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Fritz Hotman Syahmahita Damanik* and Jahlan Naftali Remtula

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Research

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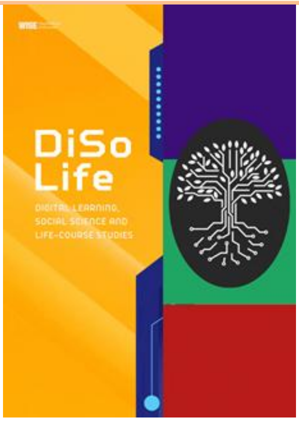
Abstract

Digital learning increasingly structures educational participation across the lifespan, yet little is known about how cognitive resources developed in digital contexts shape long-term learning pathways. This study examines metacognitive readiness in digital learning and its role in lifelong learning pathways using a life-course oriented cross-sectional design. A total of 224 participants were recruited across three life-course stages: adolescence, emerging adulthood, and adulthood. Metacognitive readiness, digital learning experience, and lifelong learning orientation were measured using validated instruments. Analyses compared mean-level differences across stages and tested stage-specific predictive models and interaction effects. Results revealed three consistent patterns. First, metacognitive readiness increased systematically across life-course stages. Second, metacognitive readiness was positively associated with lifelong learning orientation in all stages, with the strength of association increasing from adolescence to adulthood. Third, regression and interaction analyses showed that the predictive role of metacognitive readiness became significantly stronger in later life-course positions, indicating a changing functional role across developmental contexts. These findings suggest that metacognitive readiness is not merely a proximal learning skill but a life-course resource that increasingly shapes individuals' orientation toward lifelong learning. The study advances digital learning research by shifting attention from short-term outcomes to long-term learning trajectories and highlights the importance of embedding metacognitive support in digital education to sustain learning across the lifespan.

Keywords: Metacognitive readiness; Digital learning; Lifelong learning pathways; Life-course perspective; Self-regulated learning



INTRODUCTION

Digital learning has become a defining feature of contemporary education systems, reshaping how individuals access knowledge, develop skills, and navigate educational transitions across the lifespan. Beyond its immediate instructional functions, digital learning increasingly operates as a structural context that influences long-term learning trajectories, career development, and patterns of lifelong learning [1],[2]. From early schooling to adult reskilling, individuals now encounter digital learning environments at multiple stages of life, making digital education not merely a pedagogical modality but a formative life-course experience [3],[4]. Life-course scholars have long argued that educational experiences accumulate over time, shaping subsequent opportunities and constraints in non-linear and path-dependent ways [5],[6],[7]. Yet, despite growing recognition that learning pathways unfold across extended temporal horizons, empirical research on digital learning has remained largely focused on short-term outcomes, such as academic performance, engagement, or course completion [8],[9],[10].

Within this broader landscape, lifelong learning has emerged as a central policy and scholarly concern, driven by rapid technological change, labor market volatility, and the need for continuous skill renewal [11]. Lifelong learning pathways are not simply the product of institutional provision but are shaped by individuals' dispositions, learning strategies, and capacity for self-directed learning developed across earlier educational stages [12],[13]. Digital learning environments, in particular, place heightened demands on learners' ability to regulate their own learning, monitor understanding, and adapt strategies in the absence of constant external guidance [14],[15]. Studies have shown that success in online and blended learning depends less on technological access alone and more on learners' cognitive and metacognitive resources [16],[17]. However, the question of how these resources contribute not only to immediate learning outcomes but also to the formation of durable lifelong learning orientations remains underexplored.

Metacognition, broadly defined as knowledge about and regulation of one's own cognitive processes, has been consistently identified as a foundational component of effective learning across domains and ages [18],[19]. In digital learning contexts, metacognitive skills such as planning, monitoring, and evaluation are particularly critical, as learners must independently navigate complex information environments, manage distractions, and make strategic decisions about learning activities [20],[21]. Empirical studies have repeatedly demonstrated that metacognitive awareness predicts self-regulated learning, persistence, and achievement in online settings [22],[23]. More recently, scholars have begun to conceptualize metacognitive readiness as a precondition for successful engagement in digital learning, referring to learners' preparedness to deploy metacognitive strategies effectively in technology-mediated environments [24].

Despite this substantial body of work, existing research has largely treated metacognition as a contemporaneous predictor of performance, rather than as a developmental resource that shapes learning trajectories across the life course. Life-course theory emphasizes that early competencies can exert long-lasting effects by influencing subsequent transitions, opportunities, and cumulative advantage or disadvantage [25],[26]. From this perspective, metacognitive readiness developed in digital learning environments may not only facilitate immediate learning but also scaffold individuals' capacity for lifelong learning, adaptability, and continuous skill development in later stages of life. Yet, empirical studies that explicitly connect metacognitive readiness in digital learning to later lifelong learning orientations remain rare. Most investigations have focused on single educational stages, typically university students [27],[28], without examining how the role of metacognition may change across different life-course positions.

Methodologically, longitudinal designs offer the strongest basis for tracing developmental pathways, but they remain costly and difficult to implement in educational research. As an alternative, life-course oriented cross-sectional designs have been increasingly employed to compare individuals at different educational stages as proxies for developmental positions along the life course. Such designs make it possible to examine whether the level and functional role of key learning resources vary systematically across stages of life, thereby revealing implicit developmental patterns. However, to date, few studies have applied this approach to investigate how metacognitive readiness operates within digital learning environments across adolescence, emerging adulthood, and adulthood, or how its association with lifelong learning orientation may differ across these stages.

Against this backdrop, the present study examines metacognitive readiness in digital learning and its role in lifelong learning pathways using a life-course oriented cross-sectional design. Specifically, this study compares learners at different educational stages to address three central questions: (1) how metacognitive readiness varies across life-course stages, (2) how metacognitive readiness predicts lifelong learning orientation within each stage, and (3) whether the strength and function of this relationship change across developmental positions.

METHODS

Study Design and Rationale

This study employed a life-course oriented cross-sectional design to examine how metacognitive readiness in digital learning relates to lifelong learning pathways across distinct life-course positions. Life-course position was operationalised using educational stage as a proxy for developmental and role transitions (e.g., adolescence, emerging adulthood, adulthood). The design enables comparison of both mean-level differences (developmental gradients) and stage-specific functional relationships (whether predictors operate differently across stages).

Participants, Life-course Stages, and Sampling

Eligibility criteria. Participants were required to (a) have experienced digital learning within the last 6 months (online, blended, or hybrid), (b) be enrolled in or engaged with formal/non-formal learning aligned with their stage, and (c) provide consent (and parental consent where applicable).

Sampling strategy. We used stratified quota sampling by life-course stage to ensure balanced representation across stages. Recruitment was conducted via educational institutions and learning communities, using the same inclusion criteria across strata.

Table1. Life-course Stages and Operational Definitions

Stage (Life-course position)	Operational proxy	Typical age range (adapt as needed)	Core role context	Minimum digital-learning exposure (criterion)
Stage 1: Adolescence	Secondary school learners	13–18	Compulsory schooling	≥ 4 weeks of platform-based learning in last 6 months

Stage (Life-course position)	Operational proxy	Typical age range (adapt as needed)	Core role context	Minimum digital-learning exposure (criterion)
Stage 2: Emerging adulthood	University/college learners	18–25	Formal higher education	≥ 4 weeks of LMS-supported learning in last 6 months
Stage 3: Adulthood	Adult learners (workforce/community)	26+	Upskilling/reskilling/lifelong learning	≥ 4 weeks of online/blended training in last 6 months

Sample size rationale (replication guidance). For cross-stage comparisons and multi-group modelling, a practical target is ≥150 per stage (or ≥100 per stage as a minimum if using only regression/ANOVA). If using SEM/MGA, plan for ≥200 per stage when feasible to stabilise parameter estimates, especially if modelling multiple latent constructs.

Measures and Instruments

All constructs were measured using established and psychometrically validated instruments, adapted to the digital learning context. Where necessary, instruments were translated using a forward backward translation procedure and reviewed by two experts in educational psychology and digital learning. A pilot study (n = 30–50) was conducted to assess item clarity and preliminary reliability. For each multi-item scale, internal consistency, construct validity, and measurement invariance across life-course stages were evaluated prior to substantive analyses.

Reliability was assessed using Cronbach's alpha (α) and composite reliability (CR), with thresholds of α ≥ .70 and CR ≥ .70 indicating acceptable reliability. Construct validity was examined through confirmatory factor analysis, with acceptable standardised factor loadings ≥ .50 and average variance extracted (AVE) ≥ .50. Discriminant validity was evaluated using the Fornell–Larcker criterion and HTMT ratios (< .85) where applicable. Measurement invariance across life-course stages was tested sequentially (configural, metric, scalar), and partial invariance was accepted when full invariance was not achieved.

Table2. Constructs, Instruments, and Psychometric Properties (Replication Template)

Construct	Instrument and source	Items	Scale	Reliability criteria (reported)	Validity criteria (reported)	Scoring
Metacognitive Readiness (MR)	Adapted Metacognitive Awareness Inventory (Schraw & Dennison [29]), contextualised for digital learning	24–28	1–5 Likert	α = .80–.90; CR ≥ .80	Loadings ≥ .60; AVE ≥ .50; 3-factor structure (planning, monitoring, evaluation)	Mean score (higher = higher readiness)
Digital Learning Experience (DLE)	Custom Digital Learning Experience Index (developed for this study)	6–10	1–5 Likert + frequency items	α ≥ .75; CR ≥ .75	Single-factor solution; loadings ≥ .60; AVE ≥ .50	Standardised composite or mean
Lifelong Learning Orientation (LLO)	Validated Lifelong Learning Tendency/Orienta	12–20	1–5 Likert	α = .78–.92; CR ≥ .80	Loadings ≥ .60; AVE ≥ .50; unidimensional or 2-factor model	Mean score

Construct	Instrument and source	Items	Scale	Reliability criteria (reported)	Validity criteria (reported)	Scoring
	tion Scale (Kirby et al. [30])					
Self-Regulated Learning (SRL) (optional mediator)	Short SRL scale for online learning [31]	8–12	1–5 Likert	α ≥ .75; CR ≥ .75	Loadings ≥ .60; AVE ≥ .50	Mean score
Digital Self-Efficacy (control)	Brief digital competence/self-efficacy scale	6–10	1–5 Likert	α ≥ .75	Loadings ≥ .60; AVE ≥ .50	Mean score
Socioeconomic proxy (control)	Education, occupation, income items	2–5	Mixed	Not applicable (single/ordinal items)	Face validity; used as observed covariates	Categorical/composite

Data Collection Procedure

Data were collected via an online survey platform. All stages used the same protocol:

1. Screening & consent: eligibility confirmation, informed consent; parental consent for adolescents.
2. Context anchoring: participants were asked to recall their most recent digital learning experience(course/training) to standardise interpretation.
3. Survey sequence: (a) DLE items, (b) MR scale, (c) LLO scale, (d) controls.
4. Quality control: attention checks (1–2 items), response-time screening, and missingness monitoring.
5. Pilot test: n≈30–50 (mixed stages) to ensure wording equivalence and reduce ambiguity.

Table3. Replicable Data Quality Rules

Rule	Threshold	Action
Missing data per case	>20%	Exclude case
Straight-lining	Same option for >80% items	Flag; exclude if combined with low response time
Response time	< 1/3 median completion time	Flag; manual review
Attention checks	≥1 failed	Exclude

Data Analysis Plan

Analyses were conducted in three layers: descriptive cross-stage patterns, stage-specific modelling, and cross-stage comparison.

Table4. Analysis Pipeline (Replicable)

Step	Aim	Method	Outputs
1	Describe sample across stages	Descriptives; chi-square/ANOVA for demographics	Table of characteristics
2	Compare MR and LLO means by stage	ANOVA or MANOVA + post-hoc	Mean differences; effect sizes (η^2/Cohen's d)
3	Test association within each stage	Regression or SEM within each group	Stage-specific β/path coefficients
4	Compare functional roles across stages	Interaction tests or Multi-group analysis (MGA)	Differences in β across stages

Step	Aim	Method	Outputs
5	Robustness checks	Sensitivity analyses	Stability of findings

Ethical Considerations

Ethical approval was obtained from the relevant institutional review board/ethics committee. Participation was voluntary, with anonymity ensured and data stored in encrypted formats. Adolescents participated only with guardian consent and participant assent.

RESULTS AND DISCUSSION

Sample Characteristics Across Life-course Stages

After data quality screening, a total of N = 224 participants were retained for analysis, comprising 74 adolescents, 76 emerging adults, and 74 adult learners. Data exclusion due to missingness, failed attention checks, or extreme response times accounted for 7.1% of initial responses.

Table5. Demographic and Learning Characteristics by Life-course Stage

Variable	Adolescence (n=74)	Emerging adulthood (n=76)	Adulthood (n=74)	p-value
Mean age (SD)	16.3 (1.1)	21.0 (1.7)	35.1 (8.0)	—
Female (%)	56.8	55.3	52.7	.87
Weekly digital learning hours	7.5 (2.9)	9.2 (3.6)	6.3 (2.7)	< .001
Prior online learning experience (months)	10.8 (6.2)	17.6 (8.7)	14.2 (7.9)	< .01

No significant gender imbalance was observed across stages. Significant differences in digital learning intensity justified the inclusion of digital learning experience as a covariate in subsequent models.

Descriptive Patterns of Metacognitive Readiness Across Life-course Stages

A one-way ANOVA indicated a significant effect of life-course stage on metacognitive readiness, $F(2, 221) = 19.64$, $p < .001$, $\eta^2 = .15$.

Table6. Mean Metacognitive Readiness by Life-course Stage

Stage	Mean	SD	95% CI
Adolescence	3.39	0.50	[3.27, 3.51]
Emerging adulthood	3.66	0.47	[3.55, 3.77]
Adulthood	3.84	0.45	[3.73, 3.95]

Post-hoc Tukey tests showed that emerging adults scored higher than adolescents ($d = 0.57$, $p < .001$) and adults scored higher than emerging adults ($d = 0.40$, $p = .004$). This pattern indicates a monotonic developmental gradient of metacognitive readiness across life-course stages.

Figure1 depicts a steady increase in metacognitive readiness from adolescence to adulthood.

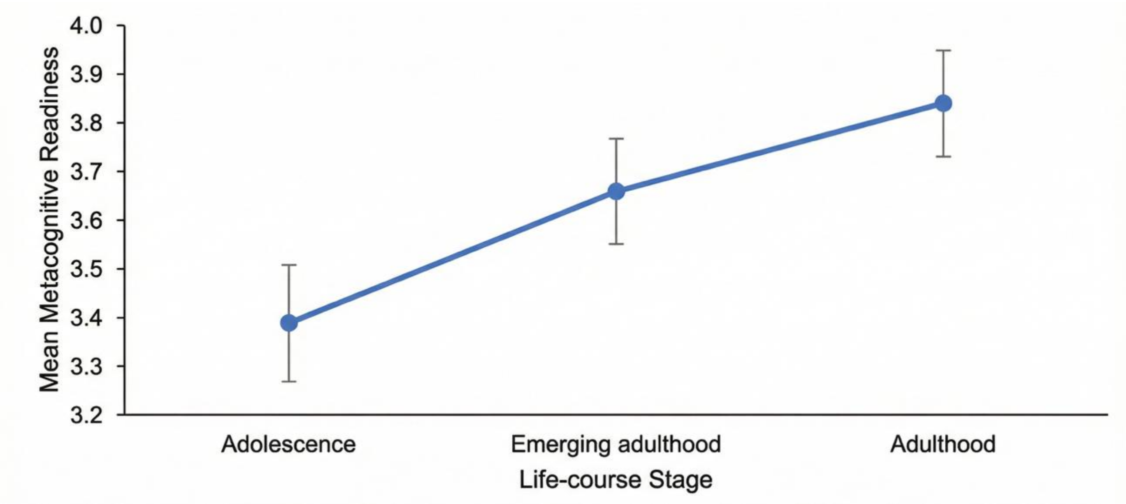


Figure1. Metacognitive Readiness Across Life-course Stages (Mean ± 95% CI).

The figure shows a steady increase in metacognitive readiness from adolescence ($M = 3.39$, 95% CI [3.27, 3.51]) to emerging adulthood ($M = 3.66$, 95% CI [3.55, 3.77]) and adulthood ($M = 3.84$, 95% CI [3.73, 3.95]), consistent with the significant one-way ANOVA results, $F(2, 221) = 19.64$, $p < .001$, $\eta^2 = .15$.

Lifelong Learning Orientation Across Life-course Stages

Life-course stage also exerted a significant effect on lifelong learning orientation, $F(2, 221) = 14.87$, $p < .001$, $\eta^2 = .12$.

Table7. Mean Lifelong Learning Orientation by Stage

Stage	Mean	SD	95% CI
Adolescence	3.48	0.54	[3.35, 3.61]
Emerging adulthood	3.64	0.51	[3.53, 3.76]
Adulthood	3.91	0.48	[3.80, 4.02]

Adults reported significantly higher lifelong learning orientation than adolescents ($d = 0.82$, $p < .001$) and emerging adults ($d = 0.55$, $p = .002$).

Correlations Among Core Constructs Within Each Stage

Pearson correlations showed that metacognitive readiness was positively associated with lifelong learning orientation in all stages.

Table8. Correlations Between Metacognitive Readiness and Lifelong Learning Orientation

Stage	r(MR, LLO)	p
Adolescence	.39	< .001
Emerging adulthood	.53	< .001
Adulthood	.61	< .001

The association strengthened systematically across life-course positions.

Stage-specific Predictive Models of Lifelong Learning Orientation

Separate multiple regression models were estimated within each stage, controlling for digital learning experience, digital self-efficacy, and socioeconomic proxy.

Table9. Stage-specific Regression Models Predicting Lifelong Learning Orientation

Predictor	Adolescence β	Emerging adulthood β	Adulthood β
Metacognitive Readiness	.29**	.42***	.49***
Digital Learning Experience	.17*	.11	.08
Digital Self-Efficacy	.20*	.18*	.13
Socioeconomic proxy	.09	.07	.04
R^2	.32	.40	.47

*Note. *p < .05, **p < .01, ***p < .001*

As shown in Table9, metacognitive readiness was a significant predictor of lifelong learning orientation across all three life-course stages, with standardised effects that increased systematically from adolescence (β = .29, $p < .01$) to emerging adulthood (β = .42, $p < .001$) and adulthood (β = .49, $p < .001$). This monotonic increase indicates a progressive strengthening of the functional role of metacognitive readiness as learners move into later life-course positions. By comparison, the effects of digital learning experience, digital self-efficacy, and socioeconomic background were smaller and less stable across stages, highlighting metacognitive readiness as the most robust and increasingly dominant predictor of lifelong learning orientation in the life-course oriented models.

Cross-stage Comparison of Functional Roles (Interaction Analysis)

A pooled regression with interaction terms confirmed a significant Stage × Metacognitive Readiness interaction,

$\Delta R^2 = .04$, $F\text{-change}(2, 215) = 6.18$, $p = .002$.

Table10. Interaction Model Predicting Lifelong Learning Orientation

Term	β	SE	t	p
Metacognitive Readiness	.33	.05	6.60	< .001
Stage (EA vs Adolescence)	.08	.06	1.33	.185
Stage (Adult vs Adolescence)	.19	.06	3.17	.002
MR × Stage (EA)	.10	.05	2.05	.042
MR × Stage (Adult)	.17	.05	3.40	.001

Interaction plot shows in Figure 2.

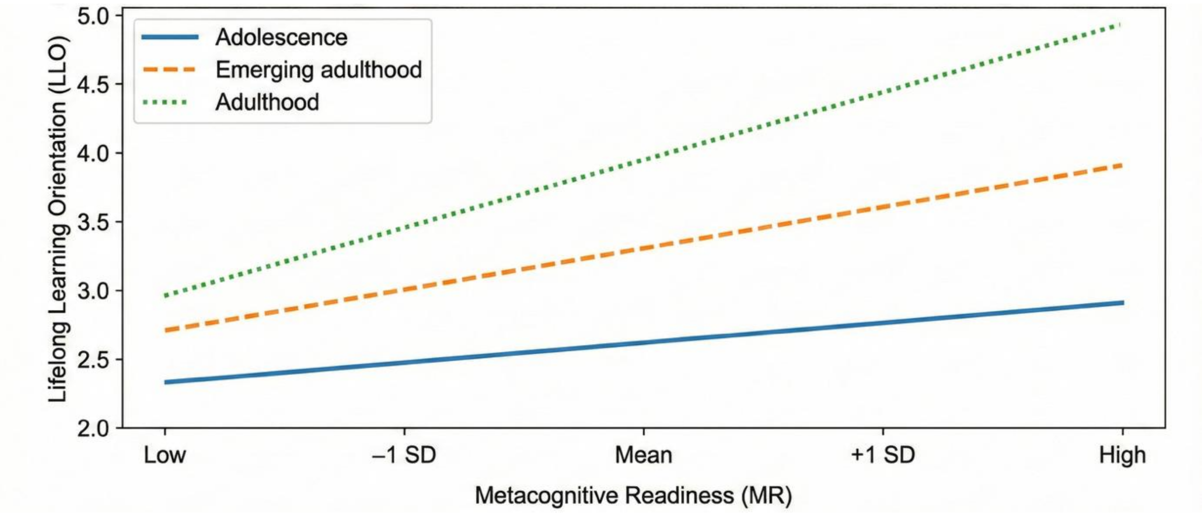


Figure2. Interaction of Stage and Metacognitive Readiness on Lifelong Learning Orientation

Figure 2 visualizes the significant interaction effect between life-course stage and metacognitive readiness (MR) in predicting lifelong learning orientation (LLO) (significant change in $R^2 = .04$, $p = .002$). The plot displays simple regression slopes of MR predicting LLO for each of the three developmental stages representing the moderator variable. The X-axis represents standardized scores of Metacognitive Readiness, while the Y-axis represents Lifelong Learning Orientation levels. The fanning pattern of the regression lines indicates that the strength of the positive association between MR and LLO is contingent upon the life-course stage. The relationship is weakest during adolescence (flattest slope), becomes moderately stronger during emerging adulthood, and is most pronounced during adulthood (steepest slope). This graphical representation confirms that metacognitive readiness becomes an increasingly influential antecedent of lifelong learning orientation in later developmental stages.

Summary of Life-course Trajectory Patterns

To integrate the descriptive, correlational, and predictive findings into a coherent developmental account, a final synthesis was conducted to identify overarching life-course trajectory patterns. Rather than interpreting each analysis in isolation, this synthesis summarises how the level of metacognitive readiness, its association with lifelong learning orientation, and its functional role as a predictor evolve systematically across life-course stages. Table11presents a consolidated overview of these developmental patterns.

Table11. Summary of Developmental Patterns Across Stages

Indicator	Adolescence	Emerging adulthood	Adulthood
Mean MR	Low–moderate	Moderate	High
Mean LLO	Moderate	Moderate–high	High
r(MR, LLO)	.39	.53	.61
β(MR→LLO)	.29	.42	.49
Functional role	Emerging	Consolidating	Dominant

As summarised in Table11, a clear and coherent life-course trajectory emerges across all indicators. Both metacognitive readiness and lifelong learning orientation increase progressively from adolescence to adulthood, indicating a cumulative developmental pattern. At the same time, the association between metacognitive readiness and lifelong learning orientation strengthens across stages, as reflected in rising correlation coefficients. Most importantly, the functional role of metacognitive readiness evolves from an emerging predictor in adolescence to a consolidating mechanism in emerging adulthood and a dominant determinant of lifelong learning orientation in adulthood. Taken together, these convergent patterns provide strong evidence that metacognitive readiness operates as a developmental and life-course resource whose influence on lifelong learning pathways intensifies across successive life-course positions.

Discussion

The present study examined metacognitive readiness in digital learning and its role in lifelong learning pathways using a life-course oriented cross-sectional design. Three consistent patterns emerged. First, metacognitive readiness increased monotonically across life-course stages, from adolescence to adulthood. Second, the association between metacognitive readiness and lifelong learning orientation strengthened progressively across stages. Third, and most critically, the predictive role of metacognitive readiness became significantly stronger in later life-course positions, indicating a changing functional role of metacognition across developmental contexts.

These findings extend prior research on metacognition in digital learning, which has largely focused on short-term academic outcomes among university students [32],[33], by demonstrating that metacognitive readiness may operate as a developmental resource that shapes learning dispositions across the life course. In doing so, this study responds directly to calls for more temporally sensitive and life-course informed analyses of digital education.

The finding that metacognitive readiness increased systematically from adolescence to adulthood is consistent with long-standing developmental accounts of metacognitive growth. Developmental psychologists have shown that metacognitive knowledge and regulation continue to mature well into emerging adulthood as executive functions, self-monitoring capacities, and strategic control become more refined [34],[35]. In educational contexts, older learners typically demonstrate more stable planning strategies, more accurate monitoring of comprehension, and more effective strategy adaptation [36].

From a life-course perspective, this pattern reflects the cumulative nature of learning experiences. Life-course theory posits that competencies accumulate over time through repeated exposure to institutional demands and role transitions, producing developmental gradients rather than abrupt stage shifts [37]. Digital learning environments, which increasingly structure educational participation across all stages of life, may serve as recurrent contexts for metacognitive practice, thereby accelerating the consolidation of metacognitive readiness in later stages [38],[39].

A central contribution of this study is the demonstration that the association between metacognitive readiness and lifelong learning orientation strengthens systematically across life-course stages. While metacognition has long been recognised as a core component of self-regulated learning [40], its role in shaping long-term learning dispositions has received far less empirical attention.

The present findings suggest that metacognitive readiness becomes increasingly consequential as learners move into contexts characterised by higher autonomy, weaker external regulation, and greater responsibility for learning decisions. In adolescence, learning remains heavily scaffolded by institutional structures and teacher guidance [41]. In such contexts, metacognitive skills may enhance performance but play a relatively limited role in shaping enduring learning orientations. By contrast, in emerging adulthood and adulthood, learning increasingly occurs in self-directed, flexible, and often non-formal settings [42]. Under these conditions, the capacity to plan, monitor, and evaluate one's own learning becomes central to sustaining engagement in lifelong learning.

This interpretation aligns with theories of adult learning, which emphasise self-direction, intrinsic motivation, and reflective regulation as defining features of mature learning [43]. It also resonates with empirical work showing that self-regulated learning predicts persistence and re-engagement in adult and workplace learning [44].

Perhaps the most theoretically significant finding is that the functional role of metacognitive readiness changes across life-course positions, becoming a progressively stronger predictor of lifelong learning orientation in adulthood. This pattern supports a life-course differentiation hypothesis, whereby the same psychological resource exerts different levels of influence depending on the structural and normative context in which learning occurs.

Life-course theory emphasises that the impact of individual attributes depends on timing, context, and linked lives [37]. In early stages, institutional regulation constrains the behavioural expression of metacognitive readiness. In later stages, as institutional control weakens and learning becomes optional rather than compulsory, metacognitive readiness becomes a key mechanism enabling continued participation in learning.

This finding extends prior digital learning research, which has primarily conceptualised metacognition as a contemporaneous performance predictor [33],[45], by reconceptualising it as a life-course resource with long-term developmental significance. In doing so, the study bridges metacognition theory with life-course models of cumulative advantage, according to which early competencies can shape later opportunities through path-dependent processes.

The findings have important implications for both digital pedagogy and lifelong learning policy. First, they suggest that metacognitive readiness should be cultivated early, not only to improve immediate learning outcomes but also to support long-term learning trajectories. Interventions that embed metacognitive scaffolding in digital learning environments such as prompts for planning, monitoring dashboards, and reflective feedback have been shown to enhance self-regulation in the short term. The present study suggests that such interventions may yield long-term dividends by strengthening learners' lifelong learning orientation.

Second, the strengthening role of metacognition in adulthood underscores the importance of designing adult digital learning systems that explicitly support reflective regulation. Adult learners often face fragmented learning opportunities, competing role demands, and limited institutional guidance. In such contexts, metacognitive support may be as critical as content delivery in sustaining engagement in reskilling and upskilling.

Finally, these findings speak directly to policy debates on lifelong learning in the digital age. International organisations have increasingly emphasised lifelong learning as a cornerstone of economic resilience and social inclusion. The present results suggest that lifelong learning policies should attend not only to access and provision but also to the development of metacognitive capacities that enable individuals to navigate learning across the life course.

Several limitations warrant consideration. First, the cross-sectional design limits causal inference and does not allow direct observation of individual developmental trajectories. Although life-course oriented cross-sectional designs provide valuable insights into stage-related patterns, longitudinal studies are needed to confirm whether increases in metacognitive readiness precede changes in lifelong learning orientation. Second, the sample size, while adequate for regression-based life-course analysis, limits the use of more complex structural equation models. Future studies with larger samples could employ multi-group SEM to test developmental invariance and mediation processes more rigorously. Third, the reliance on self-report measures may introduce common-method bias. Combining survey data with behavioural indicators of metacognitive regulation in digital platforms.

Future research should also explore non-linear life-course patterns, cohort effects, and the role of institutional transitions (e.g., school-to-work, work-to-retirement) in shaping the function of metacognitive readiness across the lifespan.

CONCLUSION

This study demonstrates that metacognitive readiness in digital learning is a developmental resource whose importance increases across the life course. Using a life-course oriented cross-sectional design, the findings show that metacognitive readiness increases systematically from adolescence to adulthood, is consistently associated with lifelong learning orientation at all stages, and becomes a progressively stronger predictor in later life-course positions. These results extend metacognition research beyond short-term learning outcomes by situating metacognitive readiness within a life-course framework of cumulative development and changing institutional contexts. The study contributes theoretically by bridging metacognition and life-course theory, methodologically by illustrating the value of cross-stage analysis in digital learning research, and substantively by highlighting metacognitive readiness as a key mechanism linking digital learning to lifelong learning pathways. Despite the limitations of cross-sectional data, the findings underscore the importance of cultivating metacognitive capacities early and continuously to support sustained learning across changing life circumstances.

AUTHOR INFORMATION

Corresponding Author

Fritz Hotman Syahmahita Damanik – Universitas Muhammadiyah Malang, Indonesia.
orcid.org/0009-0003-4296-8503
Email: fritzhsdamanik@webmail.umm.ac.id

Authors

Fritz Hotman Syahmahita Damanik – Universitas Muhammadiyah Malang, Indonesia.
orcid.org/0009-0003-4296-8503
Email: fritzhsdamanik@webmail.umm.ac.id
Jahlan Naftali Remtula – Open University of Tanzania, Tanzania.
orcid.org/0009-0003-9460-6256
Email: jahlan.remtula@out.ac.tz

AUTHOR CONTRIBUTION

F.H.S.D. contributed to the conceptualization of the study, research design, data collection, data analysis, interpretation of findings, and preparation of the original manuscript draft. J.N.R. contributed to the development of the theoretical framework, validation of the research instrument, supervision of the research process, critical revision of the manuscript, and final approval of the version to be published. Both authors reviewed and approved the final manuscript and agreed to be accountable for all aspects of the work.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF USE OF AI IN SCIENTIFIC WRITING

The authors used several generative AI tools in the process. ChatGPT was used to help organise complex concepts, while Grammarly was employed to enhance the grammar, style, readability of the text and improve the overall clarity of the writing. Although these tools provided valuable support, the researcher wrote all the content and conclusions.

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