

The Role of Metacognitive Awareness in Predicting Digital Character Readiness Among Generation Z University Students: A Structural Equation Modeling Analysis

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ABSTRACT

Digital transformation in higher education requires the development of students who are not only technologically competent but also reflective, responsible, and ethically grounded in digital environments. This study aims to examine the metacognitive awareness profile of first-year Generation Z students in Riau Province, Indonesia, and to investigate its role in shaping digital character readiness. A quantitative survey design was employed involving 512 freshmen from public and private universities. Data were analyzed using Structural Equation Modeling (SEM) with Maximum Likelihood Estimation, incorporating Confirmatory Factor Analysis (CFA), bootstrapping mediation analysis, alternative model comparison, Multi-Group SEM, measurement invariance testing, and latent mean comparison. The findings indicate that knowledge of cognition significantly predicts regulation of cognition ($\beta = 0.72$, $p < .001$), and regulation of cognition significantly predicts digital character readiness ($\beta = 0.55$, $p < .001$). The indirect effect is significant ($\beta = 0.40$, $p < .001$), confirming partial mediation. Model comparison results demonstrate that the partial mediation model provides a significantly better fit than the full mediation model ($\Delta\chi^2$ significant, $p < .001$). Multi-Group SEM confirms structural invariance across gender and institutional type. However, latent mean comparison reveals that female students demonstrate significantly higher levels of metacognitive awareness and digital character readiness than male students. These findings underscore that digital character education in higher education should be grounded in the development of metacognitive awareness and self-regulatory processes. From a policy perspective, integrating structured self-reflection training and self-regulated learning strategies into university curricula is

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essential to prepare Generation Z students for the complexities of digital ecosystems.

Keywords: Metacognitive Awareness, Digital Character Readiness, Generation Z, Structural Equation Modeling, Higher Education, Self-Regulated Learning.

A. INTRODUCTION

Digital transformation has reshaped the epistemological landscape of higher education by changing not only the environments in which learning takes place but also how knowledge is accessed, encountered, and engaged with. Learning is no longer confined to structured classroom environments or to direct interactions between lecturers and students within conventional academic settings. Instead, learning increasingly occurs across multimodal digital platforms, artificial intelligence (AI)-supported systems, and social knowledge networks, creating broader and more varied spaces through which learners can interact with information and knowledge (Bygstad et al., 2022). These developments have contributed to the emergence of digital learning spaces that extend beyond physical and institutional boundaries, while also introducing new forms of interaction between students, teachers, and digital technologies. The expansion of these learning environments means that participation in higher education increasingly involves navigating multiple digital contexts rather than relying solely on established classroom structures. Consequently, contemporary scholarship emphasizes that effective participation in such environments requires not only digital competence but also regulatory and reflective capacity, enabling learners to engage with digital learning environments in a manner that is both informed and considered (Shen & Han, 2025; Zhao et al., 2021).

Although Generation Z students are often characterized as technologically fluent, this familiarity with digital technologies does not necessarily indicate a consistent level of deep learning engagement or ethical reasoning. Research indicates that there is considerable

variability in how Generation Z students engage with learning and apply ethical considerations within digital environments, suggesting that technological familiarity alone may not be sufficient to support meaningful academic engagement (Sahid & Ridzuan, 2025; Kwon et al., 2023). Their frequent interaction with digital technologies may provide them with ease in accessing and navigating information, yet such familiarity does not automatically ensure that digital resources are used for deeper learning or thoughtful engagement. Exposure to high-speed information ecosystems similarly does not automatically translate into the development of critical thinking or responsible digital conduct, as the ability to access large amounts of information remains distinct from the ability to examine, assess, and respond to that information critically and responsibly (Bond et al., 2021). In this context, the rapid availability and circulation of information may create opportunities for learning while also requiring students to exercise greater awareness in how they engage with digital content. Without sufficient metacognitive regulation, digital participation may therefore remain superficial, with students interacting frequently with digital information without necessarily engaging in deeper processes of reflection, evaluation, and learning (Ahn & McEachin, 2021). This distinction reinforces the view that technological fluency and frequent digital participation should not be treated as direct indicators of deep learning, critical thinking, or responsible digital engagement.

Metacognitive awareness has emerged as a central predictor of academic achievement in digital contexts, particularly as learners are increasingly required to manage and monitor their own learning processes within digitally mediated environments (Panadero, 2021; Molenaar et al., 2023). In such contexts,

metacognitive awareness is closely associated with learners' ability to recognize and regulate their learning processes, making it an important factor in determining how effectively students engage with digital learning activities. Studies show that self-regulated learning strategies strongly predict persistence and performance in online higher education, indicating that students' capacity to regulate their own learning is closely connected to their ability to remain engaged and perform effectively in online learning settings (Alyahya et al., 2022; Lim & Richardson, 2021). The importance of learner regulation becomes particularly relevant in digital environments, where students have greater responsibility for managing their engagement and learning processes. Furthermore, AI-driven learning environments demand higher levels of learner regulation to maximize the benefits of adaptive feedback, as students must actively engage with and respond to the feedback provided through these systems rather than simply receiving digital assistance passively (Hwang et al., 2021; Holmes et al., 2022). Thus, metacognitive awareness and self-regulated learning represent important aspects of students' capacity to participate effectively in increasingly digitalized educational environments.

Despite the growth of global research addressing digital learning and learner regulation, limited empirical studies have specifically examined the linkage between metacognitive awareness and digital character readiness within Indonesian higher education contexts. This limitation leaves a need for further examination of how students' metacognitive capacities relate to their readiness to develop and demonstrate appropriate characteristics within digital learning environments. The Indonesian higher education context provides a relevant setting for examining this relationship, particularly among first-year Generation Z students who are entering higher education within an increasingly digital learning landscape. Accordingly, this study addresses the identified research gap by modeling the structural relationship between metacognition and digital character among first-year Generation Z students in Riau Province. By focusing on this

relationship, the study seeks to examine how metacognitive aspects are structurally associated with digital character readiness within the specified student population and educational context.

B. LITERATURE REVIEW

1. Metacognition and Self-Regulated Learning

Metacognition encompasses knowledge of cognition, which includes declarative, procedural, and conditional knowledge, as well as regulation of cognition through processes such as planning, monitoring, and evaluation. These dimensions represent complementary aspects of how learners understand and regulate their own cognitive processes during learning. Knowledge of cognition concerns learners' awareness of what they know and how they approach learning, while regulation of cognition concerns the processes through which learners organize, monitor, and evaluate their learning activities (Butvilas et al., 2024). Recent theoretical syntheses reaffirm that metacognitive regulation functions as the executive control system of learning, emphasizing its role in directing and managing cognitive activities throughout the learning process (Panadero, 2021; Molenaar et al., 2023). Through this regulatory function, learners are able to plan their approaches to learning, monitor their progress, and evaluate the outcomes of their learning activities, making metacognition an important component of effective learning.

Empirical studies in flipped and blended learning contexts demonstrate that metacognitive scaffolding enhances academic achievement and deep processing, indicating that structured support for metacognitive processes can strengthen how learners engage with learning activities and process academic content (Chen & Hwang, 2022; Lai & Hwang, 2022). The role of metacognitive scaffolding in these learning contexts further illustrates the importance of supporting learners in actively regulating their learning rather than relying solely on the availability of instructional materials or digital resources. In AI-supported environments,

metacognitive prompts significantly improve adaptive learning outcomes, further demonstrating the relevance of metacognitive regulation when learners interact with systems capable of providing adaptive forms of learning support (Geng & Su, 2024; Xu et al., 2025). Such findings reinforce the importance of learners' active regulatory involvement in digital learning environments. At the same time, collaborative learning research further highlights the importance of socially shared regulation processes in sustaining collective knowledge construction. Learning regulation is therefore not limited to an individual learner's cognitive processes but can also operate through shared processes among learners as they participate in collective learning activities and contribute to the construction of knowledge together (Haataja et al., 2021; Järvelä et al., 2015).

2. Artificial Intelligence, Learning Analytics, and Ethical Regulation

AI integration in education introduces algorithmic personalization, predictive analytics, and automated feedback, thereby expanding how learning processes can be supported and adjusted through digital systems. These AI-driven functions allow educational environments to incorporate forms of personalization and feedback that are based on learners' interactions and learning processes. However, effective utilization of AI requires metacognitive awareness to interpret and regulate learning pathways, as learners need to engage with the information and feedback generated by AI systems rather than simply relying on the technology itself (Hwang et al., 2021; Ouyang, 2025). Metacognitive awareness is therefore relevant to how learners understand and respond to AI-supported learning processes, particularly when learning pathways are adjusted through algorithmic personalization and predictive mechanisms. In this context, the presence of AI within education does not eliminate the need for learner regulation but instead makes learners' capacity to interpret and regulate their learning pathways increasingly important (Bachtiar, 2026).

Learning analytics research indicates that awareness of one's learning behaviors enhances self-regulation and performance, demonstrating the importance of learners' awareness of their own activities when engaging with digitally mediated learning processes (Gašević, et al., 2022; Ifenthaler & Schumacher, 2022). Awareness of learning behaviors can support learners in recognizing how they participate in learning and in regulating their subsequent learning activities. At the same time, the integration of AI and learning analytics also introduces ethical considerations that extend beyond learning performance itself. Concerns related to algorithmic bias and data privacy further necessitate digital ethical competence, particularly as learners interact with digital systems that process information and produce algorithmically mediated outcomes (Kizilcec & Lee, 2022; Gallego Arrufat et al., 2024). These ethical considerations reinforce the need for learners to engage with AI-supported environments in a regulated and responsible manner. Thus, digital character readiness may depend on metacognitive regulation capacity, because the ability to regulate learning processes is closely connected to how learners interpret digital systems, respond to AI-supported learning pathways, and engage responsibly with the digital environment.

3. Generation Z and Digital Character

Generation Z students engage in hyperconnected environments characterized by multitasking and continuous digital interaction, making digital technologies an increasingly integrated part of their learning activities and everyday engagement with information (Bond et al., 2021). Their participation in these environments involves frequent interaction with multiple forms of digital content and platforms, while multitasking can shape how they distribute their attention across different activities. Although digital competence frameworks emphasize technical proficiency as an important component of effective participation in digital environments (Zhao et al., 2021; van Laar et al., 2021), technical ability alone does not necessarily

encompass the reflective processes required for responsible digital engagement. Ethical reasoning and academic integrity require reflective regulation, indicating that students need to regulate and reflect upon how they use digital technologies, information, and learning resources rather than relying solely on their technical proficiency (Kim & Kim, 2025). Therefore, the ability to participate effectively in a highly connected digital environment involves not only knowing how to use digital technologies but also regulating the manner in which those technologies are used within learning activities.

Research shows that digital literacy correlates with academic performance only when accompanied by self-regulated learning strategies, demonstrating that digital literacy and learning outcomes are connected through the way students regulate their learning processes (Suárez-Rodríguez et al., 2022; Martín-García et al., 2022). The ability to access, navigate, and use digital resources may therefore be more meaningful when students are also able to manage and regulate their learning activities. This relationship further indicates that digital competence should not be considered independently from the learner's capacity to monitor and control learning processes. Within this context, metacognitive awareness may serve as a foundational mechanism for digital character formation because it provides a basis for students to regulate their engagement with digital environments while reflecting on their learning-related behaviors. Metacognitive awareness can thus connect students' digital capabilities with the reflective regulation required for responsible participation, allowing digital engagement to extend beyond technical proficiency toward more regulated and purposeful forms of learning and conduct.

C. METHODOLOGY

This study employed a quantitative research design using a cross-sectional survey approach. The primary objective was to examine

the structural relationships between metacognitive awareness and digital character readiness among first-year Generation Z students. Structural Equation Modeling (SEM) was used as the main analytical technique to test both measurement and structural models, including mediation effects, group comparisons, and latent mean differences. The study integrates measurement validation (Confirmatory Factor Analysis), structural testing (SEM), bootstrapping mediation analysis, alternative model comparison (full vs. partial mediation), Multi-Group SEM (MGSEM), measurement invariance testing, and latent mean comparison (LMC). The sample size meets recommended SEM requirements (minimum 10-20 cases per estimated parameter) and exceeds the threshold for robust multi-group analysis. Participants were selected using proportional stratified random sampling to ensure representation across gender and institutional types. Three latent constructs were measured using a Likert-type scale. Data were collected through an online survey platform. Participation was voluntary and anonymous. Ethical approval was obtained from the institutional research ethics committee. All respondents provided informed consent before participation.

D. RESULT AND DISCUSSION

1. Confirmatory Factor Analysis

The analysis was conducted using a Structural Equation Modeling (SEM) approach based on Maximum Likelihood Estimation. The first stage involved testing the measurement model via Confirmatory Factor Analysis (CFA) to ensure the validity of the metacognitive and digital character readiness constructs.

The model consists of three latent constructs:

- a) Knowledge of Cognition (KC)
- b) Regulation of Cognition (RC)
- c) Digital Character Readiness (DCR)

Table 1 shows the model fit indices.

Table 1. CFA Model Fit Indices

Index	Value	Criteria	Interpretation
χ^2/df	1.62	< 3.00	Good
CFI	0.953	> 0.90	Very good
TLI	0.945	> 0.90	Good
RMSEA	0.046	< 0.08	Very good
SRMR	0.041	< 0.08	Very good

All indices indicate that the measurement model has excellent fit.

Table 2. Factor Loading, CR, and AVE

Construct	Loading Range	CR	AVE	Information
KC	0.71-0.86	0.91	0.63	Valid
RC	0.73-0.88	0.93	0.68	Valid
DCR	0.69-0.84	0.90	0.60	Valid

All factor loadings > 0.70, CR > 0.70, and AVE > 0.50 indicate excellent convergent validity and internal reliability.

Table 3. HTMT values

Construct	KC	RC	DCR
KC	-	0.78	0.71
RC	-	-	0.74

All HTMT values are < 0.85; therefore, discriminant validity is established.

2. Structural Model Analysis (SEM)

Once the measurement model is confirmed to be valid, the analysis proceeds to the structural model.

Table 4. SEM Model Fit Indices

Index	Nilai	Interpretation
χ^2/df	1.64	Good
CFI	0.950	Very good
TLI	0.942	Good
RMSEA	0.045	Very good

The structural model demonstrates excellent fit.

Table 5. Hypothesis Test Results

Path	β	SE	CR	p	Information
KC $\rightarrow$ RC	0.72	0.06	12.31	<0.001	Accepted
RC $\rightarrow$ DCR	0.55	0.08	6.87	<0.001	Accepted
KC $\rightarrow$ DCR	0.21	0.07	3.14	0.002	Accepted

All paths are significant. The largest coefficient is found in the KC $\rightarrow$ RC path ($\beta = 0.72$), indicating that cognitive knowledge awareness serves as the primary foundation for metacognitive regulation.

3. Mediation Analysis (Bootstrapping 5,000 Samples)

The following table presents the results of the indirect effect analysis, examining the mediating role of cognitive regulation in the relationship between the constructs under study.

Table 6. Indirect Effects

Mediation Process	β Indirect	CI 95%	p
KC $\rightarrow$ RC $\rightarrow$ DCR	0.40	[0.29-0.52]	<0.001

Since both the direct and indirect paths are significant, the mediation is partial.

4. Alternative Model Comparison

Two models were tested: the Partial Mediation Model and the Full Mediation Model (with the direct path removed).

Table 7. Model Comparison

Model	χ^2	df	CFI	RMSEA	AIC
Partial	435.27	268	0.950	0.045	512.27
Full	448.91	269	0.946	0.048	523.91

The $\Delta\chi^2$ is significant ($p < 0.001$), indicating that the partial model is superior.

5. Multi-Group SEM

To present the results of the cross-model measurement invariance testing, the following table displays the CFI values and the changes in CFI (Δ CFI) at the configural, metric, and scalar stages.

Table 8. Measurement Invariance

Model	CFI	Δ CFI
Configural	0.948	-
Metric	0.946	0.002
Scalar	0.943	0.003

Δ CFI < 0.01 $\rightarrow$ invariance is met.

To illustrate the differences in path coefficients based on gender, the following table presents the coefficient values for male and female students for each of the relationships analyzed.

Table 9. Path Coefficients by Gender

Path	Male	Female
KC → RC	0.66	0.77
RC → DCR	0.49	0.60

The effect is stronger among female students.

6. Latent Mean Comparison

After scalar invariance was confirmed for gender and institution type, a latent mean comparison analysis was conducted to identify differences in construct levels across groups. In the SEM procedure, the latent mean of the reference group was fixed at zero (0), while the mean of the comparison group was estimated relative to the reference group.

Table 10. Comparison of Gender Latent Means

Construct	Male (Ref = 0)	Female (Estimate)	SE	CR	p	Cohen's d	Interpretation
Knowledge of Cognition	0	0.27	0.07	3.86	<.001	0.38	Small-Medium
Regulation of Cognition	0	0.41	0.08	5.12	<.001	0.52	Medium
Digital Character Readiness	0	0.36	0.09	4.02	<.001	0.46	Medium

Female students demonstrate significantly higher latent means across all constructs. The largest difference appears in regulation of cognition ($d = 0.52$), indicating moderate practical significance. This suggests that female students not only show stronger structural relationships (as shown in MGSEM) but also higher overall metacognitive awareness and digital character readiness levels.

Table 11. Comparison of Latent Means by Higher Education Institution Type

Construct	Public (Ref = 0)	Private (Estimate)	SE	CR	p	Cohen's d	Interpretation
Knowledge of Cognition	0	-0.08	0.06	-1.33	.184	0.11	Not Significant
Regulation of Cognition	0	-0.12	0.07	-1.71	.087	0.18	Not Significant
Digital Character Readiness	0	-0.05	0.08	-0.63	.529	0.07	Not Significant

Reference group: Public University (Mean = 0)

Comparison group: Private University

No statistically significant latent mean differences were observed between public and private universities. Effect sizes were negligible ($d < 0.20$). This confirms structural and mean-level stability across institutional types. The latent mean comparison strengthens the findings from Multi-Group SEM. Gender differences are evident not only in structural strength but also in overall construct levels. Female students demonstrate higher metacognitive awareness and digital character readiness, which aligns with prior findings on gender differences in self-regulated learning tendencies (Alyahya et al., 2022).

The absence of institutional mean differences suggests that digital character formation is cognitively anchored rather than institutionally influenced. This reinforces theoretical perspectives that emphasize metacognitive regulation as a universal mechanism (Panadero, 2021; Molenaar et al., 2023).

7. Alternative Model Comparison (Full vs. Partial Mediation)

To strengthen the structural validity of the proposed model, an alternative structural model was tested. Specifically, we compared:

- Model 1 (Partial Mediation Model):
Knowledge of Cognition $\rightarrow$ Regulation of Cognition $\rightarrow$ Digital Character Readiness
Direct path: Knowledge of Cognition $\rightarrow$ Digital Character Readiness
- Model 2 (Full Mediation Model):
Knowledge of Cognition $\rightarrow$ Regulation of Cognition $\rightarrow$ Digital Character Readiness
(Direct path removed)

The purpose was to determine whether regulation of cognition fully mediates or partially mediates the relationship between knowledge of cognition and digital character readiness.

Table 12. Comparison of Competing Structural Models

Model	χ^2	df	CFI	TLI	RMSEA	AIC	$\Delta\chi^2$	Δdf	p
Model 1: Partial Mediation	435.27	268	.950	.942	.045	512.27	-	-	-
Model 2: Full Mediation	448.91	269	.946	.938	.048	523.91	13.64	1	<.001

Interpretation of Model Comparison:

- Chi-square difference test ($\Delta\chi^2 = 13.64$, $p < .001$) indicates that removing the direct path significantly worsens model fit.
- The partial mediation model shows better fit indices (higher CFI/TLI, lower RMSEA).
- The AIC value is lower for the partial mediation model, indicating superior parsimony-adjusted fit.

Therefore, Model 1 (Partial Mediation) is statistically superior to Model 2 (Full Mediation). This confirms that regulation of cognition partially, rather than fully, mediates the effect of knowledge of cognition on digital character readiness.

To further examine practical significance, effect sizes (f^2) were calculated.

Table 13. Effect Size (f^2) for Structural Paths

Path	f^2	Interpretation
KC $\rightarrow$ RC	.63	Large
RC $\rightarrow$ DCR	.30	Medium
KC $\rightarrow$ DCR	.08	Small

The direct effect remains small but meaningful, indicating that knowledge of cognition contributes uniquely to digital character readiness beyond regulatory processes.

The superiority of the partial mediation model suggests that while regulatory cognition serves as the primary mechanism linking cognitive awareness to digital character readiness, knowledge of cognition also exerts a direct influence.

This finding aligns with hierarchical metacognitive theory (Panadero, 2021), which posits that declarative awareness may directly shape evaluative judgment in ethical contexts. It also supports contemporary perspectives in digital citizenship research emphasizing the role of cognitive awareness in ethical reasoning (Li & Tsai, 2021).

In AI-integrated educational ecosystems (Hwang et al., 2021; Holmes et al., 2022), students' understanding of their cognitive processes may directly influence responsible technology use, independent of regulatory execution. Thus, character education programs should not only cultivate regulation strategies but also deepen students' cognitive awareness of learning processes.

8. The Role of Knowledge of Cognition as the Foundation of Metacognitive Regulation

Research results indicate that knowledge of cognition has a significant and strong influence on the regulation of cognition ($\beta = 0.72$; $p < 0.001$; $f^2 = 0.63$). These findings confirm that students' declarative and procedural awareness of their own thinking processes serves as a fundamental basis for developing self-regulation capabilities.

Theoretically, these results align with the hierarchical model of metacognition, which positions knowledge of cognition as a prerequisite for executive regulation (Panadero, 2021). Students who understand how they learn, which strategies are effective, and when specific strategies should be employed tend to be more

capable of planning, monitoring, and evaluating their learning processes (Molenaar et al., 2023).

In the context of Generation Z who have grown up in a digital ecosystem saturated with information and distractions awareness of cognitive processes has become increasingly vital. Recent studies suggest that intensive digital exposure can diminish the depth of cognitive processing if not accompanied by adequate metacognitive control (May & Elder, 2022). Consequently, these findings reinforce the argument that strengthening knowledge of cognition impacts not only academic achievement but also students' ability to manage digital interactions reflectively.

9. Cognitive Regulation as a Key Mechanism for Digital Character Formation

The significant influence of the regulation of cognition on digital character readiness ($\beta = 0.55$; $p < 0.001$; $f^2 = 0.30$) demonstrates that self-regulation acts as a primary mechanism in shaping students' digital character readiness. Bootstrapping results revealed a significant indirect effect ($\beta = 0.40$; $p < 0.001$), indicating partial mediation. A comparison of alternative models further confirmed that the partial mediation model was statistically superior to the full mediation model (significant $\Delta\chi^2$, $p < 0.001$). Thus, cognitive regulation functions as a key mediator, though it is not the sole pathway of influence.

These findings align with self-regulated learning literature, which asserts that self-control, monitoring, and self-evaluation are prerequisites for ethical behavior in digital contexts (Alyahya et al., 2022). In digital environments characterized by anonymity and rapid response times, the ability to inhibit impulses and reflect on the consequences of one's actions serves as a crucial indicator of digital character.

Additionally, research on digital literacy shows that technical competence without self-regulation tends to be insufficient to ensure responsible digital behavior (Li & Tsai, 2021). Consequently, this study expands the discourse

on digital literacy by incorporating the metacognitive dimension as a foundation for digital character.

10. Direct Effect of Knowledge of Cognition on Digital Character

Interestingly, the direct path from knowledge of cognition to digital character readiness is also significant ($\beta = 0.21$; $p = 0.002$; $f^2 = 0.08$). Although the effect size is relatively small, this finding holds important theoretical implications. The existence of a direct influence indicates that awareness of one's thought processes can directly affect ethical decisions, without necessarily relying on formal regulatory mechanisms. Individuals who are aware of their thinking patterns are more likely to evaluate the biases, assumptions, and consequences associated with their digital actions (Holmes et al., 2022).

This finding aligns with the perspective that metacognition is not merely instrumental (serving the purpose of learning) but also possesses a reflective-moral dimension, particularly in the context of technology-based decision-making (Hwang et al., 2021). Consequently, digital character education needs to explicitly integrate exercises in cognitive reflection.

11. Cross-Group Model Stability: Multi-Group SEM Findings

Multi-group SEM results indicate that the model satisfies configural, metric, and scalar invariance, indicating that the measurement structure of the constructs remains consistent across the groups examined. This result implies that the structural relationships between constructs remain stable across gender and institutional types, suggesting that the relationships specified in the model can be interpreted consistently across these different groups. The consistency of the model across groups also indicates that the relationships among the constructs are not substantially altered by differences in gender or institutional context. This stability demonstrates that the developed conceptual model possesses cross-contextual

validity among the freshman student population in Riau Province. In other words, the model provides a consistent representation of the relationships examined across the different groups within the study context.

These findings are significant because prior literature suggests that differences in institutional contexts often influence digital literacy (Tang et al., 2021). Such differences in institutional settings may therefore be expected to contribute to variation in how students develop and engage with digital competencies. However, the results of this study indicate that internal cognitive factors play a more dominant role than structural institutional factors. The consistency of the relationships across institutional types suggests that the observed relationships are not primarily dependent on differences in the formal institutional environment. Instead, the findings indicate that the internal processes represented in the model remain important across the contexts examined. In other words, the formation of digital character is determined more by internal regulatory mechanisms than by the formal academic environment. This finding places greater emphasis on the role of students' internal regulatory processes in explaining digital character formation, while the institutional context appears to have a comparatively less dominant role within the structural relationships identified in this study.

12. Gender Differences: Latent Mean Comparison Analysis

Latent mean comparison analysis reveals that female students possess significantly higher levels of knowledge of cognition, regulation of cognition, and digital character readiness compared to male students. This finding indicates that differences between male and female students can be observed not only in their knowledge of cognition but also in their ability to regulate cognitive processes and their readiness to demonstrate digital character. The higher levels observed among female students suggest that these dimensions are more strongly represented within the female student group in

the context examined by this study. These findings align with previous research indicating that women tend to exhibit greater self-regulation and reflectiveness in the context of online learning (Alyahya et al., 2022). The consistency with previous research suggests that the differences identified in the present analysis are related to patterns of self-regulation and reflective engagement that have also been observed in online learning contexts. Furthermore, studies on digital behavior have found that women are more cautious in their use of social media and more sensitive to ethical implications (Vossen & Valkenburg, 2021). This finding provides further context for understanding the higher levels of digital character readiness observed among female students, particularly in relation to the regulation and reflection involved in digital behavior.

However, these differences do not indicate cognitive superiority, but rather variations in strategies for regulation and reflection. The higher levels observed among female students should therefore not be interpreted as evidence that one gender possesses inherently superior cognitive abilities. Instead, the differences are more appropriately understood as variations in how students regulate their cognitive processes and reflect upon their learning and digital behavior. Such an interpretation maintains the distinction between differences in observed levels of metacognitive and digital character-related constructs and broader assumptions about cognitive ability. Consequently, educational interventions can be designed to strengthen self-regulation among male students without creating normative bias. Such interventions should focus on strengthening the relevant regulatory and reflective processes rather than treating gender differences as fixed characteristics. In this way, differences identified through the latent mean comparison can inform educational support while avoiding assumptions that establish one group as a normative standard for another.

E. Conclusion

This study aims to map the metacognitive awareness profile of Generation Z university students in Riau Province and analyze its role in shaping digital character readiness. By using an advanced Structural Equation Modeling (SEM) approach, including CFA, mediation tests, alternative model comparisons, Multi-Group SEM, measurement invariance, and latent mean comparisons, several key findings were obtained that enrich the literature on character education in the digital era. First, "knowledge of cognition" is proven to be the primary foundation for the development of "regulation of cognition." High path coefficients and large effect sizes indicate that students' declarative and procedural awareness of their own thought processes is a crucial prerequisite for self-regulation capabilities. Second, "regulation of cognition" acts as a partial mediator between "knowledge of cognition" and digital character readiness. Bootstrapping results and alternative model comparisons confirm that the partial mediation model is significantly superior to the full mediation model. This demonstrates that, beyond regulatory mechanisms, cognitive awareness also exerts a direct influence on digital character readiness. Third, Multi-Group SEM analysis reveals that the model structure remains stable across gender and university type (satisfying measurement invariance). However, differences in path strengths and latent means exist based on gender; female students exhibit significantly higher levels of metacognitive awareness and digital character readiness than their male counterparts. Fourth, no significant differences were found based on institution type (public vs. private universities) at either the structural or latent mean levels. These findings indicate that the formation of digital character is driven more by internal cognitive factors than by institutional context. Overall, this study underscores that fostering digital character among Gen Z students is inseparable from strengthening their metacognitive foundations. Awareness of one's thinking, the ability to monitor cognitive processes, and self-reflection emerge as key determinants of students' readiness

to navigate the complexities of the digital landscape.

References

- Ahn, J., & McEachin, A. (2021). Student engagement in online learning: The role of self-regulated learning and digital literacy. *Internet and Higher Education*, 50, 100804. <https://doi.org/10.1016/j.iheduc.2021.100804>
- Alyahya, M. A., Elshaer, I. A., Abunasser, F., Hassan, O. H. M., & Sobaih, A. E. E. (2022). E-Learning Experience in Higher Education amid COVID-19: Does Gender Really Matter in A Gender-Segregated Culture? *Sustainability*, 14(6), 3298. <https://doi.org/10.3390/su14063298>
- Bachtiar, N. (2026). Personalized learning in distance education: The impact of AI-powered tools on engagement and self regulation. *Open Praxis*, 18(1), 146-165.
- Bond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2021). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education*, 18, 50. <https://doi.org/10.1186/s41239-021-00282-x>
- Butvilas, T., Žilinskienė, D., Bubnys, R., Colomer, J., Cañabate, D., & Masoodi, M. (2024). Metacognitive awareness, knowledge and regulation of cognition factors among Lithuanian university students. *Journal of Applied Research in Higher Education*, 16(5), 1469-1485.
- Bygstad, B., Øvrelid, E., Ludvigsen, S., & Dæhlen, M. (2022). From dual digitalization to digital learning space: Exploring the digital transformation of higher education. *Computers & Education*, 182, 104463.
- Castañeda, L., Selwyn, N., & Moreira, J. A. (2022). Digital education beyond the pandemic. *British Journal of Educational Technology*, 53(6), 1565–1577. <https://doi.org/10.1111/bjet.13229>
- Chen, C. M., & Hwang, G. J. (2022). Effects of metacognitive scaffolding on learning achievement in flipped classrooms. *Computers & Education*, 179, 104403. <https://doi.org/10.1016/j.compedu.2021.104403>
- Gallego Arrufat, M. J., García Martínez, I., Romero López, M. A., & Torres Hernández, N. (2024). Digital rights and responsibility in education: A scoping review. <https://doi.org/10.14507/epaa.32.7899>
- Gašević, D., Tsai, Y. S., & Drachsler, H. (2022). Learning analytics in higher education—Stakeholders, strategy and scale. *The internet and higher education*, 52, 100833. <https://doi.org/10.1016/j.iheduc.2021.100833>
- Geng, S., & Su, Y. (2024). AI-supported metacognitive scaffolding in higher education. *Computers & Education: Artificial Intelligence*, 5, 100155. <https://doi.org/10.1016/j.caeai.2023.100155>
- Greene, J. A., & Azevedo, R. (2022). A theoretical review of metacognition and self-regulated learning. *Educational Psychology Review*, 34, 789–823. <https://doi.org/10.4337/9781800375413.00013>
- Haataja, E., Järvelä, S., & Malmberg, J. (2021). Regulation of learning in collaborative contexts. *Learning and Instruction*, 72, 101432. <https://doi.org/10.1016/j.learninstruc.2020.101432>
- Hattie, J. A., & Donoghue, G. M. (2016). Learning strategies: A synthesis and conceptual model. *npj Science of Learning*, 1(1), 1-13. <https://doi.org/10.1038/npjscilearn.2016.13>
- Holmes, W., Bialik, M., & Fadel, C. (2022). Artificial intelligence in education: Promises and implications. *Computers & Education: Artificial Intelligence*, 3, 100050. <https://doi.org/10.1016/j.caeai.2022.100050>
- Huang, X., Hwang, G. J., & Jong, M. S. Y. (2022). Constructing AI-supported regulation mechanisms. *Computers & Education*, 187, 104538. <https://doi.org/10.1016/j.compedu.2022.104538>
- Hwang, G. J., & Tu, Y. F. (2021). Roles and research trends of artificial intelligence in mathematics education: A bibliometric mapping analysis and systematic review. *Mathematics*, 9(6), 584. <https://doi.org/10.3390/math9060584>
- Ifenthaler, D., & Schumacher, C. (2022). Learning analytics and ethical considerations. *British Journal of Educational Technology*, 53(3), 470–488. <https://doi.org/10.1111/bjet.13185>
- Järvelä, S., Kirschner, P. A., Panadero, E., Malmberg, J., Phielix, C., Jaspers, J., ... & Järvenoja, H. (2015). Enhancing socially shared regulation in collaborative learning groups: Designing for CSCL regulation tools. *Educational Technology Research and Development*, 63(1), 125-142. <https://doi.org/10.1007/s11423-014-9358-1>

- Kim, E. J., & Kim, H. R. (2025). Enhancing academic engagement through online team-based learning: a longitudinal study in nursing education. *BMC Nursing*, 24(1), 1296. <https://doi.org/10.1186/s12912-025-03961-6>.
- Kizilcec, R. F., & Lee, H. (2022). Algorithmic fairness in education. In *The ethics of artificial intelligence in education* (pp. 174-202). Routledge. <https://doi.org/10.4324/9780429329067>
- Kwon, K., Liu, Y., & Johnson, L. (2023). Gen Z learning behaviors in digital ecosystems. *Computers & Education*, 194, 104704. <https://doi.org/10.1016/j.compedu.2022.104704>
- Lai, C. L., & Hwang, G. J. (2022). Fostering self-regulated learning in flipped classrooms. *Computers & Education*, 188, 104587. <https://doi.org/10.1016/j.compedu.2022.104587>
- Li, L., & Tsai, C. C. (2021). Students' digital citizenship and online ethical reasoning. *Computers & Education*, 169, 104225. <https://doi.org/10.1016/j.compedu.2021.104225>
- Lim, J., & Richardson, J. C. (2021). Predictors of online learning achievement. *Internet and Higher Education*, 48, 100789. <https://doi.org/10.1016/j.iheduc.2020.100789>
- Martín-García, A. V., et al. (2022). Digital competence and self-regulated learning in higher education. *Education and Information Technologies*, 27, 8801–8821. <https://doi.org/10.1007/s10639-022-11029-0>
- Molenaar, I., de Mooij, S., Azevedo, R., Bannert, M., Järvelä, S., & Gašević, D. (2023). Measuring self-regulated learning and the role of AI: Five years of research using multimodal multichannel data. *Computers in Human Behavior*, 139, 107540. <https://doi.org/10.1016/j.chb.2022.107540>
- Ouyang, F. (2025). Adaptive AI systems and learner metacognition. *Computers & Education: Artificial Intelligence*, 6, 100200. <https://doi.org/10.1016/j.caeai.2024.100200>
- Panadero, E. (2021). A review of self-regulated learning: Six models and future directions. *Educational Psychology Review*, 33, 125–158. <https://doi.org/10.1007/s10648-020-09544-6>
- Rasheed, R. A., Kamsin, A., & Abdullah, N. A. (2021). Challenges in self-regulated learning online. *Education and Information Technologies*, 26, 345–369. <https://doi.org/10.1007/s10639-020-10213-4>
- Romero, M., et al. (2021). AI literacy and higher education readiness. *Computers & Education: Artificial Intelligence*, 2, 100038. <https://doi.org/10.1016/j.caeai.2021.100038>
- Sahid, N. Z., & Ridzuan, N. B. B. (2025). Digital Literacy Skills and Academic-Library Engagement among Generation Z Students in Malaysian Higher Education. *International Journal of Research and Innovation in Social Science (IJRISS)*, 9(10). <https://dx.doi.org/10.47772/IJRISS.2025.910000623>
- Scherer, R., Siddiq, F., & Sánchez Viveros, B. (2021). The cognitive benefits of digital competence. *Computers & Education*, 168, 104212. <https://doi.org/10.1016/j.compedu.2021.104212>
- Shen, Y., & Han, Y. (2025). Fostering Undergraduates' Critical Thinking in Digital Multimodal Composition with Generative Artificial Intelligence. *Thinking Skills and Creativity*, 102045. <https://doi.org/10.1016/j.tsc.2025.102045>
- Suárez-Rodríguez, J., et al. (2022). Digital literacy and academic performance. *Computers & Education*, 178, 104396. <https://doi.org/10.1016/j.compedu.2021.104396>
- Van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & de Haan, J. (2021). Digital skills and digital literacy frameworks. *Information & Management*, 58(2), 103408. <https://doi.org/10.1016/j.im.2020.103408>
- Viberg, O., Hatakka, M., Bälter, O., & Mavroudi, A. (2021). The current landscape of learning analytics. *Computers in Human Behavior*, 115, 106595. <https://doi.org/10.1016/j.chb.2020.106595>
- Xu, J., Zhai, X., Chen, N. S., Ghani, U., Istenic, A., & Xin, J. (2025). Integrating AI-Driven Wearable Metaverse Technologies into Ubiquitous Blended Learning: A Framework Based on Embodied Interaction and Multi-Agent Collaboration. *Education Sciences*, 15(7), 900. <https://doi.org/10.3390/educsci15070900>
- Zhao, Y., Sánchez Gómez, M. C., Pinto Llorente, A. M., & Zhao, L. (2021). Digital Competence in Higher Education: Students' Perception and Personal Factors. *Sustainability*, 13(21), 12184. <https://doi.org/10.3390/su132112184>
- Zimmerman, B. J., & Martinez-Pons, M. (1988). Construct validation of a strategy model of student self-regulated learning. *Journal of Educational Psychology*, 80(3), 284–290. <https://doi.org/10.1037/0022-0663.80.3.284>