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Learning Behavior Transformation in the Digital Era: A Literature Review of Self-Regulated Learning and Learner Autonomy

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ABSTRACT

Digital learning environments offer flexibility and opportunities for independent learning but also require learners to regulate cognition, motivation, attention, and behavior. This study examines the contribution of Self-Regulated Learning (SRL) to learning behavior transformation and learner autonomy in digitally mediated education. A qualitative narrative literature review employed structured searching and screening in ERIC and OpenAlex for studies published between 2020 and 2025. Of 149 identified records, 62 primary empirical studies met the eligibility criteria and constituted the thematic corpus; 22 contextual and secondary sources supported interpretation. The synthesis identified five interconnected domains: technological affordances, metacognitive regulation and strategy enactment, motivational-emotional regulation, pedagogical and social scaffolding, and digital challenges and regulatory constraints. Findings indicate that digital technologies support learning regulation through feedback, progress monitoring, personalization, and adaptive assistance, although their effectiveness depends on learners' regulatory skills and instructional conditions. Metacognitive strategies and motivational regulation facilitate persistence and purposeful learning, while pedagogical and social scaffolding help learners develop regulatory capacities. Drawing on these findings, the study proposes the Digital Self-Regulatory Ecosystem (DSRE), integrating four interacting dimensions: technological affordances, metacognitive regulation, motivational regulation, and pedagogical support. Digital risks function as cross-cutting constraints, behavioral adaptation connects regulatory processes with evolving learning practices, and learner

autonomy emerges as an outcome of these interactions. The framework offers a conceptual basis for understanding how learners, technologies, and pedagogy jointly shape self-regulation and autonomy, while highlighting the importance of designing digitally mediated learning experiences that support independent decision-making.

Keywords
Behavioral Adaptation
Digital Learning Environment
Digital Self-Regulatory Ecosystem
Learner Autonomy
Learning Behavior Transformation
Self-Regulated Learning

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Introduction

Digital technologies have substantially reshaped contemporary educational practices by expanding access to learning resources and increasing flexibility in when, where, and how learning occurs. Learning activities are increasingly mediated through learning management systems, mobile applications, artificial intelligence, learning analytics, and other digital environments that allow learners to access resources and make learning decisions beyond conventional classroom structures. At the same time, this flexibility transfers greater responsibility to learners for organizing, monitoring, and sustaining their own learning. Digital learning therefore involves not only technological access but also an increasing need for learners to manage their learning behavior under conditions of greater choice, complexity, and independence [1], [2].

Greater access and flexibility, however, do not automatically lead to effective independent learning. Learners may experience difficulties in maintaining attention, managing study time, monitoring understanding, selecting appropriate resources, and sustaining engagement in digitally mediated environments. Digital technologies can also create additional regulatory demands through distraction, information abundance, cognitive load, and the need to manage multiple learning pathways [3], [4]. Consequently, the central challenge of digital learning is increasingly not simply whether learners can access digital resources, but whether they can regulate their behavior effectively while using those resources. Learner autonomy should therefore be understood as a developmental capacity rather than an automatic consequence of technology use [5].

Self-Regulated Learning (SRL) provides an important theoretical perspective for explaining how learners manage these demands. SRL is generally understood as an active process

through which learners set goals, select strategies, monitor progress, regulate motivation and behavior, and evaluate learning outcomes. Foundational models emphasize that regulation involves interacting cognitive, metacognitive, motivational, and behavioral processes rather than a single learner skill [6], [7], [8]. In digital learning environments, these processes become particularly important because learners frequently need to make decisions regarding time allocation, attention, resource selection, strategy use, and help seeking with less continuous external direction [2].

Nevertheless, conceptualizing SRL primarily as an individual learner capacity may be insufficient for explaining regulation in contemporary digital learning environments. Learners' regulatory activity is increasingly shaped by technological affordances, instructional design, feedback systems, teacher scaffolding, and social interactions [9], [10], [11]. Recent reviews have documented the importance of SRL strategies and technological support in digital learning [1], [4], [11], yet the literature frequently remains organized around particular interventions, technologies, or educational outcomes rather than around the process through which regulatory capacities become changing patterns of learning behavior. The relationship between SRL and learner autonomy also remains conceptually fragmented, particularly regarding how internal regulation interacts with technological and pedagogical conditions and how these interactions translate into behavioral adaptation over time [5].

Against this background, this review examines how learning behavior is transformed in digitally mediated environments through the lens of SRL. Specifically, it aims to (1) identify the principal patterns through which SRL is enacted in digital learning environments, (2) examine how technological, metacognitive, motivational, pedagogical, and regulatory conditions interact in shaping learning behavior, and (3) explain how these interactions contribute to behavioral adaptation and the emergence of learner autonomy. Rather than treating digital technology, SRL, and autonomy as separate topics, the review seeks to synthesize their relationships as interconnected components of contemporary learning regulation.

Building on this synthesis, the study proposes the Digital Self-Regulatory Ecosystem (DSRE) as an integrative conceptual framework for explaining learning behavior transformation and learner autonomy in digital learning environments. The framework positions technological affordances, metacognitive regulation, motivational regulation, and pedagogical support as four interacting dimensions of digital learning regulation. Digital challenges, risks, and regulatory constraints are conceptualized as cross-cutting conditions that may facilitate or disrupt these interactions. Behavioral adaptation represents the process through which regulatory activity becomes reflected in changing learning practices, while learner autonomy is conceptualized as an emergent outcome. Through this perspective, the review extends an exclusively individual

conception of SRL toward a more relational understanding of regulation across learner–technology–pedagogy interactions.

Material and Methods

This study employed a qualitative narrative literature review with a structured and transparent search and screening procedure to examine how Self-Regulated Learning (SRL) contributes to learning behavior transformation and learner autonomy in digitally mediated learning environments. The narrative review design was selected because the study aimed to develop an interpretive and conceptual synthesis of relationships among regulatory processes, technological affordances, pedagogical conditions, and learner behavior rather than to estimate pooled effects or conduct a systematic meta-analysis [12]. The analytic corpus focused on studies published between 2020 and 2025, while earlier publications were used only as foundational or theoretical references and were not included in the thematic corpus.

Literature searches were conducted on 29 August 2026 using ERIC and OpenAlex. ERIC was selected because of its specialized coverage of educational research, whereas OpenAlex was used as an interdisciplinary scholarly index to broaden coverage of research on digital learning and self-regulation. In ERIC, the final search query was “self-regulated learning” AND “digital learning” AND (pubyear:2020 OR pubyear:2021 OR pubyear:2022 OR pubyear:2023 OR pubyear:2024 OR pubyear:2025), with the peer-reviewed only filter applied. This search yielded 44 records. In OpenAlex, the literal search query “self-regulated learning” “digital learning” was used with filters for journal sources, English language, Article and Review work types, and publication years 2020–2025, yielding 105 records. The combined search therefore identified 149 records. A relatively broad search formulation was retained so that studies addressing learning behavior, engagement, adaptation, or autonomy as outcomes of SRL would not be excluded solely because these terms were absent from their titles or abstracts.

Records from the two sources were merged and deduplicated using DOI matching followed by normalized-title matching for records without matching DOIs. Twenty-four duplicate records were removed, leaving 125 unique records for title and abstract screening. Studies were considered potentially eligible when they involved learners or students at any educational level, examined a digitally mediated learning environment, and treated SRL or self-regulatory processes as a central theoretical, measured, or intervention-related construct. Studies also needed to provide substantive evidence related to learning strategies, regulation, adaptation, engagement, autonomy, persistence, monitoring, time or attention management, or other aspects of learning behavior. Thirty-two records were excluded during title and abstract screening, leaving 93 reports for full-text retrieval. Three reports could not be retrieved, and 90 full texts were assessed for eligibility. For publications with different online-first and formal citation years, the formal citation year was used to determine eligibility within the 2020–2025 review period.

During full-text assessment, empirical journal studies were included in the primary analytic corpus when they met the population, digital-learning, SRL-centrality, publication-period, and substantive-relevance criteria. Studies were excluded when the digital learning environment was incidental, SRL was not substantively examined, the publication type did not meet the eligibility criteria, or the formal publication year fell outside the predefined period. Systematic reviews, meta-analyses, conceptual papers, and other secondary sources that were relevant to interpretation were retained separately as contextual sources but were not coded as primary empirical evidence, thereby reducing the risk of double-counting evidence. Following full-text assessment, six reports were excluded, 22 were retained as contextual sources, and 62 primary empirical studies formed the final thematic-analysis corpus.

The 62 included empirical studies were examined through an iterative thematic synthesis informed by Braun and Clarke's thematic analysis framework [13]. For each study, information was extracted regarding publication characteristics, educational level, digital-learning setting, SRL processes, technological features, pedagogical or social supports, learning-behavior indicators, autonomy-related outcomes, and reported challenges or contradictory findings. Initial coding focused on recurring patterns related to technology-mediated regulation, metacognitive strategy enactment, motivational-emotional regulation, pedagogical and social scaffolding, behavioral adaptation, learner autonomy, and digital regulatory constraints. Codes were repeatedly compared across studies, grouped into broader conceptual categories, and reviewed against the full empirical corpus. Individual studies were allowed to contribute to more than one theme because the regulatory processes examined in digital learning environments frequently overlapped.

This iterative process resulted in five interrelated thematic domains: (1) digital ecosystem and technological affordances, (2) metacognitive regulation and strategy enactment, (3) motivational-emotional regulation, (4) pedagogical and social scaffolding, and (5) digital challenges, risks, and regulatory constraints. The first four domains were subsequently synthesized into the four core dimensions of the proposed Digital Self-Regulatory Ecosystem (DSRE), whereas digital challenges and risks were interpreted as cross-cutting conditions influencing these dimensions. Behavioral adaptation was treated as a process layer emerging from their interaction, while learner autonomy was conceptualized as an emergent outcome.

Results and Discussions

The structured search identified 149 records from ERIC and OpenAlex. After removing 24 duplicate records, 125 unique records underwent title and abstract screening. Thirty-two records were excluded at this stage, leaving 93 reports for full-text retrieval. Three reports could not be retrieved, and 90 full-text articles were assessed against the eligibility criteria. Six studies were excluded following full-text assessment, while 22 systematic reviews, conceptual papers, or other

secondary sources were retained separately as contextual sources. The final primary empirical corpus comprised 62 studies published between 2020 and 2025, which formed the basis of the thematic synthesis.

Analysis of the empirical corpus identified five interrelated thematic domains: (1) digital ecosystem and technological affordances, (2) metacognitive regulation and strategy enactment, (3) motivational-emotional regulation, (4) pedagogical and social scaffolding, and (5) digital challenges, risks, and regulatory constraints. These themes were not treated as mutually exclusive categories because individual studies frequently contributed evidence to multiple domains. Rather, they capture interacting technological, cognitive, motivational, pedagogical, and regulatory conditions through which learning behavior is reorganized in digitally mediated environments. Table 1 summarizes the analytical focus, representative empirical evidence, critical or qualifying findings, and conceptual relationship of each theme to the proposed Digital Self-Regulatory Ecosystem (DSRE).

Table 1. Thematic Synthesis of Self-Regulated Learning and Learning Behavior Transformation in Digital Learning Environments

Thematic Domain	Analytical Focus	Representative Empirical Studies	Critical/Qualifying Synthesis	DSRE Mapping
Digital Ecosystem & Technological Affordances	Digital tools operate as regulatory resources by providing feedback, monitoring, personalization, adaptive support, and access to learning resources.	[14]; [15]; [16]; [17]	Digital systems can strengthen monitoring and engagement, but their effects depend on alignment with learner needs and pedagogical design; adaptive systems may also generate technological–pedagogical conflicts.	Technological Affordances
Metacognitive Regulation & Strategy Enactment	Planning, goal setting, monitoring, strategy selection, time/resource management, self-evaluation, and reflection organize learning in digital environments.	[18]; [19]; [20]; [21]	Metacognitive knowledge or support alone is insufficient; outcomes depend on actual strategy enactment, timing, task fit, and specificity of support.	Metacognitive Regulation
Motivational–Emotional Regulation	Self-efficacy, motivation, volitional control, persistence, and achievement emotions sustain or disrupt self-regulatory effort.	[22]; [23]; [24]	Motivational processes do not produce identical effects across learners or outcomes; their influence varies across learner profiles and learning conditions.	Motivational Regulation
Pedagogical & Social Scaffolding	Teacher facilitation, adaptive scaffolds, prompts, feedback, and technology-embedded guidance provide external regulation that can support learners' internal regulatory processes.	[16]; [25]; [26]; [27]	Scaffolding can strengthen self-efficacy, monitoring, self-evaluation, and learning, but its effectiveness depends on design, timing, and learner characteristics.	Pedagogical Support
Digital Challenges, Risks & Regulatory Constraints	Digital environments introduce distraction, device-control demands, cognitive load, excessive openness, and possible mismatches between technological support and learners' regulatory capacity.	[28]; [15]; [29]; [30]; [31]	The same flexibility or technological support can enable some learners while burdening others; stronger SRL-related support does not consistently translate into every performance outcome.	Cross-cutting condition across the four DSRE dimensions

As shown in Table 1, the five thematic domains represent related rather than independent aspects of digital learning regulation. Technological affordances frequently interacted with learners' metacognitive and motivational processes, while pedagogical and social supports influenced how regulatory strategies were enacted. At the same time, digital environments introduced constraints that could strengthen or disrupt these processes depending on learner characteristics and learning conditions. The synthesis therefore suggests that learning behavior transformation cannot be explained by technological access or individual self-regulation alone, but by the interaction between learners, technologies, and pedagogical environments.

The first thematic domain indicates that digital technologies function not merely as channels for delivering learning content but increasingly as regulatory resources that shape how learners monitor, organize, and adjust their learning. Across the reviewed studies, technological affordances included personalized feedback, learning analytics, adaptive learning systems, generative artificial intelligence, and digital platforms that make learners' progress and learning behavior more visible. For example, generative-AI-supported learning could strengthen students' behavioral engagement, motivation, and self-regulatory interactions [14]. Characteristics of AI-driven adaptive learning platforms were also associated with educational quality through pathways involving SRL and learning engagement [17]. Together, these findings suggest that the regulatory value of digital technology lies not simply in increasing access to learning resources, but in providing external information and feedback that learners can use to regulate their learning.

Evidence from learning analytics further demonstrates that technological affordances are closely intertwined with learners' regulatory activity and with the pedagogical conditions in which technologies are used. An adaptive learning analytics dashboard provided personalized feedback that could support learners' monitoring and control processes [15] . Learning analytics can also provide useful information about pupils' SRL, although the visibility and interpretation of such behavior depend strongly on learning design and teacher practices, particularly because some regulatory processes in open and collaborative activities may occur beyond what is captured in platform traces [16]. Together, these studies show that learning analytics can support and reveal aspects of learners' regulatory activity, while also illustrating the limits of interpreting digital traces independently of the learning context.

At the same time, the evidence challenges the assumption that greater technological support necessarily produces stronger self-regulation or learner autonomy. Adaptive systems may provide guidance, feedback, and opportunities for monitoring, yet learners may respond differently to these supports. Technological and pedagogical tensions were identified in learners' interactions with adaptive dashboard feedback [15]. The same technological infrastructure could also generate different observable patterns of regulation depending on the learning design [16].

This suggests that technological affordances are conditional rather than inherently beneficial. Their contribution to learning behavior transformation appears to depend on how effectively learners interpret and strategically use the regulatory information provided and on whether the surrounding pedagogical environment supports such use. Within the proposed DSRE framework, technological affordances are therefore conceptualized as one core regulatory dimension that interacts with, rather than replaces, learners' metacognitive and motivational regulation.

Across the empirical corpus, metacognitive regulation emerged as a central mechanism through which learners organized their behavior in digital learning environments. This regulation was reflected not only in learners' awareness of strategies but also in observable activities such as planning, monitoring, information seeking, revising, allocating time, and evaluating progress. A study combining digital trace data with stimulated-recall interviews revealed performance-related differences in how secondary-school students actually enacted regulatory strategies during a computer-based multi-source writing task [18]. Distinct patterns of time allocation were also identified among seventh-grade students using an online learning system during the 34 days preceding an examination [20]. Together, these studies demonstrate that metacognitive regulation in digital environments is expressed through temporal and behavioral patterns of strategy enactment, rather than through strategic knowledge alone.

Regulatory behavior also appeared to be dynamic rather than stable across a learning period. Analysis of more than three million learning events from 5,870 students across 41 bachelor's courses identified changes in learners' strategies across different course periods, with consistently deeper or resource-oriented strategies associated with stronger academic outcomes and persistent surface strategies associated with weaker performance [19]. This temporal variation suggests that learning behavior transformation involves repeated adjustments in how learners select, combine, and sustain regulatory strategies as learning demands change. Metacognitive regulation should therefore be understood as an adaptive process of strategy enactment, rather than as a fixed learner characteristic.

Importantly, the reviewed evidence also indicates that metacognitive support is not equally effective in all forms. Self-explication embedded in a digital SRL tool improved learners' metacognitive regulation, while domain-specific support showed clearer benefits than domain-general metacognitive support [21]. This finding qualifies the assumption that simply providing learners with prompts or opportunities for reflection is sufficient to strengthen SRL. The effectiveness of metacognitive support therefore appears to depend on how closely it is aligned with the learning task and on whether learners translate regulatory awareness into observable strategic action. Across these studies, the distinction between knowing how to regulate and actually enacting regulation becomes particularly important. Within the DSRE framework, metacognitive regulation is therefore conceptualized as a core dimension that transforms

regulatory intentions into adaptive learning behaviors through planning, monitoring, strategic adjustment, and reflection.

Motivational and emotional regulation emerged as a second internal mechanism that sustains learners' engagement with self-regulatory activity in digital environments. Across the reviewed studies, self-efficacy, volitional control, persistence, and achievement emotions were associated with learners' capacity to maintain effort and translate learning intentions into goal-directed behavior. An intensive longitudinal study of 227 medical students using a digital learning platform over 40 days found that volitional control mediated the relationship between momentary self-efficacy and learning-goal achievement [22]. This finding suggests that confidence in one's capability may be more likely to translate into goal attainment when it is accompanied by the capacity to sustain and regulate action over time, rather than functioning as an isolated motivational belief. Achievement emotions further complicate the relationship between motivation and learning outcomes. Domain-specific achievement emotions were associated with self-regulation strategies and language performance in an online EFL learning context [23]. These findings indicate that emotional experiences are not peripheral to SRL but are intertwined with learners' capacity to sustain, redirect, or withdraw regulatory effort. At the same time, the evidence does not support a simple assumption that more positive motivation or emotion automatically produces stronger academic performance. Rather, motivational-emotional regulation appears to influence the persistence and quality of self-regulatory engagement in ways that vary across learners and learning conditions.

This conditional relationship is further illustrated by differences across learner profiles and learning conditions. A study comparing asynchronous e-learning and synchronous online seminar conditions identified low, moderate, and high SRL profiles, with stronger gains in declarative SRL knowledge in the asynchronous condition [25]. Together, these findings reinforce the distinction between feeling motivated, knowing how to regulate, and actually improving learning performance. Within the DSRE framework, motivational regulation is therefore conceptualized as a sustaining mechanism that supports persistence and engagement, but whose effects remain dependent on strategy enactment, learner characteristics, and the surrounding learning environment.

The fourth thematic domain highlights that self-regulation in digital learning environments does not develop solely through learners' internal capacities. Across the empirical studies, teachers, digital systems, feedback mechanisms, and instructional scaffolds functioned as forms of external support that assisted learners in monitoring, evaluating, and adjusting their learning. Pupils' use of learning analytics was strongly shaped by learning design and teacher practices, indicating that the same digital platform could support different forms of self-regulation depending on how learning activities were structured [16]. This suggests that

pedagogical design is not merely a background condition but an active component in shaping how technological affordances are translated into regulatory behavior.

Experimental evidence further demonstrates that external scaffolding can support learning processes that are relevant to learners' developing regulatory capacity. In a 2 × 2 experiment with 102 university students, scaffolding improved recall and self-efficacy, while no significant main effect was found for whether regulation was primarily system-based or self-directed [25]. This finding challenges the assumption that learner-controlled regulation is necessarily superior to externally supported regulation. Rather, appropriately designed scaffolding may provide regulatory support that assists learners in performing processes they may not yet manage effectively on their own.

Similar patterns are evident in digitally embedded forms of scaffolding. Web-based supports were used to identify and remediate difficulties in self-evaluation and self-efficacy among young learners [26]. An expert-system-guided SRL approach in digital game-based language learning also improved vocabulary achievement and self-regulation without increasing anxiety, while interview evidence suggested that goal-setting support helped learners focus more deliberately on learning strategies [27]. Together, these findings indicate that pedagogical support can be particularly valuable when it provides targeted and adaptive regulation rather than simply increasing external control. Within the DSRE framework, pedagogical support is therefore conceptualized as a core dimension that can support the development of learners' regulatory capacity while creating opportunities for increasing independence.

The fifth thematic domain reveals that the regulatory opportunities provided by digital learning environments are accompanied by substantial demands on learners' attention, cognitive resources, and capacity for self-management. Self-directed digital vocabulary learning involved not only access to smartphones and laptops but also the need to control devices and manage distraction from notifications [28]. Adaptive dashboard feedback could similarly support monitoring and regulation while also generating technological and pedagogical tensions [15]. These findings indicate that digital technologies can operate simultaneously as regulatory resources and sources of regulatory demand, requiring learners to manage not only the learning task itself but also the conditions created by the technology through which learning occurs.

The evidence also suggests that greater flexibility and openness are not equally beneficial for all learners. In asynchronous digital learning paths, successful learners were able to activate individual strategies and productive work habits, whereas less successful learners experienced excessive openness and confusion [29]. Goal setting and task strategies also played mediating roles in the relationships between engagement and cognitive load in online learning [30]. Taken together, these findings suggest that the same digital conditions that create opportunities for

autonomous learning may also impose greater cognitive and regulatory demands on learners who have not yet developed sufficiently effective self-regulatory strategies.

A further qualification concerns the assumption that stronger self-regulatory processes necessarily produce better learning outcomes. Information feedback was significantly related to self-efficacy, SRL strategies, and perceived and actual learning effectiveness in a digital game-based learning system; however, SRL strategy itself did not significantly predict actual learning effectiveness [31]. This finding reinforces the broader pattern identified across the review: regulatory support and self-regulatory activity can contribute to learning, but their effects are not uniformly reflected in measurable performance gains. Within the DSRE framework, digital challenges, risks, and regulatory constraints are therefore not conceptualized as a separate fifth dimension. Instead, they function as cross-cutting conditions that can influence technological affordances, metacognitive regulation, motivational regulation, and pedagogical support simultaneously.

Taken together, the five thematic domains suggest that self-regulated learning in digital environments is better understood as an ecosystem of interacting regulatory processes than as an individual learner capacity operating in isolation. Based on this synthesis, the Digital Self-Regulatory Ecosystem (DSRE) is proposed as a conceptual framework comprising four interconnected core dimensions: technological affordances, metacognitive regulation, motivational regulation, and pedagogical support. These dimensions correspond to the first four thematic domains identified in the empirical synthesis. Digital challenges, risks, and regulatory constraints, however, are not positioned as a fifth dimension; rather, they represent cross-cutting conditions that can strengthen, disrupt, or alter the functioning of all four dimensions.

Within the DSRE, technological affordances provide regulatory resources such as feedback, monitoring, personalization, and adaptive guidance, while metacognitive regulation enables learners to plan, monitor, evaluate, and strategically adjust their learning. Motivational regulation supports persistence, volitional control, and continued engagement, whereas pedagogical support provides external structures through scaffolding, feedback, teacher facilitation, and technology-embedded guidance. The thematic findings indicate that these dimensions do not operate independently. Technological support may facilitate monitoring but becomes less effective when it is poorly aligned with learning design; metacognitive strategies require motivational continuity to be sustained; and external scaffolding can support learners' regulatory processes without necessarily reducing learner agency. The DSRE therefore conceptualizes learning regulation as emerging through learner–technology–pedagogy interactions rather than residing solely within the learner.

A central process connecting these dimensions to learning behavior transformation is behavioral adaptation. In the present framework, behavioral adaptation is not treated as an

additional DSRE dimension or as a final learning outcome. Instead, it represents the process layer through which regulatory capacities become visible in learners' changing patterns of action. Such adaptation may involve reorganizing study time, modifying strategy use, responding differently to feedback, regulating attention, selecting resources more strategically, persisting through difficulty, or shifting between externally supported and increasingly self-directed forms of learning. Evidence across the reviewed studies indicates that these behaviors can vary across learning periods and according to task demands, learner characteristics, technological conditions, and the availability of appropriate support. Behavioral adaptation therefore provides the conceptual bridge between the regulatory ecosystem and the transformation of learning behavior.

Learner autonomy is consequently conceptualized as an emergent outcome of this regulatory process rather than as a fixed personal characteristic or an automatic consequence of technology use. Greater autonomy may become possible as learners increasingly coordinate metacognitive and motivational regulation, make strategic use of technological resources, and engage with available pedagogical supports in increasingly self-directed ways. However, this progression is neither linear nor guaranteed. Digital distraction, cognitive load, excessive openness, inappropriate scaffolding, or mismatches between learner needs and technological support may interrupt or redirect the process. The DSRE therefore explains learning behavior transformation as a dynamic and recursive process in which interactions among regulatory capacities, technological affordances, pedagogical support, and environmental constraints shape behavioral adaptation and may contribute to the emergence of learner autonomy.

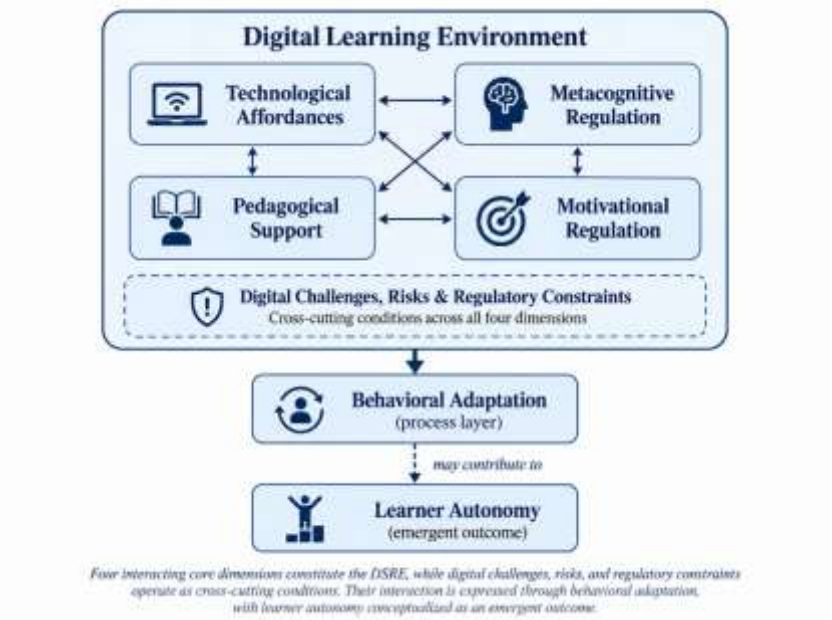


Fig 1. Digital Self-Regulatory Ecosystem (DSRE) Framework for Learning Behavior Transformation and Learner Autonomy

The framework should not be interpreted as a linear sequence in which regulatory support inevitably results in learner autonomy. Rather, the relationships are recursive and conditional. Learners may repeatedly adjust their strategies, motivation, use of digital resources, and responses to pedagogical support as learning demands change. Digital constraints may interrupt or redirect these regulatory processes, while appropriately aligned technological and pedagogical supports may facilitate further adaptation. The DSRE therefore conceptualizes learner autonomy as an emergent outcome that may develop through the interaction of regulatory capacities, technological affordances, pedagogical support, and behavioral adaptation, rather than as a predetermined endpoint of technology-mediated learning.

Conclusion

This review examined learning behavior transformation in digitally mediated learning environments through the perspective of Self-Regulated Learning (SRL). Drawing on a primary empirical corpus of 62 studies published between 2020 and 2025, the synthesis identified five interrelated thematic domains: technological affordances, metacognitive regulation and strategy enactment, motivational-emotional regulation, pedagogical and social scaffolding, and digital challenges, risks, and regulatory constraints. The findings indicate that learning behavior transformation is not simply a consequence of increased access to digital technologies. Rather, it emerges through interactions among learners' regulatory capacities, technological resources, motivational processes, pedagogical support, and the constraints embedded within digital learning environments. Importantly, the evidence also indicates that regulatory support does not produce uniform outcomes; its effectiveness varies according to learner characteristics, task demands, learning design, and the extent to which regulatory strategies are actually enacted.

The principal conceptual contribution of this review is the proposed Digital Self-Regulatory Ecosystem (DSRE). The framework conceptualizes digital learning regulation through four interacting core dimensions: technological affordances, metacognitive regulation, motivational regulation, and pedagogical support. Digital challenges, risks, and regulatory constraints are positioned not as an additional dimension but as cross-cutting conditions that can facilitate, disrupt, or reshape the operation of these four dimensions. Within this ecosystem, behavioral adaptation functions as a process layer through which regulatory capacities become visible in changing learning practices, while learner autonomy represents an emergent outcome. The DSRE therefore extends an exclusively individual view of SRL by conceptualizing learning regulation as a dynamic and recursive process emerging through learner–technology–pedagogy interactions.

The review was restricted to studies retrieved through ERIC and OpenAlex and to the 2020–2025 publication period, which may have excluded relevant studies indexed elsewhere or outside this period. In addition, the included studies represented diverse educational levels,

technologies, methodological approaches, and learning contexts, limiting the extent to which particular relationships within the DSRE can be generalized across populations. The proposed framework also remains conceptual and requires empirical validation. Future research should therefore examine the DSRE across different educational levels and sociocultural settings, investigate regulatory processes longitudinally using combinations of self-report and digital trace data, and examine how emerging technologies particularly artificial intelligence and adaptive learning systems may simultaneously create regulatory affordances and new forms of regulatory burden. Such research may further clarify how behavioral adaptation may contribute to the emergence of learner autonomy in digital learning environments.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] A. Faza and I. A. Lestari, "Self-Regulated Learning in the Digital Age: A Systematic review of Strategies, Technologies, Benefits, and Challenges," *International Review of Research in Open and Distributed Learning*, vol. 26, no. 2, pp. 23–58, May 2025, doi: 10.19173/irrodl.v26i2.8119.

[2] N. Edisherashvili, K. Saks, M. Pedaste, and Ä. Leijen, "Supporting self-regulated learning in distance learning contexts at higher education level: Systematic literature review," *Front. Psychol.*, vol. 12, pp. 1–21, Jan. 2022, doi: 10.3389/fpsyg.2021.792422.

[3] R. A. Rasheed, A. Kamsin, and N. A. Abdullah, "Challenges in the online component of blended learning: A systematic review," *Comput. Educ.*, vol. 144, 2020, doi: 10.1016/j.compedu.2019.103701.

[4] D. Prasse *et al.*, "Challenges in promoting self-regulated learning in technology supported learning environments: An umbrella review of systematic reviews and meta-analyses," *Technology, Knowledge and Learning*, vol. 29, no. 4, pp. 1809–1830, Dec. 2024, doi: 10.1007/s10758-024-09772-z.

[5] N. Gupta, K. Ali, D. Jiang, T. Fink, and X. Du, "Beyond autonomy: unpacking self-regulated and self-directed learning through the lens of learner agency- a scoping review," *BMC Med. Educ.*, vol. 24, no. 1, 2024, doi: 10.1186/s12909-024-06476-x.

[6] B. J. Zimmerman, "Becoming a self-regulated learner: An overview," *Theory Pract.*, vol. 41, no. 2, pp. 64–70, May 2002, doi: 10.1207/s15430421tip4102_2.

[7] E. Panadero, "A review of self-regulated learning: Six models and four directions for research," *Front. Psychol.*, vol. 8, no. APR, pp. 1–28, Apr. 2017, doi: 10.3389/fpsyg.2017.00422.

[8] D. H. Schunk and J. A. Greene, *Handbook of self-regulation of learning and performance*, 2nd ed. Routledge, 2018.

[9] A. F. Hadwin, S. Järvelä, and M. Miller, "State of the art: Metacognition in education," *Handbook of Metacognition in Education*, pp. 313–333, 2018.

[10] I. Molenaar, "The concept of hybrid human-AI regulation: Exemplifying how to support young learners' self-regulated learning," *Computers and Education: Artificial Intelligence*, vol. 3, p. 100070, 2022, doi: 10.1016/j.caeai.2022.100070.

[11] K. Sharma, A. Nguyen, and Y. Hong, "Self-regulation and shared regulation in collaborative learning in adaptive digital learning environments: A systematic review of empirical studies," 2024. doi: 10.1111/bjet.13459.

[12] J. Sukhera, "Narrative Reviews: Flexible, Rigorous, and Practical," *J. Grad. Med. Educ.*, vol. 14, no. 4, pp. 414–417, Aug. 2022, doi: 10.4300/JGME-D-22-00480.1.

[13] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qual. Res. Psychol.*, vol. 3, no. 2, pp. 77–101, Jan. 2006, doi: 10.1191/1478088706qp063oa.

[14] D. T. K. Ng, C. W. Tan, and J. K. L. Leung, "Empowering student self-regulated learning and science education through ChatGPT: A pioneering pilot study," *British Journal of Educational Technology*, vol. 55, no. 4, pp. 1328–1353, Jul. 2024, doi: 10.1111/bjet.13454.

[15] E. Park, D. Ifenthaler, and R. B. Clariana, "Adaptive or adapted to: Sequence and reflexive thematic analysis to understand learners' self-regulated learning in an adaptive learning analytics dashboard,"

British Journal of Educational Technology, vol. 54, no. 1, pp. 98–125, Jan. 2023, doi: 10.1111/bjet.13287.

[16] T. Paavilainen, S. López-Pernas, S. Väisänen, S. Kontkanen, and L. Hirsto, "Using learning analytics to support self-regulated learning in primary education - A learning design perspective," *Technology, Knowledge and Learning*, vol. 30, no. 3, pp. 1299–1319, Sep. 2025, doi: 10.1007/s10758-024-09808-4.

[17] Z. Ouyang, "Self-regulated learning and engagement as serial mediators between AI-driven adaptive learning platform characteristics and educational quality: a psychological mechanism analysis," *Front. Psychol.*, vol. 16, 2025, doi: 10.3389/fpsyg.2025.1646469.

[18] O. Aksela, J. Lämsä, and S. Järvelä, "Secondary school students' enacted self-regulated learning strategies in a computer-based writing task–insights from digital trace data and interviews," *Technology, Knowledge and Learning*, vol. 30, no. 3, pp. 1727–1756, Sep. 2025, doi: 10.1007/s10758-024-09789-4.

[19] T. S. Cristea *et al.*, "Dynamics of self-regulated learning: The effectiveness of students' strategies across course periods," *Comput. Educ.*, vol. 228, Apr. 2025, doi: 10.1016/j.compedu.2025.105233.

[20] C. Y. Hsu, I. Horikoshi, H. Li, R. Majumdar, and H. Ogata, "Supporting 'time awareness' in self-regulated learning: How do students allocate time during exam preparation?," *Smart Learning Environments*, vol. 10, no. 1, Dec. 2023, doi: 10.1186/s40561-023-00243-z.

[21] E. Braad, N. Degens, W. Barendregt, and W. IJsselsteijn, "Improving metacognition through self-explication in a digital self-regulated learning tool," *Educational Technology Research and Development*, vol. 70, no. 6, pp. 2063–2090, Dec. 2022, doi: 10.1007/s11423-022-10156-2.

[22] J. Breitwieser and G. Brod, "The interplay of motivation and volitional control in predicting the achievement of learning goals: An intraindividual perspective," *J. Educ. Psychol.*, vol. 114, no. 5, pp. 1048–1061, 2022, doi: 10.1037/edu0000738.

[23] L. S. Teng and J. Pan, "Achievement emotions in online language learning: Domain-specific components and interactions with self-regulation strategies and language performance," *Appl. Linguist.*, p. amae080, 2024, doi: 10.1093/applin/amae080.

[24] N. Barz, M. Benick, L. Dörrenbächer-Ulrich, and F. Perels, "Fostering self-regulated learning using synchronous or asynchronous digital learning environments: a latent profile analysis of pre-service teachers' individual differences," *Front. Educ. (Lausanne).*, vol. 9, Dec. 2024, doi: 10.3389/feduc.2024.1445182.

[25] A. Herold and T. Seufert, "Who regulates? Effects of scaffolding in system- and self-regulated learning," *Front. Psychol.*, vol. 16, 2025, doi: 10.3389/fpsyg.2025.1543024.

[26] T. Sergent, M. Daniel, F. Bouchet, and T. Carron, "How can self-evaluation and self-efficacy skills of young learners be scaffolded in a web application?," *IEEE Transactions on Learning Technologies*, vol. 17, pp. 1184–1197, 2024, doi: 10.1109/TLT.2024.3360121.

[27] S.-T. Chu, G.-J. Hwang, S.-Y. Chien, and S.-C. Chang, "Incorporating teacher intelligence into digital games: An expert system-guided self-regulated learning approach to promoting EFL students' performance in digital gaming contexts," *British Journal of Educational Technology*, vol. 54, no. 2, pp. 534–553, 2023, doi: 10.1111/bjet.13260.

[28] M. Bowles, "Digital, self-regulated vocabulary learning and device control in out-of-class, higher education settings," *The Electronic Journal of e-Learning*, vol. 22, no. 1, pp. 17–30, 2024, doi: 10.34190/ejel.22.1.3261.

[29] S. Drumm, "Applying individual strategies enhances learning in asynchronous learning paths," *Computers and Education Open*, vol. 8, Jun. 2025, doi: 10.1016/j.caeo.2025.100257.

[30] J. C.-Y. Sun and Y. Liu, "The mediation effect of online self-regulated learning between engagement and cognitive load: A case of an online course with smart instant feedback," *International Journal of Online Pedagogy and Course Design*, vol. 12, no. 1, pp. 1–17, 2022, doi: 10.4018/IJOPCD.295953.

[31] Y.-L. Lin, W.-T. Wang, and M.-J. Hsieh, "The effects of students' self-efficacy, self-regulated learning strategy, perceived and actual learning effectiveness: A digital game-based learning system," *Educ. Inf. Technol. (Dordr).*, vol. 29, no. 16, pp. 22213–22245, 2024, doi: 10.1007/s10639-024-12700-4.

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