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Digital and AI Literacy, Self-Efficacy, Motivation, and Self-Directed Learning of Pre-Service Teachers: The Mediating Role of Engagement

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Abstrak

Pembelajaran mandiri (self-directed learning) merupakan kompetensi kunci bagi calon guru, mengingat AI generatif dapat menimbulkan ketergantungan. Namun, penelitian sebelumnya sebagian besar bersifat bivariat dan jarang menyertakan literasi AI. Studi cross-sectional ini menguji apakah keterlibatan belajar (learning engagement) memediasi hubungan antara literasi digital (termasuk literasi AI), efikasi diri akademik, dan motivasi belajar dengan pembelajaran mandiri. Sebanyak 620 mahasiswa di sebuah fakultas pendidikan guru di Bogor, Indonesia, diundang untuk berpartisipasi. Sebanyak 226 orang memberikan respons, dan 199 respons yang valid dianalisis menggunakan confirmatory factor analysis, path analysis, dan bootstrapping. Hasilnya menunjukkan bahwa literasi digital (β=0.18β=0.18), motivasi (β=0.27β=0.27), dan keterlibatan belajar (β=0.31β=0.31) berasosiasi positif dengan pembelajaran mandiri (R2=0.44R 2 =0.44), sedangkan efikasi diri tidak. Efikasi diri hanya berasosiasi secara tidak langsung melalui keterlibatan belajar (β=0.08β=0.08, 95% CI [0.03, 0.14]), sedangkan motivasi berasosiasi secara komplementer (β=0.15β=0.15, 95% CI [0.06, 0.25]). Pendidikan guru perlu memadukan pembelajaran yang menarik dengan literasi digital dan literasi AI yang kritis. Studi longitudinal diperlukan untuk penelitian lebih lanjut.

Kata Kunci: Efikasi Diri Akademik; Literasi AI; Literasi Digital; Keterlibatan Belajar; Motivasi Belajar; Calon Guru; Pembelajaran Mandiri.

Abstract

Self-directed learning is a key competence for pre-service teachers, as generative AI may foster dependence, yet previous studies have mostly been bivariate and rarely included AI literacy. This cross-sectional study examined whether learning engagement mediates the associations of digital literacy (including AI literacy), academic self-efficacy, and learning motivation with self-directed learning. All 620 students of a teacher training faculty in Bogor, Indonesia, were invited; 226 responded, and 199 valid responses were analysed using confirmatory factor analysis, path analysis, and bootstrapping. Digital literacy (β = 0.18), motivation (β = 0.27), and engagement (β = 0.31) were positively associated with self-directed learning (R^2 = 0.44), whereas self-efficacy was not. Self-efficacy showed an indirect-only association through engagement (β = 0.08, 95% CI [0.03, 0.14]), and motivation a complementary one (β = 0.15, 95% CI [0.06, 0.25]). Teacher education should combine engaging learning with critical digital and AI literacy; longitudinal studies are needed.

Keyword: Academic Self-Efficacy; AI Literacy; Digital Literacy; Learning Engagement; Learning Motivation; Pre-Service Teachers; Self-Directed Learning.

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1. Introduction

Self-directed learning is increasingly regarded as a core competence in higher education because knowledge acquired during university studies quickly becomes outdated. Students are expected not only to receive material from lecturers but also to recognise their learning needs, set goals, choose strategies, find learning resources, and evaluate their own progress (Cadorin *et al.*, 2017), a capacity that is shaped by students' prior learning experiences (Kemp *et al.*, 2024). For students in faculties of teacher training and education, this competence carries a double meaning: they must direct their own learning during their studies and, as future teachers, cultivate the same capacity in their pupils. Pre-service teachers who are not accustomed to managing their own learning are likely to find it difficult to foster self-directed learning among their students. This concern is particularly relevant in Indonesia, where students' literacy achievement in international assessments remains low and is shaped by both individual and school-level factors (Santi *et al.*, 2022, 2024). At the same time, students now learn in a highly digital environment that includes generative artificial intelligence (AI). A survey of more than 6,300 students in Germany found that almost two thirds had used AI-based tools in their studies (von Garrel & Mayer, 2023). This situation calls for digital literacy that covers technological, cognitive, and social skills (Tinmaz *et al.*, 2022) and extends to AI literacy, namely the ability to critically evaluate AI and use it as a tool (Long & Magerko, 2020); the use of generative AI for independent learning has also been associated with higher AI literacy (Zou *et al.*, 2026). Whether such competence actually supports independent learning, however, remains an open empirical question, because AI tools can either scaffold students' own regulation of learning or replace it. Three gaps remain in the literature. First, Indonesian studies are mostly bivariate, use small samples, or involve school students rather than pre-service teachers. Second, few studies have tested digital literacy, academic self-efficacy, and learning motivation simultaneously with learning engagement as a mediator of self-directed learning. Third, digital literacy is rarely measured with AI literacy included, even though AI tools have become part of students' everyday learning. Unlike previous studies that examined these factors separately or through bivariate correlations, this study tests digital literacy, including AI literacy, academic self-efficacy, and learning motivation simultaneously, with learning engagement as a mediator of self-directed learning among Indonesian pre-service teachers. It contributes in three ways: it (a) extends the measurement of digital literacy to AI literacy; (b) estimates the unique contribution of each personal resource while controlling for the others; and (c) identifies the type of mediation for each resource, which clarifies how the mechanisms proposed by Social Cognitive Theory and Self-Determination Theory operate in teacher education. Accordingly, this study examined the direct and indirect associations of digital literacy, academic self-efficacy, and learning motivation with self-directed learning through learning engagement. The theoretical framework and hypotheses are developed below.

2. Literature Review

2.1 Theoretical Framework

This study draws on Social Cognitive Theory (SCT) and Self-Determination Theory (SDT). SCT views learning as the product of reciprocal interactions among personal factors, behaviour, and the environment, in which self-efficacy beliefs determine how much effort students invest and how long they persist (Schunk & DiBenedetto, 2021); learners who believe in their capabilities set more challenging goals and regulate their own learning more actively (Pham Thi & Duong, 2024). Within this framework, digital literacy and academic self-efficacy are personal resources, namely the capability and the belief needed to use learning tools and opportunities; learning engagement is the behavioural expression of these resources; and self-directed learning is the self-regulatory outcome through which students plan, monitor, and evaluate their own learning. SDT adds a motivational explanation: autonomous motivation, which arises when learning is perceived as interesting or

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personally valuable, fosters engagement and persistence (Ryan & Deci, 2000). Combining the two theories, the three personal resources are expected to be associated with self-directed learning both directly and through students' active engagement in learning.

2.2 Hypotheses Development

1) Digital literacy
   Digital literacy, including AI literacy, enables students to locate, evaluate, and use learning resources without depending on lecturers. Indonesian studies have reported positive relationships between digital literacy and self-directed learning among university students (Aswan, 2023; Sanova *et al.*, 2022) and senior high school students (Riswan *et al.*, 2024), and students with good self-regulation benefit more from digital learning environments (Sutarni *et al.*, 2021). Students who use ChatGPT for self-directed learning report greater confidence in studying independently (Giray *et al.*, 2025), and among Indonesian university students digital literacy improves academic performance partly through self-efficacy and digital competence (Zakir *et al.*, 2025). Digital literacy has also been associated with learning engagement, partly through self-efficacy (Feng *et al.*, 2026), as digital skills strengthen students' academic confidence (Rehman *et al.*, 2024; Yuan *et al.*, 2024). However, self-reported digital skills may exceed actual proficiency (Calderón *et al.*, 2022), and among pre-service teachers digital readiness was only weakly related to online self-regulated learning (Fuchs *et al.*, 2022). Therefore: *H1: Digital literacy is positively associated with self-directed learning; H4: Digital literacy is positively associated with learning engagement.*
2) Academic self-efficacy
   Academic self-efficacy is students' belief in their capability to master course material and succeed academically. Self-efficacy predicts self-regulation in online learning (Zheng & Xiao, 2024), but Matook *et al.* (2024) found no effect on metacognitive skills, indicating that its direct link with self-directed learning is not consistent. In contrast, its relationship with engagement is well established (Baños *et al.*, 2023; Wang & Zhang, 2024), with a moderate pooled effect in a meta-analysis of 24 studies (Fatimah *et al.*, 2024), and teacher autonomy support increases engagement through self-efficacy and self-regulated learning (Miao & Ma, 2023). Therefore: *H2: Academic self-efficacy is positively associated with self-directed learning; H5: Academic self-efficacy is positively associated with learning engagement.*
3) Learning motivation
   According to SDT, autonomous motivation leads students to invest effort in learning and to take responsibility for it. Autonomous motivation is related to students' ability to manage and monitor their own learning (R. Zhao & Ling, 2022), learning motivation has been associated with the self-directed learning of Indonesian students (Riswan *et al.*, 2024), and motivation and self-efficacy are key drivers of self-directed learning in AI-enhanced environments (Wu *et al.*, 2024). Motivation is also a strong predictor of engagement (Y. Yang *et al.*, 2025), including in AI-assisted learning (Singh *et al.*, 2026). Therefore: *H3: Learning motivation is positively associated with self-directed learning; H6: Learning motivation is positively associated with learning engagement.*
4) Learning engagement as a mediator
   Learning engagement is a positive, fulfilling state characterised by vigour, dedication, and absorption (Schaufeli & Bakker, 2004), and in this study it also includes active participation in class. Engagement is positively correlated with self-directed learning ability (Zhang *et al.*, 2026) and closely related to self-regulated learning among Indonesian students (Normawati *et al.*, 2026), and self-directed learning skills are among the factors associated with online learning engagement (Hu & Xiao, 2025). Because both SCT and SDT regard engagement as the behavioural channel through which beliefs and motivation are translated into learning actions, engagement is expected to carry part of the associations of the three personal resources with self-directed learning. Therefore: *H7: Learning engagement is positively associated with self-directed learning; H8–H10: Learning engagement mediates the associations of digital literacy (H8), academic self-efficacy (H9), and learning motivation (H10) with self-directed learning.*

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3. Research Methodology

3.1 Research Design

This study employed a quantitative approach using an explanatory cross-sectional survey design. Data were collected from pre-service teachers at a single point in time through a structured questionnaire. The study examined the relationships among digital literacy, academic self-efficacy, learning motivation, learning engagement, and self-directed learning. Regression-based path analysis was used to examine the direct relationships among the variables through two regression equations. In addition, the indirect relationships were examined using a bootstrapping procedure to assess the mediating role of learning engagement. This design enabled the study to evaluate the proposed relationships and mediation model based on the collected survey data. Because the data are cross-sectional, all paths are interpreted as associations rather than causal effects.

3.2 Population and Sample

The population comprised 620 active students in semester 3 or above from five study programmes at the Faculty of Teacher Training and Education, Universitas Muhammadiyah Bogor Raya, in the 2026/2027 academic year. A census approach was used: the questionnaire link was distributed to all 620 students through the class leaders and lecturers of each study programme, and participation was voluntary. Because only part of the population responded, the final sample is a voluntary-response sample rather than a complete census, and possible non-response bias was therefore examined (Section 3.1.1). The minimum sample size, calculated with G*Power for multiple regression with four predictors, a medium effect size ($f^2 = 0.15$), $\alpha = 0.05$, and power of 0.95, was 129 respondents (Faul *et al.*, 2009). Of the 226 responses received (a response rate of 36.5%), 26 were excluded because the respondents failed the attention check (16), gave identical answers to all items (4), met both conditions (5), or came from a study programme outside the population (1), leaving 200 valid responses. These 200 responses were used for the measurement analyses (descriptive statistics, reliability, and confirmatory factor analysis). One further case was removed as an extreme, internally inconsistent outlier before the structural analysis (Section 3.1.1), so the path and mediation analyses were based on 199 respondents. The respondents came from Early Childhood Teacher Education (121), Educational Administration (41), Indonesian Language and Literature Education (19), English Education (16), and Science Education (3); because of these unequal numbers, no comparisons between study programmes were made.

3.3 Research Location

The study was conducted at the Faculty of Teacher Training and Education, Universitas Muhammadiyah Bogor Raya, a private university in Bogor, West Java, Indonesia. The faculty prepares prospective teachers and education personnel through five study programmes, making it a relevant setting for examining the self-directed learning of pre-service teachers in a context where digital and AI-based learning tools are increasingly used.

3.4 Instrumentation

The instrument was a 29-item questionnaire with a five-point Likert scale (1 = strongly disagree to 5 = strongly agree), plus one attention-check item. All five variables were treated as latent constructs (Table 1). The instrument was adapted in four steps. First, the dimensions and indicators of each construct were identified from established source scales (Table 1); for digital literacy, the technological, cognitive, and social dimensions were complemented by two AI literacy items on understanding the strengths and limitations of AI tools and on verifying AI-generated answers. Second, items were written directly in Indonesian on the basis of these indicators and adjusted to the context of teacher education, rather than translated literally from the source items. Third, content validity was assessed by three experts in curriculum evaluation, Indonesian language literacy, and English linguistics, who rated the relevance of each item on a four-point scale; items were retained when Aiken's $V \geq 0.667$ and every expert gave a score of at least 3 (Aiken, 1985). All

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29 items met this criterion, with V values ranging from 0.778 to 1.000 (mean V = 0.927). Two experts judged the instrument usable without revision and one judged it usable with minor revisions; their suggestions concerned the wording of a few items, namely clarifying the term "credibility" in the digital literacy items and specifying the learning obstacles and academic success referred to in the self-efficacy items. Fourth, because no separate pilot test was conducted, construct validity and reliability were examined on the main sample through confirmatory factor analysis (CFA), composite reliability, and Cronbach's alpha. A five-point format was retained to stay close to the source scales and to give respondents with a genuinely neutral position an appropriate option.

Table 1. Research variables and instruments

Variable	Indicators	Items	Adapted from
Digital literacy (X1)	Technological, cognitive, social, AI literacy	6	Long & Magerko (2020); Tinmaz *et al.* (2022)
Academic self-efficacy (X2)	Confidence in understanding material, completing tasks, and succeeding	5	Midgley *et al.* (2000)
Learning motivation (X3)	Intrinsic goal, extrinsic goal, task value	6	Pintrich *et al.* (1991)
Learning engagement (M)	Vigour, dedication, absorption, active participation	6	Schaufeli & Bakker (2004)
Self-directed learning (Y)	Awareness, strategy, activity, evaluation, interpersonal skills	6	Cadorin *et al.* (2017)

3.5 Data Collection Procedures

A preliminary observation of students' learning practices was conducted in September 2026, and the questionnaire data were collected online through Google Forms in October 2026. The first page explained the purpose of the study and requested informed consent; participation was voluntary, anonymous, and unrelated to course grades. Respondents who did not give consent were directed to end the questionnaire. An attention-check item asked respondents to select a specific option, and responses that failed this check or showed identical answers across all items were excluded before analysis.

3.6 Data Analysis

Construct validity was first examined through CFA of the five-factor measurement model using maximum likelihood estimation in JASP version 0.98.1 (JASP Team, 2026) (n = 200). Model fit was evaluated with χ^2/df (≤ 3), CFI and TLI (≥ 0.90), RMSEA (≤ 0.08), and SRMR (≤ 0.08) (Kline, 2023). Convergent validity was assessed through standardised loadings, composite reliability (CR ≥ 0.70), and average variance extracted (AVE ≥ 0.50, with lower values considered acceptable when CR exceeds 0.60), and discriminant validity through the heterotrait–monotrait ratio (HTMT < 0.85) (Hair *et al.*, 2022); reliability was also assessed with Cronbach's α (≥ 0.70) and item–total correlations ($r > 0.139$). Because regression-based path analysis processes observed variables, each construct was then represented by the mean of its items (composite score). Common method bias was examined using full collinearity VIF with a threshold of 3.3 (Kock, 2015) and by comparing the five-factor model with a single-factor model. Possible non-response bias was examined by comparing early and late respondents (the first and last quartiles of submission time), on the assumption that late respondents resemble non-respondents. Classical assumptions were tested through outlier detection (standardised residual $|z| > 3$), residual normality (Kolmogorov–Smirnov), multicollinearity (VIF < 10), and heteroscedasticity (Glejser test), and the structural results were re-estimated with all 200 cases as a sensitivity check. Direct paths (H1–H7) were tested with two regression equations, M = X1 + X2 + X3 and Y = X1 + X2 + X3 + M, and are reported

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as standardised coefficients (β) with standard errors and 95% confidence intervals. Indirect effects (H8–H10) were tested with the bootstrap method (5,000 resamples) using the PROCESS macro for SPSS (Model 4), with the other two predictors entered as covariates (Hayes, 2022); an indirect effect was significant when its 95% confidence interval excluded zero. Following X. Zhao *et al.* (2010), mediation was classified as indirect-only when only the indirect effect was significant, complementary when both the indirect and direct effects were significant and in the same direction, and direct-only (no mediation) when only the direct effect was significant. Regression and mediation analyses were performed in IBM SPSS Statistics. Because students were nested within five study programmes, the intraclass correlation coefficient (ICC) of each variable was computed from a one-way random-effects model, and study-programme dummy variables were added to both equations as a robustness check (Santi *et al.*, 2021).

3.7 Ethical Considerations

The study was a minimal-risk, anonymous online survey. The first page of the questionnaire explained the purpose of the study, stated that participation was voluntary, anonymous, and unrelated to course grades, and requested informed consent; respondents who declined were directed to end the questionnaire. No names, student numbers, or other identifying information were collected, and the data were stored securely and used only for research purposes. Because the first author is a lecturer in the faculty, the questionnaire link was distributed through class leaders and lecturers of each study programme, and respondents were informed that participation was anonymous and unrelated to course grades, so that declining to participate would have no consequences for them. The study did not undergo formal review by an institutional ethics committee. A certificate issued by the Dean of the Faculty of Teacher Training and Education (No. B.3-2349/KET/UMBR/XI/2026, dated 20 November 2026) confirms that the study was conducted in the faculty and that the faculty has no objection to the publication of the anonymised data.

4. Results and Discussion

4.1 Results

4.1.1 Respondent Profile, Descriptive Statistics, and Data Quality

A total of 200 valid respondents were included in the measurement analyses. Most were female (89.5%) and enrolled in semester 3 (50.5%). The largest proportion came from the Early Childhood Teacher Education programme (60.5%), followed by Educational Administration (20.5%), Indonesian Language and Literature Education (9.5%), English Education (8.0%), and Science Education (1.5%). Regarding the use of digital technology, 49.0% of respondents reported using AI-based tools for learning often or almost every day, while 61.5% spent approximately one to two hours per day studying independently. All 29 items had item–total correlations above the critical value, and Cronbach's α ranged from 0.778 to 0.860 (Table 2). In the CFA, the five-factor model with seven a priori residual covariances between items that share the same sub-indicator or behavioural content (for example, the two AI literacy items and the two task-value items) showed acceptable fit on most indices, $\chi^2(360) = 656.65$, $\chi^2/df = 1.82$, RMSEA = 0.064 (90% CI [0.056, 0.072]), and SRMR = 0.066, although CFI (0.879) and TLI (0.864) were slightly below 0.90. Standardised loadings ranged from 0.39 to 0.85; the lowest loading belonged to the absorption item on losing track of time while studying. CR values (0.76–0.87) exceeded 0.70, whereas AVE exceeded 0.50 only for academic self-efficacy (0.57) and ranged from 0.34 to 0.44 for the other constructs, which is acceptable given CR values above 0.60 but indicates moderate convergent validity. All HTMT values were below 0.85 (Table 3), supporting discriminant validity, although learning motivation and learning engagement were closely related (HTMT = 0.83; latent correlation = 0.91), and a model combining these two constructs did not fit significantly worse than the five-factor model ($\Delta\chi^2(4) = 9.00$, $p = .061$). This overlap is taken into account in interpreting H6 and

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H10. Learning motivation had the highest mean score (M = 4.25), indicating that respondents generally perceived their learning activities as important and relevant to their future professional roles. Academic self-efficacy and digital literacy also showed high mean scores, whereas learning engagement (M = 3.70) and self-directed learning (M = 3.62) had comparatively lower mean scores, although both remained within the high category. At the item level, respondents gave the highest rating to checking AI-generated answers before using them in assignments (M = 4.26). In contrast, searching for academic information using appropriate keywords and sources received a lower rating (M = 3.87). The lowest-rated items were recognising personal learning needs without lecturers' direction (M = 3.00), becoming fully absorbed in learning activities (M = 3.14), and studying for extended periods without becoming bored (M = 3.21). These descriptive findings indicate that, although respondents reported relatively high motivation and confidence, some aspects of independent learning and sustained engagement may still require attention.

Table 2. Descriptive statistics, reliability, and convergent validity (n = 200)

Variable	Mean	SD	Category	Item–total r	λ	α	CR	AVE
Digital literacy (X1)	4.04	0.51	High	0.629–0.790	0.53–0.74	0.792	0.787	0.381
Academic self-efficacy (X2)	4.14	0.55	High	0.756–0.845	0.67–0.85	0.860	0.866	0.566
Learning motivation (X3)	4.25	0.48	Very high	0.600–0.759	0.47–0.68	0.778	0.764	0.341
Learning engagement (M)	3.70	0.54	High	0.641–0.763	0.39–0.78	0.789	0.789	0.367
Self-directed learning (Y)	3.62	0.57	High	0.637–0.797	0.58–0.75	0.819	0.823	0.443

Table 3. Correlations between composite scores and heterotrait–monotrait ratios

Variable	X1	X2	X3	M	Y
Digital literacy (X1)	—	0.606	0.609	0.476	0.493
Academic self-efficacy (X2)	0.501	—	0.776	0.689	0.471
Learning motivation (X3)	0.487	0.618	—	0.826	0.643
Learning engagement (M)	0.413	0.577	0.654	—	0.695
Self-directed learning (Y)	0.461	0.473	0.582	0.584	—

Common method bias was unlikely to be a serious concern: full collinearity VIF values ranged from 1.50 to 2.28, below the threshold of 3.3, and a single-factor model fitted the data considerably worse than the five-factor model ($\chi^2(370) = 1012.77$, CFI = 0.738, RMSEA = 0.093; $\Delta\chi^2(10) = 356.12$, $p < .001$). Early respondents (the first quartile by submission time, n = 49) and late respondents (the last quartile, n = 49) did not differ significantly on any of the five variables (all $p > .36$; $|d| \leq 0.18$), suggesting that non-response bias was limited, although it cannot be ruled out entirely. Casewise diagnostics identified one extreme case with a standardised residual of −6.18, far beyond the ±3 criterion. This respondent gave the lowest possible score (1) to all six self-directed learning items while giving the highest possible scores to the academic self-efficacy and learning motivation items. Such a pattern is internally inconsistent, as the same respondent reported high confidence and motivation yet complete dependence on lecturers, and it is more plausibly explained by careless responding on one block of the questionnaire than by a genuine extreme position; the case was therefore excluded from the structural analysis (n = 199). To check that this decision did not drive the results, all models were re-estimated with the full sample of 200. Every hypothesis decision remained unchanged: the indirect associations of academic self-efficacy ($\beta = 0.091$, 95% CI [0.037, 0.157]) and learning motivation ($\beta = 0.164$, 95% CI [0.067, 0.279]) remained significant, that of digital literacy remained non-significant ($\beta = 0.021$, 95% CI [−0.027, 0.068]), and the main difference was a lower explained variance in self-directed learning ($R^2 = 0.371$), as expected when a

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case with a very large residual is retained. With 199 cases, the residuals of both equations were normally distributed (Kolmogorov–Smirnov: D = 0.046, p = .200 and D = 0.063, p = .054), the highest VIF was 2.15, and the Glejser test showed no significant predictor (all p > .30), so the regression assumptions were met. ICC values ranged from −0.035 to 0.028 (M = 0.028; Y = 0.010), differences between study programmes were not significant for any variable (all p > .12), and adding study-programme dummy variables did not change any hypothesis decision; therefore, single-level path analysis was considered adequate.

4.1.2 Path Analysis and Direct Effects

The standardised path coefficients are presented in Table 4 and Figure 1. The three predictors jointly explained 47.8% of the variance in learning engagement, and the four predictors explained 43.9% of the variance in self-directed learning. Five of the seven direct-path hypotheses were supported. Digital literacy (H1; β = 0.184, 95% CI [0.057, 0.311]), learning motivation (H3; β = 0.265, 95% CI [0.110, 0.421]), and learning engagement (H7; β = 0.314, 95% CI [0.167, 0.460]) were positively associated with self-directed learning, and academic self-efficacy (H5; β = 0.261, 95% CI [0.126, 0.397]) and learning motivation (H6; β = 0.465, 95% CI [0.331, 0.600]) were positively associated with learning engagement. The confidence intervals for academic self-efficacy → self-directed learning (H2) and digital literacy → learning engagement (H4) included zero, so these two hypotheses were not supported. The strongest path was from learning motivation to learning engagement; given the close relationship between these two constructs in the CFA, this coefficient should be interpreted with caution.

Table 4. Standardised path coefficients and direct-path hypothesis testing (n = 199)

H	Path	β	SE	95% CI	t	p	Decision
H1	Digital literacy → Self-directed learning	0.184	0.065	[0.057, 0.311]	2.848	.005	Supported
H2	Academic self-efficacy → Self-directed learning	0.035	0.074	[−0.111, 0.182]	0.478	.633	Not supported
H3	Learning motivation → Self-directed learning	0.265	0.079	[0.110, 0.421]	3.364	< .001	Supported
H4	Digital literacy → Learning engagement	0.056	0.062	[−0.067, 0.178]	0.898	.370	Not supported
H5	Academic self-efficacy → Learning engagement	0.261	0.069	[0.126, 0.397]	3.797	< .001	Supported
H6	Learning motivation → Learning engagement	0.465	0.068	[0.331, 0.600]	6.821	< .001	Supported
H7	Learning engagement → Self-directed learning	0.314	0.074	[0.167, 0.460]	4.214	< .001	Supported

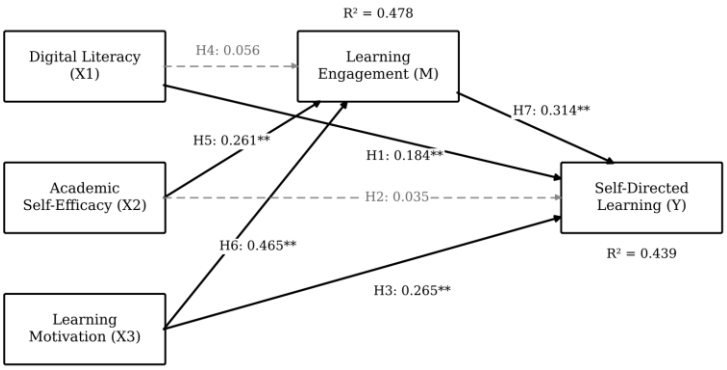


Figure 1. Path model with standardised coefficients (n = 199)

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Figure 1 summarises the structural model. Solid arrows denote significant paths and dashed grey arrows denote non-significant paths (H2 and H4); the values on the arrows are the standardised coefficients from Table 4, and the R^2 values show the proportion of variance explained in learning engagement and self-directed learning. The figure shows two routes to self-directed learning: a direct route from digital literacy and learning motivation, and an indirect route in which academic self-efficacy and learning motivation are linked to self-directed learning through learning engagement.

4.1.3 Mediation Analysis

Table 5 presents the mediation results as completely standardised effects, so that the direct effects are identical to the path coefficients in Table 4. The indirect association of digital literacy through learning engagement was not significant (β = 0.017, 95% CI [−0.027, 0.059]), whereas its direct association was significant; following X. Zhao *et al.* (2010), this is direct-only non-mediation (H8 not supported). Academic self-efficacy showed a significant indirect association (β = 0.082, 95% CI [0.033, 0.140]) but no significant direct association, which is indirect-only mediation (H9 supported). Learning motivation showed both a significant indirect association (β = 0.146, 95% CI [0.059, 0.250]) and a significant direct association in the same direction, which is complementary mediation (H10 supported); about 35.5% of its total association with self-directed learning was transmitted through learning engagement. The total association of academic self-efficacy was not significant (β = 0.117, p = .117), whereas its indirect association was, which illustrates that a significant total effect is not a precondition for mediation (X. Zhao *et al.*, 2010).

Table 5. Mediation analysis with completely standardised effects (bootstrap, 5,000 resamples; n = 199)

H	Path	Total effect	Direct effect	Indirect effect	Boot SE	95% CI (indirect)	Mediation type
H8	X1 → M → Y	0.201**	0.184**	0.017	0.021	[−0.027, 0.059]	Direct-only (no mediation)
H9	X2 → M → Y	0.117	0.035	0.082	0.027	[0.033, 0.140]	Indirect-only
H10	X3 → M → Y	0.411**	0.265**	0.146	0.050	[0.059, 0.250]	Complementary

4.2 Discussion

Digital literacy was directly associated with self-directed learning, consistent with previous studies reporting positive relationships between the two (Aswan, 2023; Riswan *et al.*, 2024; Sanova *et al.*, 2022). Students who can operate learning technologies, judge the credibility of information, and verify AI-generated answers are likely to be better equipped to find and process learning resources without depending on lecturers, in line with the finding that self-regulated students make better use of digital learning environments (Sutarni *et al.*, 2021). Contrary to H4, however, digital literacy was not associated with learning engagement once academic self-efficacy and learning motivation were controlled for. This differs from Feng *et al.* (2026), who reported a positive association, but the comparison is not direct: Feng *et al.* examined digital literacy as the sole predictor with sequential mediators, whereas in the present model digital literacy shared considerable variance with self-efficacy and motivation (r = 0.50 and 0.49), while its zero-order correlation with engagement was moderate (r = 0.41; Table 3). The non-significant path therefore indicates that digital literacy has little unique association with engagement beyond the other two resources, not that it is unrelated to engagement. A similarly weak link between digital readiness and online self-regulated learning has been reported among pre-service teachers (Fuchs *et al.*, 2022). Two further explanations are possible but could not be tested in this study and should be treated as hypotheses for future research: digital skills may function mainly as tools for searching, filtering, and checking information rather than as sources of enthusiasm for learning, and self-reported digital literacy may

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overestimate actual competence (Calderón *et al.*, 2022). The descriptive results are consistent with the first explanation, as students reported checking AI-generated answers frequently but rated their skill in searching for academic information with appropriate keywords and sources lower. Academic self-efficacy was not directly associated with self-directed learning but was associated with learning engagement, through which its association with self-directed learning was transmitted (indirect-only mediation). This pattern may help reconcile previous inconsistent results, in which self-efficacy predicted self-regulation in some studies (Zheng & Xiao, 2024) but not metacognitive skills in others (Matook *et al.*, 2024). Confidence alone may not make students independent learners; it appears to matter when it is accompanied by effort and persistence in learning activities. This interpretation is consistent with Social Cognitive Theory, which holds that self-beliefs shape effort and persistence (Pham Thi & Duong, 2024), with meta-analytic evidence of a moderate association between self-efficacy and engagement (Fatimah *et al.*, 2024), and with studies in which self-efficacy channels other personal resources into engagement (Baños *et al.*, 2023; Feng *et al.*, 2026; Singh *et al.*, 2026; Wang & Zhang, 2024). Because self-efficacy was substantially correlated with motivation ($r = 0.62$), its non-significant direct path should be read as a lack of unique association after motivation is controlled for, rather than as evidence that self-efficacy is irrelevant. The combination of a non-significant total association and a significant indirect association also shows that the role of self-efficacy would have been overlooked if only its total or direct association had been examined. Learning motivation was associated with self-directed learning both directly and indirectly through engagement, and its path to engagement was the strongest in the model. This is consistent with Self-Determination Theory, which states that autonomous motivation fosters engagement and persistence (Ryan & Deci, 2000), and with studies reporting strong associations between motivation and engagement (Singh *et al.*, 2026; Y. Yang *et al.*, 2025). The direct association with self-directed learning is in line with findings that autonomous motivation is related to students' ability to manage and monitor their own learning (Riswan *et al.*, 2024; R. Zhao & Ling, 2022) and that learning motivation is a key driver of self-directed learning in AI-enhanced environments (Wu *et al.*, 2024).

Two cautions apply. First, motivation and engagement were very highly correlated at the latent level (0.91), and a model combining them did not fit significantly worse than the five-factor model; part of the strong motivation–engagement path may therefore reflect conceptual and measurement overlap, since both constructs capture students' willingness to invest effort in learning. Second, the association was weaker than the very strong effect reported by Y. Yang *et al.* (2025) in a self-directed e-learning context, possibly because the present model controlled for self-efficacy and digital literacy simultaneously and involved face-to-face learners in teacher education. The descriptive data suggest that students' motivation rests mainly on task value, that is, the belief that course content is important and useful for their future profession. Learning engagement was positively associated with self-directed learning and served as the channel through which self-efficacy and motivation were linked to it. This is consistent with the positive association between engagement and self-directed learning ability reported by Zhang *et al.* (2026) and with the close relationship between self-regulated learning and engagement among Indonesian students (Normawati *et al.*, 2026). The direction of this relationship, however, cannot be established with cross-sectional data. Zhang *et al.* (2026) modelled self-directed learning ability as a predictor of engagement, and self-directed learning skills are also listed among the antecedents of online engagement (Hu & Xiao, 2025), whereas the present model, guided by SCT and SDT, specified the opposite direction. Both directions are theoretically plausible, and the two variables are probably linked reciprocally: engaged students practise setting goals and evaluating their learning, while students who already direct their own learning engage more deeply. The mediation results should therefore be read as consistent with, rather than as proof of, the proposed mechanism. The relatively low scores for absorption, endurance in studying, and recognising learning needs without the lecturer's direction indicate the aspects that most need attention. In addition, the model explained less than half of the variance in self-directed learning, suggesting that other factors, such as lecturer autonomy support, peer support, and the learning environment emphasised in Social Cognitive Theory, also play a role (Miao & Ma, 2023; Pham Thi & Duong, 2024), as may personal

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regulatory capacities such as self-control (Y.-D. Yang *et al.*, 2024). Taken together, the results point to differentiated routes to self-directed learning rather than a single pathway. Digital literacy appeared as an instrumental resource directly associated with independent learning, academic self-efficacy as a belief linked to self-directed learning only through engagement, and learning motivation as a resource linked through both routes. This differentiation may explain why bivariate studies often report positive correlations for all three variables, as also observed in Table 3, while a simultaneous model shows that their unique contributions differ. It also suggests, pending longitudinal or experimental confirmation, that interventions targeting only one resource, such as confidence-building programmes without changes in learning activities, may bring limited benefits for self-directed learning. Theoretically, the findings extend models of self-directed learning based on SCT and SDT in two ways. They identify learning engagement as the main channel linking personal resources to self-directed learning, particularly for academic self-efficacy, whose association depends entirely on engagement, and they show that resources which correlate well in bivariate analyses make distinct unique contributions when examined together, which argues for testing them simultaneously rather than separately. The inclusion of AI literacy also broadens the digital literacy construct to the current learning environment. Practically, lecturers should design learning that not only builds confidence and motivation but also actively involves students, for example through discussions, projects, and challenging tasks relevant to the teaching profession. Digital and AI literacy programmes remain important because they are directly associated with self-directed learning, especially in training students to find appropriate sources and evaluate information critically.

From an educational management perspective, the findings offer a basis for managing student learning at the faculty level. Learning engagement and self-directed learning can be included as indicators in the internal quality assurance system and monitored each semester through brief student surveys alongside academic performance. Study programmes can use these indicators to evaluate whether curricula and teaching methods encourage active participation, and academic advisors can use them to identify students who remain dependent on lecturers' direction, since pre-service teachers differ considerably in their self-regulated learning profiles and need differentiated support (Barz *et al.*, 2024). Professional development for lecturers should emphasise student-centred strategies that promote engagement, while digital and AI literacy should be integrated into courses rather than offered only as separate technical training; institutional digital support has been shown to improve students' digital literacy partly by strengthening their self-efficacy (Yan & Hu, 2025). Such decisions are consistent with the view that engagement is shaped by both individual and contextual factors and can be strengthened through institutional design (Hu & Xiao, 2025; Normawati *et al.*, 2026). This study has several limitations. First, although all students in the population were invited, only 36.5% responded, so the sample is a voluntary-response sample; respondents were dominated by Early Childhood Teacher Education and Educational Administration students, and Science Education was represented by only three students. The early–late comparison did not indicate non-response bias, but this test is indirect, and the findings should be generalised with caution beyond the respondents and the faculty studied. Second, the cross-sectional design does not permit causal or temporal conclusions: all paths are associations, the mediation results are consistent with but do not prove the proposed mechanism, and reverse or reciprocal relationships, particularly between engagement and self-directed learning, cannot be excluded. Third, all variables were self-reported in a single questionnaire, so common method variance cannot be ruled out entirely despite the diagnostic tests, and self-reported digital literacy may exceed actual proficiency (Calderón *et al.*, 2022). Fourth, the measurement model showed only moderate convergent validity (AVE below 0.50 for four constructs and CFI and TLI slightly below 0.90), learning motivation and learning engagement overlapped strongly, and the instrument was not pilot-tested on a separate sample. Fifth, the structural analysis used composite scores, so measurement error was not modelled and the path coefficients may be attenuated. Finally, the first author teaches in the faculty; although participation was anonymous and the questionnaire was distributed through class leaders and lecturers, socially desirable responding cannot be fully

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excluded, and the small number of study programmes did not allow programme-level random effects to be modelled. Future research should use probability or quota sampling across several institutions to obtain higher response rates and proportional representation of study programmes, and should adopt longitudinal (for example, cross-lagged panel) or experimental designs to test the direction of the relationships, especially between engagement and self-directed learning. Such data would also allow multilevel and multivariate mixed models that treat learning engagement and self-directed learning as joint outcomes with random effects at the student and institutional levels (Santi *et al.*, 2022, 2026). The instrument should be refined, particularly by sharpening the distinction between motivation and engagement items and strengthening weakly loading items, and tested for measurement invariance across groups; latent structural equation modelling can then account for measurement error. Performance-based measures of digital and AI literacy would help distinguish perceived from actual competence, and contextual factors such as lecturer autonomy support and peer interaction may be examined as antecedents or moderators of learning engagement among pre-service teachers.

5. Conclusion

This study examined how digital literacy (including AI literacy), academic self-efficacy, and learning motivation are associated with the self-directed learning of pre-service teachers and whether learning engagement mediates these associations. The three resources were linked to self-directed learning through different routes: digital literacy directly, academic self-efficacy only through learning engagement (indirect-only mediation), and learning motivation both directly and through engagement (complementary mediation). The main contribution of the study is evidence that, when personal resources are examined simultaneously, learning engagement is the channel through which beliefs and motivation are linked to independent learning, whereas digital and AI literacy act as a direct, instrumental resource. For practice, the findings suggest several concrete steps. Lecturers can include at least one engagement-oriented activity in each course, such as project-based tasks, structured discussions, or micro-teaching linked to the teaching profession, and ask students to set and review their own learning goals during the semester. Study programmes can embed critical digital and AI literacy into existing courses, for example by requiring students to report the sources they used and how they verified AI-generated content in their assignments. At the faculty level, short engagement and self-directed learning scales can be added to the semester learning evaluation within the internal quality assurance system, and academic advisors can use the results to support students who still depend heavily on lecturers' direction. Because the data are cross-sectional, self-reported, and drawn from a voluntary-response sample at one faculty, these conclusions describe associations rather than causal effects; they should be confirmed through longitudinal, multi-institutional studies using latent variable modelling and performance-based measures of digital and AI literacy.

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