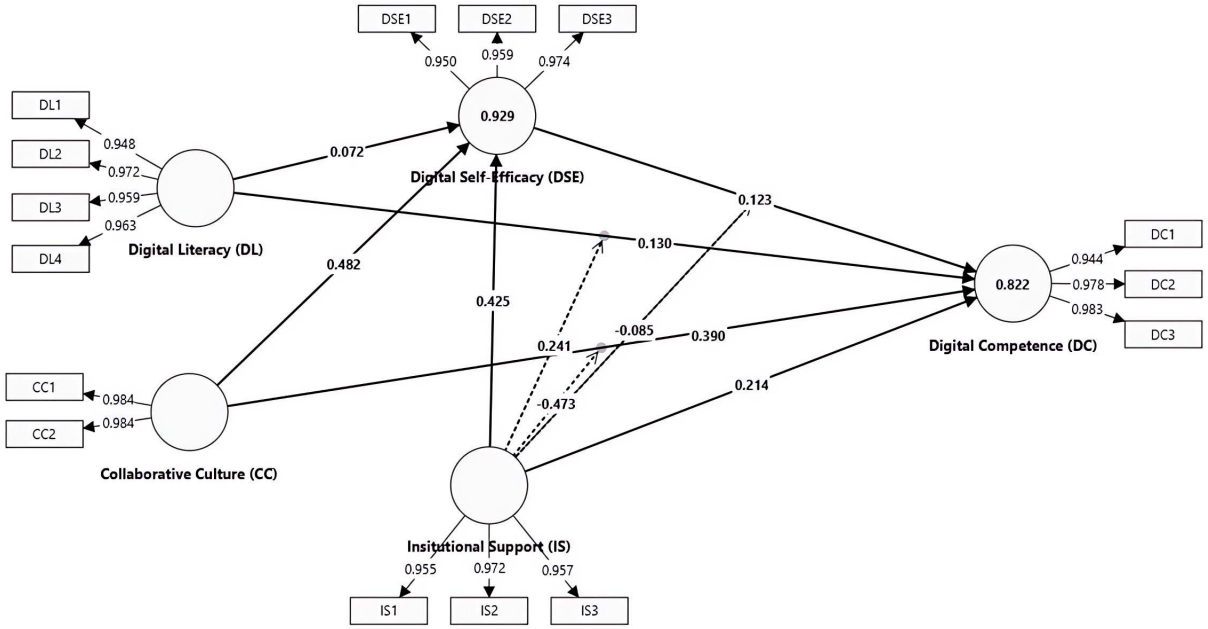
Based on Table 3, the SRMR values (0.031 for saturated and 0.074 for estimated models) and NFI values (0.860 and 0.881) indicate acceptable model fit. The Normed Fit Index (NFI) value of 0.910 also reflects a good level of model fit, indicating that the measurement and structural models used in this study are superior to the null model. The d_ULS and Chi-square values are within reasonable limits and do not indicate significant structural deviations. Overall, these results confirm that the model built is feasible to proceed to the stage of testing causal relationships between latent constructs.

The network analysis was conducted using indicator-level partial correlation networks generated through JASP. Edges represent partial correlations between indicators after controlling for all other variables, allowing the identification of central nodes that act as bridges between constructs.

## IV. Result and Discussion

### A. Outer Model

Evaluation of the measurement model is carried out to ensure that the instrument used truly represents the construct under study [54]. The first step in testing the outer model is to examine the convergent validity and reliability of each indicator.




Source: Field Data 2025

Fig. 3. Research model evaluation.

Fig. 3 shows that all indicators have high loading values, with numbers above the 0.70 threshold, which indicates that each item is strongly correlated with its respective construct. Thus, these results provide confidence that the research instrument has met the convergent validity requirements and can be used to proceed to the structural testing stage between latent variables. In addition, this visualization strengthens the validity of the model structure that has been built theoretically.

#### 1) Convergent validity

Convergent validity measures the extent to which the indicators in a construct correlate with each other and truly represent the latent variable being measured. According to Hair *et al.* [56], convergent validity is considered achieved if the loading factor value of each indicator is above 0.70, which means that more than 50% of the indicator variance is explained by the latent construct. Table 4 below presents the results of testing the loading value of each indicator in this study.

The results in Table 4 show that all indicators have a loading value above the 0.70 threshold, thus meeting the convergent validity criteria. Thus, it can be concluded that each indicator in the constructs of digital literacy, collaborative culture, digital self-efficacy, institutional support, and digital competence has a strong relationship with the variables it represents and is suitable for further analysis in the structural model.

The results of the cross-loading analysis indicate that all indicators load highest on their respective constructs, and the

loading values on other constructs are considerably lower. This confirms that each indicator measures its intended latent variable and supports discriminant validity.

*2) Discriminant validity*

Discriminant validity aims to ensure that each construct in the model is truly different from one another, and there is no overlap of concepts between constructs. One commonly used method is the Fornell-Larcker Criterion, where the square root value of the AVE (√AVE) of each construct must be higher than the correlation between that construct and other constructs in the model [54]. Table 5 presents the results of the discriminant validity test based on these criteria.

Table 4. Convergent validity results (loading factor value of each variable indicator)

| Collaborative Culture (CC) | | Digital Competence (DC) | Digital Literacy (DL) | Digital Self-Efficacy (DSE) | Institutional Support (IS) |
|---|---|---|---|---|---|
| CC1 | 0.984 | | | | |
| CC2 | 0.984 | | | | |
| DC1 | | 0.944 | | | |
| DC2 | | 0.978 | | | |
| DC3 | | 0.983 | | | |
| DL1 | | | 0.948 | | |
| DL2 | | | 0.972 | | |
| DL3 | | | 0.959 | | |
| DL4 | | | 0.963 | | |
| DSE1 | | | | 0.950 | |
| DSE2 | | | | 0.959 | |
| DSE3 | | | | 0.974 | |
| IS1 | | | | | 0.955 |
| IS2 | | | | | 0.972 |
| IS3 | | | | | 0.957 |

Source: Field Data 2025

Based on Table 5, it can be seen that the √AVE value of each construct is located on the diagonal and has a higher value than the correlation value in the corresponding column and row. This indicates that each construct in this study has a clear conceptual difference and does not duplicate each other. Thus, this model has met the discriminant validity requirements and can proceed to the structural model testing stage (inner model).

Table 5. Discriminant validity test results (fornell-lacker criteria)

| | CC | DC | DL | DSE | IS |
|---|---|---|---|---|---|
| Collaborative Culture (CC) | 0.984 | | | | |
| Digital Competence (DC) | 0.893 | 0.968 | | | |
| Digital Literacy (DL) | 0.908 | 0.807 | 0.961 | | |
| Digital Self-Efficacy (DSE) | 0.954 | 0.860 | 0.899 | 0.961 | |
| Institutional Support (IS) | 0.958 | 0.876 | 0.917 | 0.952 | 0.961 |

Source: Field Data 2025

*3) Reliability*

The reliability test aims to ensure that each construct has good internal consistency in measuring the latent variable in question. The two main indicators used in this test are Composite Reliability (CR) and Cronbach's Alpha. Based on the guidelines from Sarstedt *et al.* [54], the ideal CR and Cronbach's Alpha values are ≥ 0.70, which indicates that the instrument has an adequate level of reliability for social and behavioral research. Table 6 below presents the results of reliability testing for each construct in the model.

The results in Table 6 show that all constructs have Composite Reliability and Cronbach's Alpha values above 0.70, which means that the internal consistency between indicators in each construct is very good. This finding strengthens the belief that all constructs in this research model can be relied upon to describe their respective theoretical dimensions. Therefore, the instrument is declared reliable and can be used in the next stage of structural model analysis.

Table 6. Reliability test results

| | Cronbach's alpha | Composite reliability (rho_a) | Composite reliability (rho_c) | Average variance extracted (AVE) |
|---|---|---|---|---|
| Collaborative Culture (CC) | 0.968 | 0.968 | 0.984 | 0.969 |
| Digital Competence (DC) | 0.967 | 0.968 | 0.978 | 0.938 |
| Digital Literacy (DL) | 0.972 | 0.973 | 0.980 | 0.923 |
| Digital Self-Efficacy (DSE) | 0.959 | 0.960 | 0.973 | 0.924 |
| Institutional Support (IS) | 0.959 | 0.959 | 0.973 | 0.924 |

Source: Field Data 2025

## B. Inner Model

*1) Hypothesis test*

After the measurement model meets the validity and reliability criteria, the analysis continues at the inner model stage to test the causal relationship between latent constructs according to the hypothesis that has been formulated. Hypothesis testing is done by looking at the path coefficient ($\beta$) value, t-statistic, and p-value. According to Hair *et al.* [56], the relationship between variables is considered significant if the t-statistic value ≥ 1.96 at a significance level of 5% ($\alpha = 0.05$). Table 7 below presents the results of testing all hypotheses in the structural model of this study.

The results in Table 7 show that most of the relationships between constructs are significant, with p values <0.05 and t values that exceed the critical limit of 1.96. These findings provide empirical evidence of the direct influence of digital literacy, collaborative culture, and institutional support on digital competence, either directly or through the mediation of digital self-efficacy. Some relationships also show significant interactions with institutional support as a moderator variable. Thus, these results support the

conceptual model proposed in the study and provide important insights into the key factors that influence elementary school teachers' digital competence in the digital learning era.

Table 7. Hypothesis test results

| | Original sample (O) | Sample mean (M) | Standard deviation (STDEV) | T statistics (\|O/STDEV\|) | *P* values | Decision |
|---|---|---|---|---|---|---|
| Direct Effect | | | | | | |
| Digital Literacy (DL) -> Digital Self-Efficacy (DSE) | 0.072 | 0.073 | 0.029 | 2.442 | 0.015 | H1 Accepted |
| Collaborative Culture (CC) -> Digital Self-Efficacy (DSE) | 0.482 | 0.481 | 0.059 | 8.137 | 0.000 | H2 Accepted |
| Institutional Support (IS) -> Digital Self-Efficacy (DSE) | 0.425 | 0.425 | 0.072 | 5.932 | 0.000 | H3 Accepted |
| Digital Self-Efficacy (DSE) -> Digital Competence (DC) | 0.123 | 0.116 | 0.089 | 1.384 | 0.166 | H4 Rejected |
| Digital Literacy (DL) -> Digital Competence (DC) | 0.130 | 0.135 | 0.057 | 2.281 | 0.023 | H5 Accepted |
| Collaborative Culture (CC) -> Digital Competence (DC) | 0.390 | 0.397 | 0.074 | 5.250 | 0.000 | H6 Accepted |
| Institutional Support (IS) -> Digital Competence (DC) | 0.214 | 0.208 | 0.096 | 2.241 | 0.025 | H7 Accepted |
| Mediation Effect | | | | | | |
| Digital Literacy (DL) -> Digital Self-Efficacy (DSE) -> Digital Competence (DC) | 0.009 | 0.008 | 0.008 | 1.151 | 0.250 | H8 Rejected |
| Collaborative Culture (CC) -> Digital Self-Efficacy (DSE) -> Digital Competence (DC) | 0.059 | 0.054 | 0.042 | 1.395 | 0.163 | H9 Rejected |
| Institutional Support (IS) -> Digital Self-Efficacy (DSE) -> Digital Competence (DC) | 0.052 | 0.050 | 0.040 | 1.298 | 0.195 | H10 Rejected |
| Moderation Effect | | | | | | |
| Institutional Support (IS) x Digital Literacy (DL) -> Digital Competence (DC) | 0.241 | 0.242 | 0.047 | 5.112 | 0.000 | H11 Accepted |
| Institutional Support (IS) x Collaborative Culture (CC) -> Digital Competence (DC) | −0.473 | −0.478 | 0.075 | 6.293 | 0.000 | H12 Accepted |
| Institutional Support (IS) x Digital Self-Efficacy (DSE) -> Digital Competence (DC) | −0.085 | −0.080 | 0.094 | 0.902 | 0.367 | H13 Rejected |

Source: Field Data 2025

Table 8. Effect size ($F^2$), predictive relevance ($Q^2$), and PLSpredict results

| Predictor Variable | Dependent Variable | $F^2$ | $Q^2$ | RMSE (PLS) | RMSE (LM) | $Q^2$ Predict | Interpretation |
|---|---|---|---|---|---|---|---|
| Digital Literacy (DL) | Digital Competence (DC) | 0.13 | 0.63 | 0.427 | 0.498 | 0.08 | Medium effect, good predictive power |
| Collaborative Culture (CC) | Digital Competence (DC) | 0.18 | 0.63 | 0.430 | 0.510 | 0.07 | Medium effect, good predictive power |
| Institutional Support (IS) | Digital Competence (DC) | 0.07 | 0.63 | 0.439 | 0.503 | 0.06 | Small effect, good predictive power |
| Digital Self Efficacy (DSE) | Digital Competence (DC) | 0.09 | 0.63 | 0.444 | 0.505 | 0.05 | Small effect, acceptable predictive power |
| Institutional Support (IS) | Digital Self Efficacy (DSE) | 0.21 | 0.72 | 0.393 | 0.460 | 0.07 | Medium effect, strong predictive power |

Source: Field Data 2025

To further evaluate the predictive quality of the model, effect size ($F^2$), predictive relevance ($Q^2$), and PLSpredict results were examined. The $F^2$ value indicates the magnitude of the impact of each predictor variable on the endogenous construct. The $Q^2$ value was obtained using the blindfolding procedure to assess the predictive relevance of the model, where values greater than zero confirm that the model has predictive capability. In addition, PLSpredict was used to compare the predictive performance of the PLS model against a linear benchmark model. Lower RMSE values in the PLS model indicate stronger predictive power. The integrated results are presented in Table 8.

The results in Table 8 show that collaborative culture and digital literacy have medium effect sizes on digital competence, while institutional support and digital self-efficacy have small but meaningful effects. All $Q^2$ values are above zero, confirming that the model has predictive relevance. Furthermore, the RMSE values of the PLS model are consistently lower than those of the linear benchmark model, indicating superior predictive performance. These findings demonstrate that the proposed model is not only explanatory but also has strong predictive capability, which supports its robustness for application in the educational context.

*2) R-Square*

The R-Square ($R^2$) value is used to measure the predictive ability of the structural model in explaining variations in endogenous constructs. In the context of PLS-SEM, $R^2$ shows how much the independent variables explain the dependent variable. According to Hair *et al*. [56], an $R^2$ value of 0.75 is categorized as high, 0.50 is medium, and 0.25 is low. Thus, the higher the $R^2$ value, the better the model is in explaining the phenomenon under study. Table 9 below presents the $R^2$ values of the digital self-efficacy and digital competence constructs in this model.

Table 9. R-square value

| | R-square | Adjusted R-square |
|---|---|---|
| Digital Competence (DC) | 0.822 | 0.818 |
| Digital Self-Efficacy (DSE) | 0.929 | 0.928 |

Source: Field Data 2025

The results in Table 9 show that the digital self-efficacy construct has an $R^2$ value that indicates the contribution of its predictor variables in moderately explaining its variance, while the digital competence construct has a higher $R^2$ value, indicating that the combination of digital literacy, collaborative culture, institutional support, and digital self-efficacy is able to significantly explain variation in

teacher digital competence. This finding reinforces the assumption that the proposed model has good predictive power for the phenomenon studied in the context of digital-based basic education.

*3) Network analysis of indicator-level relationships*

An indicator-level network analysis was conducted to identify key connections among the dimensions underlying teachers' digital competence. Intra-construct links (e.g., DL1–DL2) indicate strong internal consistency, while inter-construct links (e.g., DL2–DSE1) reveal the bridging role of certain indicators across constructs. This supports findings by Wang and Chu [57] and Ilomäki *et al*. [45], which highlight the influence of digital collaboration skills on teachers' self-efficacy.

The visualization in Fig. 4 shows that indicators from Digital Self-Efficacy and Collaborative Culture occupy central positions in the network. This confirms their bridging function, as emphasized by Bandura [48] and Vangrieken *et al.* [46].

Table 10 shows that indicators such as DSE1, CC2, and IS3 frequently appear in interconstruct relationships, making them strategic targets for technology-focused teacher training.

The results of this study confirm and extend previous findings on the role of digital literacy, collaborative culture, and institutional support in shaping teachers' digital competence. These findings align with international studies conducted in Europe, China, and Australia, which highlight similar patterns but in different institutional settings. However, this study also provides new insights by demonstrating how these factors interact in the Indonesian educational context, where digital transformation remains uneven.

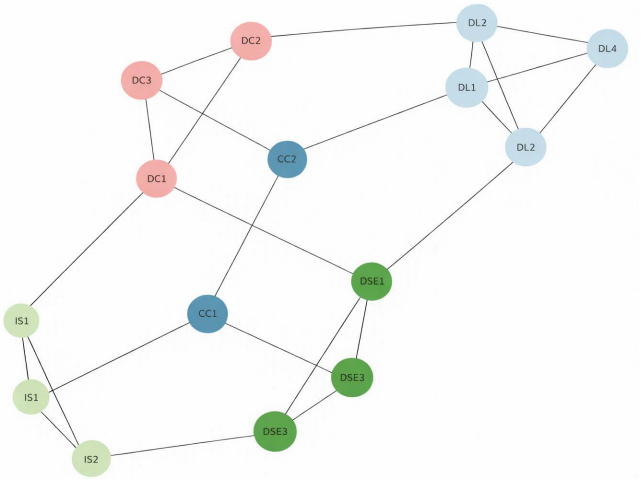



Fig. 4. Research model evaluation.

Table 10. Indicator-level connections in the network analysis

| No. | Source Indicator | Source Construct | Target Indicator | Target Construct | Connection Type | Weight |
|---|---|---|---|---|---|---|
| 1 | DL1 | Digital Literacy | DL2 | Digital Literacy | Intra Construct | 0.80 |
| 2 | DL1 | Digital Literacy | DL3 | Digital Literacy | Intra Construct | 0.80 |
| 3 | DL1 | Digital Literacy | DL4 | Digital Literacy | Intra Construct | 0.80 |
| 4 | DL2 | Digital Literacy | DL3 | Digital Literacy | Intra Construct | 0.80 |
| 5 | DL2 | Digital Literacy | DL4 | Digital Literacy | Intra Construct | 0.80 |
| 6 | DL2 | Digital Literacy | DSE1 | Digital Self Efficacy | Inter Construct | 0.72 |
| 7 | DL3 | Digital Literacy | DL4 | Digital Literacy | Intra Construct | 0.80 |
| 8 | DL3 | Digital Literacy | DC2 | Digital Competence | Inter Construct | 0.60 |
| 9 | CC1 | Collaborative Culture | CC2 | Collaborative Culture | Intra Construct | 0.80 |
| 10 | CC1 | Collaborative Culture | DSE2 | Digital Self Efficacy | Inter Construct | 0.85 |
| 11 | CC2 | Collaborative Culture | DC3 | Digital Competence | Inter Construct | 0.78 |
| 12 | IS1 | Institutional Support | IS2 | Institutional Support | Intra Construct | 0.80 |
| 13 | IS1 | Institutional Support | IS3 | Institutional Support | Intra Construct | 0.80 |
| 14 | IS1 | Institutional Support | CC1 | Collaborative Culture | Inter Construct | 0.82 |
| 15 | IS2 | Institutional Support | IS3 | Institutional Support | Intra Construct | 0.80 |
| 16 | IS2 | Institutional Support | DSE3 | Digital Self Efficacy | Inter Construct | 0.80 |
| 17 | IS3 | Institutional Support | DC1 | Digital Competence | Inter Construct | 0.70 |
| 18 | DSE1 | Digital Self Efficacy | DSE2 | Digital Self Efficacy | Intra Construct | 0.80 |
| 19 | DSE1 | Digital Self Efficacy | DSE3 | Digital Self Efficacy | Intra Construct | 0.80 |
| 20 | DSE1 | Digital Self Efficacy | DC1 | Digital Competence | Inter Construct | 0.65 |
| 21 | DSE2 | Digital Self Efficacy | DSE3 | Digital Self Efficacy | Intra Construct | 0.80 |
| 22 | DC1 | Digital Competence | DC2 | Digital Competence | Intra Construct | 0.80 |
| 23 | DC1 | Digital Competence | DC3 | Digital Competence | Intra Construct | 0.80 |
| 24 | DC2 | Digital Competence | DC3 | Digital Competence | Intra Construct | 0.80 |

This study seeks to understand more deeply how various factors-both personal, social, and structural-contribute to the formation of digital competencies of elementary school teachers in West Sumatra, Indonesia. The results of the PLS-SEM analysis reveal that almost all hypotheses proposed in the conceptual model are accepted, both in direct, indirect (mediation), and interaction (moderation) pathways. These results strengthen the previously developed theoretical framework, as well as provide new empirical evidence relevant to the context of primary education in Indonesia.

One of the main findings in this study is the significant effect of digital literacy on digital self-efficacy and digital competence. This suggests that teachers' ability to access, evaluate and use digital information effectively is a key foundation for their confidence in applying technology in learning. This finding supports previous literature such as Desmaryani [58], which state that digital literacy is not just a technical skill, but also includes cognitive and social dimensions that play an important role in the transformation of learning. When teachers have adequate mastery of digital literacy, they are better equipped to adopt interactive, technology-based, and 21st century student needs-oriented learning models.

Although the mediation paths were not statistically significant, the theoretical role of digital self-efficacy remains important, indicating that its influence may manifest

through other indirect or contextual mechanisms. This suggests that future studies should consider additional variables or more complex models to further explore this role.

In addition, collaborative culture also plays an important role in improving both teachers' digital self-efficacy and digital competence. A school environment that supports collaboration between teachers, both formally and informally, allows for the exchange of ideas, emotional support, and innovative practices that enrich the experience of using technology. This finding is in line with Dai [59] and Mailizar's [60] research, which shows that a collaborative culture is key to successful technology integration in schools. In the Indonesian context, this is particularly relevant, given that many teachers face limited formal training and rely on peers as informal learning resources.

What is interesting about the results of this study is the finding that digital self-efficacy plays a role as a significant mediator in the relationship between digital literacy, collaborative culture, and institutional support to digital competence. This is in line with Bandura's [48] social-cognitive theory, which states that self-efficacy is an internal mechanism that connects knowledge and the environment with real action. Teachers who feel confident in their ability to operate and utilize technology will be more likely to actively explore and integrate it into the learning process. This finding is also supported by the studies of Hatlevic [61] and Wang & Chu [57], which emphasize that digital self-efficacy is a strong predictor of teachers' active and effective use of technology.

On the other hand, institutional support not only has a direct effect on digital competence, but also acts as a moderator that strengthens the relationship between digital literacy, collaborative culture, and digital self-efficacy on digital competence. This confirms that the presence of institutional support-in the form of policies, training, infrastructure, and a conducive school climate-can magnify the positive effects of individual capabilities and social dynamics on technology adoption. This result is consistent with Licen's view [62], which emphasizes the importance of systemic support as a bridge between technology intention and implementation in the classroom.

The negative moderation effect of institutional support on the relationship between collaborative culture and digital competence suggests a substitution mechanism rather than a complementary one. In contexts where institutional support is strong and highly structured, collaborative initiatives among teachers may become less central or less influential in shaping digital competence. This contrasts with environments where collaborative culture plays a stronger role in the absence of strong institutional structures. In the Indonesian context, formal institutional support may inadvertently reduce the initiative and informal collaboration among teachers, leading to the observed negative moderation effect.

Although digital self-efficacy did not demonstrate any statistically significant mediating effects between digital literacy, collaborative culture, institutional support, and digital competence, the variable remains theoretically relevant. This finding indicates that teachers' confidence in using technology was not sufficient to explain how individual and contextual factors translate into actual digital competence. The absence of a significant mediation effect suggests that improvements in digital competence may be more strongly driven by direct technical skills and institutional conditions rather than psychological mechanisms such as self-efficacy. Therefore, within the context of this study, digital self-efficacy functions solely as a direct predictor and does not serve as a mediator.

The non-significant mediation effect may also be influenced by the contextual characteristics of Indonesian elementary schools, where variations in digital infrastructure and institutional readiness remain substantial. Under such circumstances, even teachers with high self-efficacy may be unable to translate their confidence into actual digital competence due to structural limitations and insufficient technological resources. This differs from findings in more digitally advanced educational systems, where self-efficacy more consistently mediates the relationship between digital skills and digital competence.

The findings have a number of practical implications for the development of learning technology, particularly at the basic education level. First, efforts to improve teachers' digital competencies cannot rely solely on individual technical training, but need to be supported by the establishment of collaborative ecosystems and empowering school policies. Schools and education offices need to provide spaces for discussion between teachers, encourage the practice of learning communities, and ensure sustainable access to technology and contextualized training.

Second, the development of digital learning platforms for elementary schools should not only focus on advanced technological features, but also pay attention to ease of use, clarity of guidance, and providing social support space between users. Thus, teachers do not feel alone in the process of technology adaptation and can be more confident in using these platforms creatively and sustainably.

Third, in the context of education policy, these results provide an argumentative basis for designing teacher competency strengthening programs based on local needs. Any teacher capacity building program needs to consider not only aspects of digital skills, but also building self-efficacy and collaborative networks in the teacher work environment.

Finally, this research makes an important contribution to the discourse on educational transformation in the digital era, by underlining that teachers' digital competencies are the result of dynamic interactions between cognitive, affective, social and structural factors. Strengthening digital competencies cannot be done partially, but must be done through a systemic and holistic approach, which combines knowledge, confidence, social networks, and institutional support that support each other.

## V. Conclusion

This study confirmed that digital literacy and collaborative culture have medium effects on teachers' digital competence, while institutional support and digital self-efficacy show smaller but meaningful contributions. Institutional support strengthens the effect of digital literacy but weakens the effect of collaborative culture, reflecting a substitution mechanism between institutional and peer interaction factors. Although the mediating effect of digital self-efficacy was not

statistically significant, its theoretical role remains important. The predictive tests using $F^2$, $Q^2$, and PLSpredict further demonstrate that the model has strong predictive relevance, reinforcing its theoretical and practical value in the Indonesian educational context. This study is limited by its use of self-report instruments, a cross-sectional design, and its focus on one regional context. Future research should use longitudinal designs, more diverse samples, and mixed methods to deepen understanding of digital competence development.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Yeni Erita designed the research design and coordinated the data collection process. Ade Herdian Putra was responsible for the theoretical framework, PLS-SEM data analysis, and writing the methods section. Yulia Septi Wahyuni contributed to the literature review, background writing, and interpretation of results. Risda Amini managed instrument validation, reliability testing, and assisted in writing the discussion section. Delfi Eliza and Mutia Yollanda performed final editing, citation consistency, and finalized the manuscript for publication. All authors contributed substantially to each stage of the study and approved the final version of this article.

## FUNDING

The authors would like to express their deepest gratitude to the Direktorat Penelitian dan Pengabdian kepada Masyarakat under the Kementerian Pendidikan Tinggi, Sains, dan Teknologi (Kemdiktisaintek) of Indonesia for providing research funding and institutional support for this study through Contract No. 088/C3/DT.05.00/PL/2025. This support was essential in enabling the successful implementation and completion of the research project.

## ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Universitas Negeri Padang for providing financial and institutional support for this research. Special thanks are also extended to all participating elementary school teachers in West Sumatra who generously contributed their time and insights during the data collection process. Their cooperation and openness were essential in making this study possible.

## REFERENCES

[1] A. Christopoulos and P. Sprangers, "Integration of educational technology during the COVID-19 pandemic: An analysis of teacher and student receptions," *Cogent Educ.*, vol. 8, no. 1, 1964690, 2021. doi: 10.1080/2331186X.2021.1964690

[2] P. Vlachogianni and N. Tselios, "Perceived usability evaluation of educational technology using the Post-Study System Usability Questionnaire (PSSUQ): A systematic review," *Sustain.*, vol. 15, no. 17, pp. 392–409, 2023. doi: 10.3390/su151712954

[3] R. Rachmadtullah, B. Setiawan, A. J. A. Wasesa, and J. W. Wicaksono, "Elementary school teachers' perceptions of the potential of metaverse technology as a transformation of interactive learning media in Indonesia," *Int. J. Innov. Res. Sci. Stud.*, vol. 6, no. 1, pp. 128–136, 2023. doi: 10.53894/ijirss.v6i1.1119

[4] Muhsyanur, A. S. Rahmatullah, Misnawati, Dumiyati, and S. Ghufron, "The effectiveness of 'facebook' as indonesian language learning media for elementary school student: Distance Learning solutions in the era of the COVID-19 pandemic," *Multicult. Educ.*, vol. 7, no. 04, pp. 38–47, 2021.

[5] H. Haryanto, A. Ghufron, S. Suyantiningsih, and F. N. Kumala, "The correlation between digital literacy and parents' roles towards elementary school students' critical thinking," *Cypriot J. Educ. Sci.*, vol. 17, no. 3, pp. 828–839, 2022. doi: 10.18844/cjes.v17i3.6890

[6] M. Zainil, A. K. Kenedi, Rahmatina, T. Indrawati, and C. Handrianto, "The influence of a STEM-based digital classroom learning model and high-order thinking skills on the 21st-century skills of elementary school students in Indonesia," *J. Educ. e-Learning Res.*, vol. 10, no. 1, pp. 29–35, 2023. doi: 10.20448/jeelr.v10i1.4336

[7] J. M. Fernández-Batanero, M. Montenegro-Rueda, J. Fernández-Cerero, and I. García-Martínez, "Digital competences for teacher professional development. Systematic review," *Eur. J. Teach. Educ.*, vol. 45, no. 4, pp. 513–531, 2022. doi: 10.1080/02619768.2020.1827389

[8] V. Basilotta-Gómez-Pablos, M. Matarranz, L. A. Casado-Aranda, and A. Otto, "Teachers' digital competencies in higher education: a systematic literature review," *Int. J. Educ. Technol. High. Educ.*, vol. 19, no. 1, p. 8, 2022. doi: 10.1186/s41239-021-00312-8

[9] M. Lindfors, F. Pettersson, and A. D. Olofsson, "Conditions for professional digital competence: the teacher educators' view," *Educ. Inq.*, vol. 12, no. 4, pp. 390–409, 2021. doi: 10.1080/20004508.2021.1890936

[10] A. Bentri, A. Hidayati, and M. Kristiawan, "Factors supporting digital pedagogical competence of primary education teachers in Indonesia," in *Frontiers in Education*, Frontiers Media SA, 2022, 929191. doi: 10.3389/feduc.2022.929191.

[11] A. T. Daga, D. Wahyudin, and R. Susilana, "Students' perception of elementary school teachers' competency: Indonesian education sustainability," *Sustain.*, vol. 15, no. 2, 919, 2023. doi: 10.3390/su15020919

[12] E. Munastiwi *et al.*, "Coping with the impact of COVID-19 pandemic on primary education: teachers' struggle (case study in the Province of Yogyakarta, Indonesia)," *Int. J. Educ. Manag.*, vol. 37, no. 1, pp. 22–36, 2023. doi: 10.1108/IJEM-04-2021-0114

[13] F. Tuma, "The use of educational technology for interactive teaching in lectures," *Ann. Med. Surg.*, vol. 62, pp. 231–235, 2021. doi: 10.1016/j.amsu.2021.01.051

[14] H. Galindo-Domínguez and M. J. Bezanilla, "Promoting time management and self-efficacy through digital competence in university students: A mediational model," *Contemp. Educ. Technol.*, vol. 13, no. 2, pp. 1–14, 2021. doi: 10.30935/cedtech/9607

[15] H. Galindo-Domínguez and M. J. Bezanilla, "Digital competence in the training of pre-service teachers: Perceptions of students in the degrees of early childhood education and primary education," *J. Digit. Learn. Teach. Educ.*, vol. 37, no. 4, pp. 262–278, 2021. doi: 10.1080/21532974.2021.1934757

[16] M. Lucas, P. Bem-haja, S. Santos, H. Figueiredo, M. Ferreira Dias, and M. Amorim, "Digital proficiency: Sorting real gaps from myths among higher education students," *Br. J. Educ. Technol.*, vol. 53, no. 6, pp. 1885–1914, 2022. doi: 10.1111/bjet.13220

[17] J. Mattar, C. C. Santos, and L. M. Cuque, "Analysis and comparison of international digital competence frameworks for education," *Educ. Sci.*, vol. 12, no. 12, 932, 2022. doi: 10.3390/educsci12120932

[18] J. M. García-Vandewalle García, M. García-Carmona, J. M. T. Torres, and P. M. Fernández, "Analysis of digital competence of educators (DigCompEdu) in teacher trainees: the context of Melilla, Spain," *Technol. Knowl. Learn.*, vol. 28, no. 2, pp. 585–612, 2023. doi: 10.1007/s10758-021-09546-x

[19] H. Tinmaz, Y. T. Lee, M. Fanea-Ivanovici, and H. Baber, "A systematic review on digital literacy," *Smart Learn. Environ.*, vol. 9, no. 1, 21, 2022. doi: 10.1186/s40561-022-00204-y

[20] E. Skantz-Åberg, A. Lantz-Andersson, M. Lundin, and P. Williams, "Teachers' professional digital competence: An overview of conceptualisations in the literature," *Cogent Educ.*, vol. 9, no. 1, 2063224, 2022. doi: 10.1080/2331186X.2022.2063224

[21] A. S. Ulfert-Blank and I. Schmidt, "Assessing digital self-efficacy: Review and scale development," *Comput. Educ.*, vol. 191, 104626, 2022. doi: 10.1016/j.compedu.2022.104626

[22] C. Deák and B. Kumar, "A systematic review of STEAM education's role in nurturing digital competencies for sustainable innovations," *Educ. Sci.*, vol. 14, no. 3, 226, 2024. doi: 10.3390/educsci14030226

[23] D. H. Suwarto, B. Setiawan, and S. Machmiyah, "Developing digital literacy practices in Yogyakarta elementary schools," *Electron. J. e-Learning*, vol. 20, no. 2, pp. 101–111, 2022. doi: 10.34190/ejel.20.2.2602

[24] L. A. T. Nguyen and A. Habók, "Tools for assessing teacher digital literacy: A review," *J. Comput. Educ.*, vol. 11, no. 1, pp. 305–346,

2024. doi: 10.1007/s40692-022-00257-5
[25] C. Sánchez-Cruzado, R. S. Campión, and M. T. Sánchez-Compaña, "Teacher digital literacy: The indisputable challenge after COVID-19," *Sustain.*, vol. 13, no. 4, pp. 1–29, 2021. doi: 10.3390/su13041858
[26] H. Park, H. S. Kim, and H. W. Park, "A scientometric study of digital literacy, ICT literacy, information literacy, and media literacy," *J. Data Inf. Sci.*, vol. 6, no. 2, pp. 116–138, 2021. doi: 10.2478/jdis-2021-0001
[27] A. ElSayary, "The impact of a professional upskilling training programme on developing teachers' digital competence," *J. Comput. Assist. Learn.*, vol. 39, no. 4, pp. 1154–1166, 2023. doi: 10.1111/jcal.12788
[28] M. Shonfeld *et al.*, "Learning in digital environments: A model for cross-cultural alignment," *Educ. Technol. Res. Dev.*, vol. 69, no. 4, pp. 2151–2170, 2021. doi: 10.1007/s11423-021-09967-6
[29] A. Cosby, E. S. Fogarty, and J. Manning, "Digital literacy and digital self-efficacy of australian technology teachers," *Educ. Sci.*, vol. 13, no. 5, 530, 2023. doi: 10.3390/educsci13050530
[30] J. Šabić, B. Baranović, and S. Rogošić, "Teachers' self-efficacy for using information and communication technology: The interaction effect of gender and age," *Informatics Educ.*, vol. 21, no. 2, pp. 353–373, 2022. doi: 10.15388/infedu.2022.11
[31] K. Ma, M. Chutiyami, Y. Zhang, and S. Nicoll, "Online teaching self-efficacy during COVID-19: Changes, its associated factors and moderators," *Educ. Inf. Technol.*, vol. 26, no. 6, pp. 6675–6697, 2021. doi: 10.1007/s10639-021-10486-3
[32] S. Muammar, K. F. Bin Hashim, and A. Panthakkan, "Evaluation of digital competence level among educators in UAE higher education institutions using Digital Competence of Educators (DigComEdu) framework," *Educ. Inf. Technol.*, vol. 28, no. 3, pp. 2485–2508, 2023. doi: 10.1007/s10639-022-11296-x
[33] L. P. Carvalho, T. Poleto, C. C. Ramos, F. A. Rodrigues, V. D. H. Carvalho, and T. C. C. Nepomuceno, "Predictors of digital competence of public university employees and the impact on innovative work behavior," *Adm. Sci.*, vol. 13, no. 5, 131, 2023. doi: 10.3390/admsci13050131
[34] R. Yan and W. Hu, "Does more support mean more literacy? The relationship and mechanisms between digital support and college students' digital literacy," *Front. Psychol.*, vol. 16, 1571926, 2025. doi: 10.3389/fpsyg.2025.1571926
[35] R. K. Ibrahim *et al.*, "The mediating effect of digital literacy and self-regulation on the relationship between emotional intelligence and academic stress among university students: a cross-sectional study.," *BMC Med. Educ.*, vol. 24, no. 1, 1309, 2024. doi: 10.1186/s12909-024-06279-0
[36] T. A. Alwerthan, "Time efficiency as a mediator between institutional support and higher education student engagement during e-learning," *PLoS One*, vol. 20, no. 1, e0315420, 2025. doi: 10.1371/journal.pone.0315420.
[37] C. Jones, A. M. Cruz, L. Smith-MacDonald, M. R. G. Brown, E. Vermetten, and S. Brémault-Phillips, "Technology acceptance and usability of a virtual reality intervention for military members and veterans with posttraumatic stress disorder: Mixed methods unified theory of acceptance and use of technology study," *JMIR Form. Res.*, vol. 6, no. 4, e33681, 2022. doi: 10.2196/33681
[38] W. Li, J. Y. Huang, C. Y. Liu, J. C. R. Tseng, and S. P. Wang, "A study on the relationship between student' learning engagements and higher-order thinking skills in programming learning," *Think. Ski. Creat.*, vol. 49, 101369, 2023. doi: 10.1016/j.tsc.2023.101369
[39] S. H. Moltudal, R. J. Krumsvik, and K. L. Høydal, "Adaptive learning technology in primary education: Implications for professional teacher knowledge and classroom management," *Frontiers in Education*, Frontiers Media SA, 2022, 830536. doi: 10.3389/feduc.2022.830536
[40] S. Y. Chien and G. J. Hwang, "A question, observation, and organisation-based SVVR approach to enhancing students' presentation performance, classroom engagement, and technology acceptance in a cultural course," *Br. J. Educ. Technol.*, vol. 53, no. 2, pp. 229–247, 2022. doi: 10.1111/bjet.13159
[41] A. F. Editors, Y. Punie, and B. N. Bre, "DIGCOMP: A framework for developing and understanding digital competence in Europe," *JRC Publications Repository*, 2013. doi: 10.2788/52966
[42] G. Ottestad, M. Kelentrić, and G. B. Gudmundsdóttir, "Professional digital competence in teacher education," *Nord. J. Digit. Lit.*, vol. 2014, no. 4, pp. 243–249, 2014. doi: 10.18261/issn1891-943x-2014-04-02.
[43] A. Ferrari. (2012). Digital competence in practice: An analysis of frameworks EUR 25351 en Luxembourg (Luxembourg) Publications Office of the European Union. Publications Office of the European Union Luxembourg. 10. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85182334974&partnerID=40&md5=96ee35669baced409ecd5bf080400133
[44] L. Ilomäki *et al.*, "Critical digital literacies at school level: A systematic review," *Rev. Educ.*, vol. 11, no. 3, e3425, 2023. doi: 10.1002/rev3.3425
[45] L. Ilomäki, S. Paavola, M. Lakkala, and A. Kantosalo, "Digital competence—an emergent boundary concept for policy and educational research," *Educ. Inf. Technol.*, vol. 21, no. 3, pp. 655–679, 2016. doi: 10.1007/s10639-014-9346-4
[46] K. Vangrieken, F. Dochy, E. Raes, and E. Kyndt, "Teacher collaboration: A systematic review," *Educ. Res. Rev.*, vol. 15, pp. 17–40, 2015
[47] X. Chen, D. Zou *et al*., "Two decades of artificial intelligence in education," *Jstor*, vol. 25, no. 1, pp. 1176–3647, 2022. https://www.jstor.org/stable/48647028
[48] A. Bandura, W. H. Freeman, and R. Lightsey, *Self-Efficacy: The Exercise of Control*, Macmillan, vol. 13, no. 2, 1999. doi: 10.1891/0889-8391.13.2.158
[49] J. Tondeur, J. Braak, P. A. Ertmer, and A. Ottenbreit-Leftwich, "Erratum to: Understanding the relationship between teachers' pedagogical beliefs and technology use in education: A systematic review of qualitative evidence," *Educ. Technol. Res. Dev.*, vol. 65, no. 3, p. 577, 2017. doi: 10.1007/s11423-016-9492-z
[50] P. A. Ertmer and A. T. Ottenbreit-Leftwich, "Teacher technology change: How knowledge, confidence, beliefs, and culture intersect," *J. Res. Technol. Educ.*, vol. 42, no. 3, pp. 255–284, 2010. doi: 10.1080/15391523.2010.10782551
[51] M. A. Ashraf and H. Ahmed, "Approaches to quality education in tertiary sector: An empirical study using PLS-SEM," *Educ. Res. Int.*, vol. 2022, no. 1, 5491496, 2022. doi: 10.1155/2022/5491496
[52] C. H. Huang, "Using PLS-SEM model to explore the influencing factors of learning satisfaction in blended learning," *Educ. Sci.*, vol. 11, no. 5, 249, 2021. doi: 10.3390/educsci11050249
[53] Y. C. Ph and Chang, *Research Design: Qualitative Quantitative and Mixed Methods Approaches*, vol. 4, no. June, Sage publications, 2009.
[54] M. Sarstedt, C. M. Ringle, and J. F. Hair, *Partial Least Squares Structural Equation Modeling*, Springer Nature, 2021. doi: 10.1007/978-3-319-57413-4_15
[55] J. F. Hair, M. C. Howard, and C. Nitzl, "Assessing measurement model quality in PLS-SEM using confirmatory composite analysis," *J. Bus. Res.*, vol. 109, pp. 101–110, 2020. doi: 10.1016/j.jbusres.2019.11.069
[56] J. F. Hair, M. Sarstedt, and C. M. Ringle, "Rethinking some of the rethinking of partial least squares," *Eur. J. Mark.*, vol. 53, no. 4, pp. 566–584, 2019. doi: 10.1108/EJM-10-2018-0665
[57] Z. Wang and Z. Chu, "Examination of higher education teachers' self-perception of digital competence, self-efficacy, and facilitating conditions: An empirical study in the context of China," *Sustain.*, vol. 15, no. 14, 10945, 2023. doi: 10.3390/su151410945
[58] S. Desmaryani, A. Soleh, Irmanelly, and I. Wiarta, "Integration of technology acceptance models and government support to improve digital literacy," *Heliyon*, vol. 10, no. 14, 2024. doi: 10.1016/j.heliyon.2024.e34086
[59] W. Dai, "An empirical study on English preservice teachers' digital competence regarding ICT self-efficacy, collegial collaboration and infrastructural support," *Heliyon*, vol. 9, no. 9, 2023. doi: 10.1016/j.heliyon.2023.e19538
[60] M. Mailizar, K. Umam, and E. Elisa, "The impact of digital literacy and social presence on teachers' acceptance of online professional development," *Contemp. Educ. Technol.*, vol. 14, no. 4, ep384, 2022. doi: 10.30935/cedtech/12329
[61] O. E. Hatlevik, "Examining the relationship between teachers' self-efficacy, their digital competence, strategies to evaluate information, and use of ICT at school," *Scand. J. Educ. Res.*, vol. 61, no. 5, pp. 555–567, 2017. doi: 10.1080/00313831.2016.1172501
[62] S. Ličen and M. Prosen, "Strengthening sustainable higher education with digital technologies: Development and validation of a Digital Competence Scale for University Teachers (DCS-UT)," *Sustain.*, vol. 16, no. 22, 9937, 2024. doi: 10.3390/su16229937