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Integration of SOLE-Based Progressive Web Apps: Trends and Empirical Insights for Critical Thinking in Education

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ABSTRACT

Digital education expands rapidly, yet research on Progressive Web Apps (PWA) and Self-Organized Learning Environments (SOLE) often proceeds separately, obscuring how integration with standardized critical-thinking measures improves learning. This review addresses that gap by synthesizing evidence, specifying how PWA affordances scaffold SOLE processes, and offering guidance for practice and policy. A Systematic Literature Review (SPAR-4-SLR) was conducted. Searches in Scopus, SINTA, and Google Scholar covered 2020–2025 using Boolean strings (PWA and SOLE and "critical thinking"). Inclusion targeted peer-reviewed studies in formal education reporting learning or critical-thinking outcomes; screening followed PRISMA 2020. Instruments comprised a four-criterion Likert quality appraisal (objectives clarity, methodological appropriateness, data quality and completeness, educational relevance; cutoff ≥ 12), a standardized data-extraction form, and NVivo 12 for thematic analysis with calibration and inter-rater agreement (Cohen's κ ≥ 0.70). Twenty-five studies were included. Results show 32% focused on PWA (flexibility, motivation, project-based engagement), 40% on SOLE (independence, collaboration, inquiry), and 28% on integrated approaches indicating potential for adaptive, participatory, contextual ecosystems, although instruments are heterogeneous and causal designs limited. Theoretically, the review specifies a technology–pedagogy alignment that maps offline access, installability, responsiveness, and notifications to SOLE phases and core critical-thinking dimensions. Practically, it recommends a design checklist for educators, rubric and outcome alignment for curriculum developers, and policies prioritizing device access, reliable connectivity with offline options, lightweight authentication, and professional development for SOLE facilitation.

Keywords: Progressive Web Apps; Self-Organized Learning Environments; Critical Thinking; Digital Learning; Education.

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1. INTRODUCTION

Digital transformation in education is reshaping how learning is designed, delivered, and assessed, while critical thinking becomes a core competency for navigating uncertain and complex contexts. Empirical studies show that sustained motivation and well-aligned curricula predict growth in higher order thinking, which is central to academic and workplace performance (Berestova et al., 2022; Wang & Jia, 2023). In vocational and professional tracks, this competence supports adaptive decision making and performance in real tasks aligned with outcomes-based

frameworks (Aulia, 2023). Alignment between goals, pedagogy, and assessment remains a lever for improving critical thinking at scale (Prabowo et al., 2023).

Employability is a strategic priority because it directly influences graduates' work readiness. Evidence indicates that collaborative learning and targeted soft skills development strengthen employability when embedded in authentic tasks and reflective practice (Rofiudin, 2024). Teaching Factory implementations have been associated with creativity, production discipline, and industry relevance through real project pipelines and quality standards (Wibowo et al., 2025). These directions situate critical thinking as both an academic outcome and a Labor market capability that bridges school and industry expectations (Aulia, 2023; Prabowo et al., 2023).

On the technology side, Progressive Web Apps offer offline access, install ability, responsiveness, and background synchronization that widen access across devices and bandwidth conditions. Educational deployments report higher engagement and flexible pacing, provided that usability and user experience are rigorously designed and evaluated (Ming et al., 2022; Wulandari et al., 2023; Alfarizi et al., 2023). Integrating these affordances with pedagogy is an emerging priority in digital learning strategies (Lampropoulos et al., 2022).

Pedagogically, Self Organized Learning Environments emphasize big questions, minimal direct instruction, collaborative exploration, and public presentation. Studies report gains in mathematical communication, creativity, motivation, self-regulation, and higher order thinking when SOLE is structured with clear prompts and reflection cycles in digital or blended settings (Isnaintri & Nindiasari, 2023; Septiani et al., 2022; Azizah, 2022; Sulistyanto et al., 2022). Pandemic era reforms expanded opportunities to adopt SOLE at scale through technology enhanced delivery (Poungjinda & Pathak, 2022).

A key research gap is the persistent separation between PWA and SOLE studies. Technology focused work tends to prioritize performance and usability, while pedagogy focused work canters on facilitation and group dynamics, which fragments design decisions and limits cumulative evidence. Instrument heterogeneity in measuring critical thinking further constrains comparability across implementations (Carreira et al., 2022). The novelty in this line of inquiry is an integrative mapping that connects concrete PWA affordances to specific SOLE phases and to multi-dimensional indicators of critical thinking, yielding a concept to design crosswalk that can inform both development and evaluation (Lampropoulos et al., 2022; Ming et al., 2022).

To strengthen the theoretical connection, PWA affordances are positioned as supports for SOLE processes and cognitive operations linked to higher order thinking. Offline access and caching can extend exploration and interpretation; install ability and responsiveness can stabilize collaboration and explanation across diverse devices; background synchronization and notifications can scaffold regulation, evidence gathering, analysis, and public presentation cycles. This alignment reframes technology as a scaffold for inquiry, collaboration, and evaluation rather than a neutral carrier of content (Ming et al., 2022; Wulandari et al., 2023; Carreira et al., 2022).

Methodologically, transparent synthesis is required to clarify what works, for whom, and under what conditions. The scope focuses on peer reviewed empirical studies in formal education that investigate PWA, SOLE, or their integration and report learning or critical thinking outcomes within 2020 to 2025. The approach employs a SPAR 4 SLR guided SLR with PRISMA screening, a four criterion Likert appraisal of study quality, and standardized data extraction to enable thematic comparison and design implications, responding to calls for measurement rigor and reporting consistency (Carreira et al., 2022; Alfarizi et al., 2023; Wulandari et al., 2023).

Accordingly, this study aims to map trends, evidence, and gaps in integrating PWA and SOLE for strengthening critical thinking; to articulate a theory informed crosswalk that links PWA

affordances to SOLE phases and to core dimensions of higher order thinking; and to delimit the scope to formal education and peer reviewed empirical work during 2020 to 2025 with explicit outcome reporting. Expected contributions include a clearer conceptual model connecting technology and pedagogy, a practical checklist for implementation and facilitation routines, and policy facing recommendations for low bandwidth deployment, device access, and rigorous evaluation using standardized instruments.

2. METHODS

2.1 Research Design

This study adopts a Systematic Literature Review using the SPAR-4-SLR protocol because its three stages planning, conducting, reporting explicitly align with the study's objectives: mapping trends (RQ1), analysing pedagogical/technological applications (RQ2), and identifying integration opportunities (RQ3). Unlike PRISMA (primarily a reporting standard), SPAR-4-SLR structures upfront scoping, boundary setting, and question–method fit while remaining compatible with PRISMA for transparent documentation (Paul & Criado, 2020; Page et al., 2021). The design is theory-driven: inclusion, coding, and synthesis are anchored to technology affordances (PWA: offline access, install ability, responsiveness, notifications), pedagogy processes (SOLE: big question, exploration, collaboration, presentation), and critical-thinking dimensions (interpretation, analysis, evaluation, inference, explanation, self-regulation), as shown in Figure 1.

Figure 1. SPAR-4-SLR framework adapted from Sari & Prasetya (2025).

2.2 Research Questions

The planning stage of the SPAR-4-SLR protocol begins with the formulation of research questions (RQ), which serve as the foundation of the literature review. These research questions are designed to guide the article selection and analysis process, ensuring alignment with the study's objectives, namely to map trends, analyse applications, and identify opportunities for

integrating technology and pedagogy (Braun & Clarke, 2021). Based on these objectives, the research questions in this study are as follows:

RQ1: What are the research trends related to the development of Progressive Web Apps (PWA) in the context of education?

RQ2: How is the Self-Organized Learning Environments (SOLE) model applied to improve students' critical thinking skills?

RQ3: What opportunities exist for integrating PWA and SOLE to support digital learning, particularly in strengthening critical thinking skills in education?

2.3 Inclusion and Exclusion Criteria

In conducting a Systematic Literature Review (SLR), establishing inclusion and exclusion criteria is a crucial step to ensure that the analysed articles are aligned with the research focus. Applying these criteria ensures that only studies consistent with the purpose of the review are included, thus maintaining validity and enhancing the reliability of the findings. Inclusion criteria define which articles are eligible for analysis, whereas exclusion criteria eliminate studies that do not meet methodological or substantive standards (Snyder, 2019), as shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

Aspect	Inclusion Criteria	Exclusion Criteria
Publication Year	Published between 2020–2025	Published before 2020
Article Type	Empirical studies using quantitative, qualitative, or mixed-methods approaches	Conceptual papers, opinion pieces, editorials, or grey literature without empirical data
Publication Type	Peer-reviewed journal articles (indexed in Scopus, SINTA, or Google Scholar)	Conference proceedings, internal reports, books, or other non-journal publications
Language	Published in Indonesian or English	Articles in languages other than Indonesian or English
Main Topics	Focused on PWA, SOLE, critical thinking, digital learning, or education	Studies outside the scope, e.g., PWA for e-commerce or SOLE in non-educational fields
Educational Context	Conducted in formal education settings (elementary, secondary, vocational, or higher)	Conducted outside formal education, e.g., PWA in non-educational industries

2.4 Literature Search Procedure

The literature search procedure was carried out using a systematically formulated keyword strategy: ("Progressive Web Apps" OR "PWA") AND ("Self-Organized Learning Environments" OR "SOLE") AND ("critical thinking" OR "higher-order thinking skills" OR "digital learning" OR "education"). The search was conducted across international and national indexed databases, namely Scopus, Google Scholar, and SINTA, and was limited to empirical articles published between 2020 and 2025. The article selection process followed the PRISMA reporting protocol, which includes the stages of identification, screening, eligibility, and inclusion, to ensure traceability and transparency at each step of the review, as shown in Table 2.

Table 2. Stages of Article Selection

Stage	Number of Articles
Initial search results	225
After removal of duplicates	180
After title and abstract screening	90
After full-text eligibility assessment	40
Final articles included in the analysis	25

The detailed process of article elimination and selection is illustrated in a PRISMA flow diagram, which provides a transparent overview of each stage of identification, screening, eligibility, and inclusion. The diagram also demonstrates the traceability of the literature selection process, culminating in the inclusion of 25 final articles for analysis in this study, as shown in Figure 2.

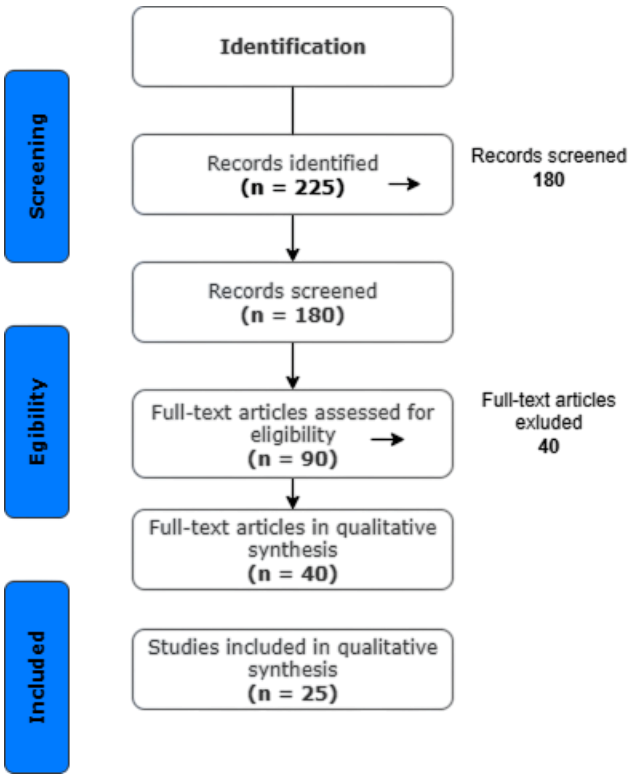

Figure 2. Article Selection Using the PRISMA Protocol

The article selection process in this study followed the internationally recognized PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting standards (Page et al., 2021). The selection flow was visualized in a PRISMA diagram to ensure transparency and traceability throughout the review stages, culminating in the inclusion of the final articles for analysis.

2.5 Study Quality Assessment

Quality assessment was conducted to ensure that only articles meeting methodological standards and relevant to the research focus were included for further analysis. Each article that passed the selection stage was assessed based on four main criteria: clarity of research objectives, appropriateness of methodology, quality and completeness of data, and relevance to the

educational context (Munn et al., 2018). Scores were assigned using a 1–4 Likert scale, where a score of 1 indicated very low quality and a score of 4 indicated very high quality (Koo & Yang, 2025). Articles with a total score of ≥12 were considered eligible for further analysis, whereas those scoring below the threshold were excluded from the synthesis process, as shown in Table 3.

Table 3. Quality Assessment Criteria for Included Studies

Evaluation Criteria	Score 1 (Very Low)	Score 2 (Low)	Score 3 (High)	Score 4 (Very High)
Clarity of Research Objectives	No explicit research objectives	Objectives are stated in general terms, not focused on PWA–SOLE–CT	Objectives are clear and related to one of the focuses (PWA, SOLE, or CT)	Objectives are very clear and specifically address the integration of PWA–SOLE and the strengthening of critical thinking
Methodological Appropriateness	Research methodology is not explained	Methodology is mentioned but inappropriate for the study context	Methodology is appropriate (empirical: quantitative, qualitative, or mixed methods)	Methodology is detailed, valid, and highly relevant for assessing PWA–SOLE integration in education
Data Quality and Completeness	Data is unavailable or unverifiable	Data is limited and insufficient to support the analysis	Data is sufficiently complete and supports partial analysis	Data is comprehensive, valid, and fully supports the discussion of PWA–SOLE–CT integration
Relevance to Educational Context	Not relevant to the educational context	Educational context is weakly or unclearly mentioned	Partially relevant to formal education	Highly relevant to formal and vocational education, including the integration of learning technology

2.6 Data Extraction and Synthesis

Data extraction used a structured form derived from PRISMA items and SLR guidance, capturing bibliographic details, educational context, design and methods, focus classification (PWA, SOLE, or integrated), learning and critical-thinking outcomes, and implementation features (PWA affordances and SOLE phases). The instrument was piloted on five studies; the template is provided in Appendix A. Title and abstract screening and full text eligibility checks were conducted in duplicate by independent reviewers. A 30% calibration sample established an operational codebook; inter rater reliability was estimated with Cohen's kappa (target $k \geq 0.70$), with disagreements resolved by consensus, codebook refinement, and back coding as needed. An audit trail in NVivo 12 recorded coding comparisons and analytic memos. Thematic analysis followed Braun and Clarke's six phases, using NVivo Matrix Coding Query to examine co-occurrence patterns and Relationship Mapping to visualize conceptual links, with peer debriefing to safeguard objectivity (Braun & Clarke, 2021).

2.7 Reporting Review Results

In the final stage, eligible articles were systematically synthesized through publication trend analysis, thematic synthesis, and research mapping. Trend analysis describes the distribution of studies by year, discipline, and educational context, while thematic synthesis identifies key patterns in the integration of PWAs and SOLE to strengthen critical thinking. Research mapping highlights gaps and directions for future studies, thereby ensuring that the SLR provides a transparent and comprehensive overview of the research objectives (Snyder, 2019).

3. RESULT AND DISCUSSION

3.1 Literature Identification Based on SPAR-4-SLR

From an initial 225 articles, 25 met the inclusion criteria as empirical studies published between 2020 and 2025 in either Indonesian or English, focusing on the integration of PWAs and SOLE in enhancing critical thinking in education. Using the SPAR-4-SLR model, the selection process included duplicate removal, title and abstract screening, full-text assessment, and methodological quality review. These articles formed the basis for a thematic synthesis examining publication trends, key findings, and thematic categories, as shown in Table 4.

Table 4. Final Articles Included in the Review Based on Key Findings and Thematic Categories

No.	Author(s)	Article Title	Summary of Key Findings	Thematic Category
1	(Indriani and Ramadhan, 2025)	The Effect of SOLE (Self-Organized Learning Environment) Model and Reading Interest on Writing Skills	SOLE model improves writing skills through collaborative learning.	SOLE – Critical Thinking
2	(De Klerk et al., 2025)	Enhancing Critical Thinking Through Collaborative Learning: The Impact of a Partial Pre-Release Assessment Format	Collaborative learning strengthens students' critical thinking.	Critical Thinking – Pedagogy
3	(Abu et al., 2024)	Exploring the Impact of the SOLE Model on Student Response and Higher-Order Thinking Skills (HOTS)	SOLE enhances learning outcomes and student independence.	SOLE – Digital Learning
4	(Budiarto et al., 2024)	E-Learning Platform for Enhancing 21st Century Skills for Vocational School Students: A Systematic Literature Review	PWA-based e-learning supports the development of digital and higher-order skills.	PWA – Digital Learning
5	(Anuar and Othman, 2024)	Development and Validation of Progressive Web Application Usability Heuristics (PWAUH)	PWA usability heuristics are valid and effective for web-based learning.	PWA
6	(Liu and Wei, 2024)	A Study on Critical Thinking Cultivation in Senior High School English Teaching Considering the Internet Background	Systematic learning strategies enhance critical thinking in senior high school students.	Critical Thinking
7	(Zuurmond et al., 2024)	Learning to Question the Status Quo: Critical Thinking, Citizenship Education, and Building in Vocational Education	Critical pedagogy reinforces the relevance of vocational education.	Vocational – Critical Pedagogy
8	(Hidayati et al., 2024)	Development of Learning Media to Improve Critical Thinking Skills and Creativity of Vocational Students	Digital media effectively fosters critical thinking and creativity.	Digital Learning – Critical Thinking

No.	Author(s)	Article Title	Summary of Key Findings	Thematic Category
9	(Yanti et al., 2024)	The SOLE Model on the Critical Thinking of Fifth Grade Elementary School Students	SOLE improves critical thinking among elementary students.	SOLE – Critical Thinking
10	(Tsamago and Bayaga, 2023)	The Effect of SOLE Pedagogy on Learners' Metacognitive Skills in the Physical Sciences Classroom	SOLE significantly enhances student engagement in learning.	SOLE
11	(Katual et al., 2023)	Game-Based Learning to Improve Critical Thinking and Knowledge Sharing: Literature Review	Game-based learning supports critical thinking and knowledge sharing.	Critical Thinking – Digital Learning
12	(Angelelli et al., 2023)	Developing Critical Thinking Skills Through Gamification	Gamification effectively improves students' critical thinking.	Critical Thinking – Digital Learning
13	(Muaziyah et al., 2023)	Implementation of the Merdeka Curriculum Using Citizen Science Project Weather-it to Improve Critical Thinking	SOLE integration supports the Merdeka Curriculum and HOTS.	SOLE – Curriculum
14	(Indahwati et al., 2023)	Integration of PJBL, STEAM, and Learning Tool Development in Improving Students' Critical Thinking Skills	Integration of PJBL and STEAM strengthens higher-order thinking, including critical thinking.	Critical Thinking – Pedagogy
15	(Eunike et al., 2023)	Application of Progressive Web Apps (PWA) on PT SKA's E-Commerce Website	PWA supports flexible student project work.	PWA – Vocational
16	(Hudianti et al., 2023)	Implementation of Progressive Web Apps for the Management System of Kali Opak Tujuh Bulan	PWA improves accessibility of academic and institutional information.	PWA – Digital Learning
17	(Yuan and Mengmeng, 2023)	Research on the Psychological Path to Enhance Social Recognition of Vocational Education	Learning psychology influences the improvement of critical thinking.	Critical Thinking
18	(Khairani, 2023)	Application of the SOLE Learning Model to Improve Critical Thinking in Sixth Grade Social Studies	SOLE improves critical thinking in junior high school students.	SOLE – Critical Thinking
19	(Putro et al., 2023)	Collaboration of PWA and Firebase Cloud Messaging (FCM) for Optimal Performance Mailing Software	Collaboration between PWA and SOLE produces adaptive learning solutions.	PWA – SOLE
20	(Ghufron et al., 2023)	The Effect of STAD-Type Cooperative Learning on Critical Thinking in Writing Materials	Cooperative learning strengthens critical thinking skills.	Critical Thinking
21	(Herman and Frederick, 2023)	Progressive Web Apps: Development and Acceptance Study among Indonesian Students Using Scrum and UTAUT	PWA adoption is proven effective in vocational education.	PWA – Vocational
22	(Kusmiyati, 2023)	Implementation of the SOLE Model to Enhance Learning Outcomes and Student Independence	SOLE consistently improves critical thinking and learning independence.	SOLE – Critical Thinking
23	(Umamah and Noviyanti, 2023)	The Effectiveness of the SOLE Model to Enhance Students' Critical Thinking	SOLE is effective at the elementary school level.	SOLE

No.	Author(s)	Article Title	Summary of Key Findings	Thematic Category
24	(Wang and Jia, 2023)	Research on Curriculum Reform and Teaching Mode of Vocational Education Based on Learning Theory	Curriculum reform supports critical-thinking-based learning.	Curriculum – Critical Thinking
25	(Isnaintri and Nindiasari, 2023)	Students' Mathematical Communication Skills Through the SOLE Model Assisted by Phet Simulation on Quadratic Functions	SOLE enhances mathematical communication and student independence.	SOLE – Critical Thinking

The Table 4 above summarizes 25 selected articles along with their authors, titles, key findings, and thematic categories. The analysis reveals three dominant themes. First, the implementation of Progressive Web Apps (PWA), which emphasizes flexibility of access, enhanced motivation, and support for project-based learning, particularly in educational contexts. Second, the application of Self-Organized Learning Environments (SOLE), which consistently contributes to the development of critical thinking skills through big-question-driven learning and independent as well as collaborative engagement. Third, the integration of PWA and SOLE as adaptive, collaborative, and contextual pedagogical strategies, although studies explicitly examining their integration remain relatively limited. These selections provide a basis to interpret patterns through cognitive load, self-regulated learning, and ICAP lenses in the subsequent synthesis.

3.2 Thematic Synthesis of Literature Review

The thematic synthesis in this literature review was developed to address the previously formulated research questions, focusing on the development of Progressive Web Apps (PWA), the application of Self-Organized Learning Environments (SOLE), and their potential integration in strengthening critical thinking skills in education. Based on 25 selected articles analysed through the SPAR-4-SLR protocol, categorization was conducted according to their relevance to each research question (RQ). The synthesis process highlighted both the empirical contributions of each study and the identification of thematic trends, methodological patterns, and research gaps that remain open.

a. Progressive Web Apps (PWA) in Digital Education (RQ1)
   Of the 25 articles analysed, 8 (32%) focused on the use of Progressive Web Apps (PWA) in digital education, reporting consistent findings that the technology enhances accessibility, flexibility, and student engagement through features such as offline access and user-friendly interfaces. PWA is positioned not only as a technological innovation but also as a pedagogical tool to support learning and skill development. However, studies explicitly linking PWA implementation to the development of critical thinking skills remain limited, leaving open opportunities to further explore PWA's contribution to measurable higher-order cognitive outcomes.
b. Self-Organized Learning Environments (SOLE) in Strengthening Critical Thinking (RQ2)
   A total of 10 articles (40%) analysed in the review focused on the application of Self-Organized Learning Environments (SOLE) in education. The main findings indicate that SOLE consistently supports the strengthening of critical thinking, independent learning, and collaborative abilities through a learning approach driven by big questions. Its application is effective across multiple educational levels, from elementary to higher

education, with consistent results in enhancing student engagement and promoting mastery of higher-order thinking skills (HOTS). However, few studies have explored comprehensive and standardized skill measurement, leaving room for further research to establish measurable indicators of critical thinking in the context of SOLE.

c. PWA–SOLE Integration as a 21st Century Pedagogical Strategy (RQ3)
A total of 7 articles (28%) examined the opportunities for integrating Progressive Web Apps (PWA) with Self-Organized Learning Environments (SOLE) as a pedagogical strategy. The synthesis indicates that their combination has the potential to offer more adaptive, collaborative, and contextual learning to support critical thinking skills. The integration of PWA–SOLE is seen as capable of bridging the gap between technology and pedagogy, particularly in educational contexts that emphasize work readiness and skill development. However, studies explicitly addressing their integration remain limited and largely exploratory, underscoring the need for further in-depth and comprehensive research.

d. Theoretical integration across RQ1–RQ3
The patterns above align with established cognitive and digital learning theories. From a cognitive load perspective, PWA features such as offline access, caching, and responsive delivery reduce extraneous load and stabilise access, which supports sustained processing during inquiry. Within the ICAP framework, SOLE tasks move learners from active to constructive and interactive engagement as they generate explanations and negotiate meaning. Self-regulated learning is supported by PWA notifications and background synchronisation that prompt planning, monitoring, and reflection, while SOLE's big-question and presentation cycles elicit metacognitive control. Principles of multimedia learning are reflected when PWA interfaces minimise unnecessary elements and foreground task-relevant cues, thereby improving germane processing during exploration and collaboration. Together, these mechanisms explain why PWA, SOLE, and their integration are theoretically suited to strengthen higher-order thinking, as shown in Table 5.

Table 5. Distribution of Thematic Categories from 25 Selected Articles (2020–2025)

Thematic Category	Number of Articles	Percentage	Main Focus
RQ1 – Progressive Web Apps (PWA) in Digital Education	8	32%	Enhancing the flexibility of digital learning, increasing student motivation and engagement, and supporting education through lightweight and adaptive web-based media.
RQ2 – Self-Organized Learning Environments (SOLE) in Strengthening Critical Thinking	10	40%	Developing critical thinking, independent learning, creativity, and collaboration through contextual and big-question-based learning.
RQ3 – Integration of PWA and SOLE in Digital Pedagogy	7	28%	Providing adaptive, collaborative, and contextual learning models to support skill development, particularly critical thinking, and ensuring relevance to work readiness in digital-era education.

In addition to the distribution of thematic categories, article quality assessment is a crucial step to ensure that each publication analysed meets appropriate academic standards. This evaluation was conducted to determine whether the selected articles demonstrate clear research objectives, employ suitable methodological designs, present data of sufficient quality, and report findings relevant to the educational context. The assessment process used a Likert scale-based instrument, producing average scores that offer an objective overview of the methodological strengths and limitations of the analysed articles. A summary of the article quality assessment results is presented in the following Table 6.

Table 6. Average Scores of Article Quality Assessment Based on the Likert Scale

Criteria	Average Score
Clarity of Research Objectives	3.56
Methodological Appropriateness	3.72
Data Quality and Relevance	3.52
Relevance of Findings to Educational Context	3.44

The results of the article quality assessment show variations in the average scores across evaluation criteria. Methodological Appropriateness received the highest score (3.72), indicating that most articles employed methodological approaches relevant to and consistent with their research objectives, although differences remained in the depth of technical reporting. Clarity of Research Objectives achieved a relatively high score (3.56), confirming that the majority of articles explicitly and purposefully conveyed their research focus in line with the themes of PWA, SOLE, and critical thinking. Meanwhile, the scores for Data Quality and Relevance (3.52) and Relevance of Findings to Educational Context (3.44) were slightly lower. This suggests that although the data used was generally valid, there were variations in the completeness of documentation and in the extent to which findings were connected to formal educational contexts. These findings highlight the need to improve empirical data reporting and strengthen the linkage of research outcomes to broader educational contexts. Overall, while the analyzed articles met adequate methodological standards, there remains room for improvement, particularly in terms of data documentation and contextual alignment.

3.3 Visualization of Research Synthesis Results

The visualization of the results shows that studies on Self-Organized Learning Environments (SOLE) in strengthening critical thinking skills account for the largest portion, at 40% of the articles analysed. This finding reinforces evidence that big-question-driven and independent collaborative learning strategies remain a central focus of researchers. The dominance of SOLE is also consistent with educational needs, where students are expected not only to master factual knowledge but also to develop critical, creative, and independent thinking skills. This indicates that pedagogical aspects remain a strong foundation in the current literature, despite the rise of various technological innovations in education.

On the other hand, research on Progressive Web Apps (PWA) in digital education represented 32% of the literature. This proportion is relatively significant, particularly in relation to the broader trend of digital transformation, which accelerates the adoption of web-based learning technologies. Articles in this category generally highlight flexibility of access, ease of use, and the capacity of PWAs to foster learning engagement. However, most studies remain focused on

technical aspects and user experience, while investigations into the integration of PWAs with pedagogical models that foster critical thinking remain limited.

The integration of PWA–SOLE accounted for 28% of the total articles, indicating that literature explicitly linking web-based technological innovations with SOLE pedagogical strategies is still minimal. This finding highlight both a gap and an opportunity for further research, as the integration of the two is believed to foster adaptive, collaborative, and contextual learning models. The relatively low proportion of articles in this category suggests that integrative research is still exploratory in nature and requires methodological strengthening as well as broader empirical implementation, as shown in Figure 3.

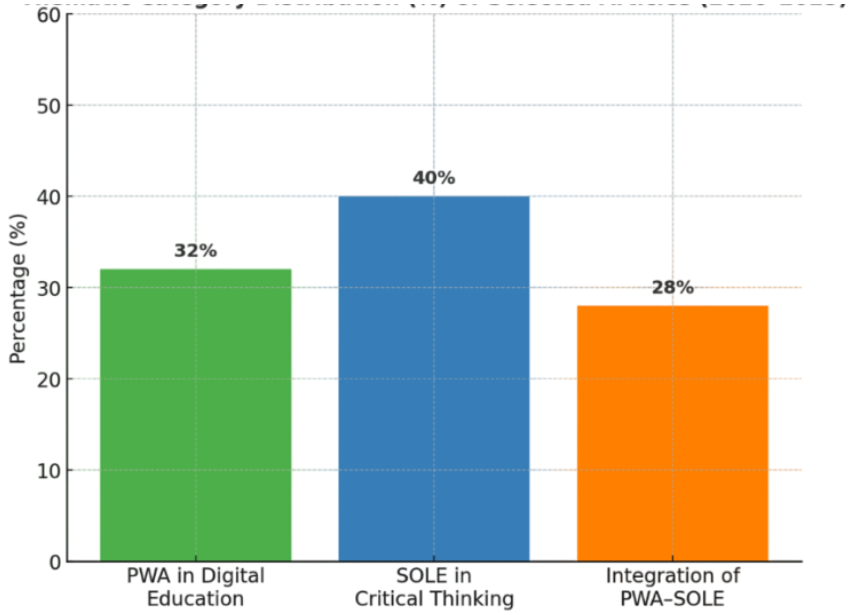

Figure 3. Thematic Category Distribution of Selected Articles (2020-2025)

Thus, the visualization of this synthesis study not only offers a quantitative overview of the research focus distribution but also highlights directions for future research. The dominance of SOLE indicates a strong emphasis on pedagogical aspects, while the significant proportion of PWA reflects the growing relevance of digital technology innovation. Conversely, the limited integration of PWA–SOLE underscores a gap in the literature that requires attention. Therefore, further research that emphasizes the integration of technological innovation and pedagogical strategies is urgently required to strengthen critical thinking skills in the context of digital education.

3.4 Interpretation of Critical Discussion Results and Implications

a. Progressive Web Apps in Digital Education

The implementation of PWAs in digital education is relevant not only for supporting technical flexibility but also for synergizing with cutting-edge technological transformations. A recent literature review confirms that integrating PWAs with the Internet of Things (IoT) offers strategic opportunities to enhance digital learning experiences and strengthen the learning ecosystem (Prasetya, et al., 2025).

Based on 7 articles (28% of the total), the literature synthesis indicates that the combination of these two approaches can contribute significantly to strengthening

students' critical thinking skills. The findings highlight that the main advantage of PWAs lies in their ability to merge the practicality of web applications with the user experience of mobile applications, including offline access and direct installation features, which are highly relevant for distance and project-based learning (Anuar & Othman, 2024; Budiarto et al., 2024). Empirical evidence further demonstrates that the use of PWAs in education can increase student engagement and facilitate the personalization of learning materials to individual needs, thereby improving the quality of digital interactions (Hidayati et al., 2024; Rongmin et al., 2024).

In addition to supporting technical flexibility, PWAs also contribute to improving pedagogical quality. Recent studies confirm that the use of PWAs in digital classrooms positively influences students' intrinsic motivation and promotes higher learning outcomes (Ahmed et al., 2025; Alzahrani, 2024). Similar findings are reported in other studies that emphasize the importance of digital media integration in developing skills, particularly within educational contexts (De Klerk et al., 2025; Zuurmond et al., 2024).

From a user perspective, heuristic evaluations in PWA development indicate that interface design quality, response speed, and ease of navigation are key factors determining the effectiveness of digital learning (Parveen & Ramzan, 2024). Furthermore, the integration of interactive features in PWAs, such as adaptive quizzes and online discussion forums, has been shown to contribute to enhancing critical thinking skills by stimulating collaborative activities (Abu et al., 2024; Indriani & Ramadhan, 2025). However, the use of PWAs in education continues to face limitations, with most studies focusing primarily on technical development and user experience, while integration with innovative pedagogical models remains relatively underexplored (Liu & Wei, 2024). This gap indicates the need for further research to clarify the linkage between PWAs and competency-based learning outcomes, particularly in the development of skills such as critical thinking, collaboration, and creativity. Thus, the literature review confirms that PWAs hold strong potential as a digital education platform that not only enhance accessibility but also enrich contextual and adaptive learning experiences. However, to maximize their contribution, further research is needed to link the technical advantages of PWAs with collaborative pedagogical strategies, thereby transforming digital learning into a more effective, inclusive, and critical-thinking-oriented process.

b. Self-Organized Learning Environments (SOLE) in Strengthening Critical Thinking

In the context of education, the application of SOLE is further reinforced through the integration of innovative digital applications. Studies examining the use of CLO3D in fashion education programs demonstrate that simulation-based technology can be integrated with SOLE to enhance student exploration and creativity (Prasetya, et al., 2025). Furthermore, the application of the PBET strategy demonstrates that a technology-based collaborative approach can foster critical thinking skills while linking learning to digital business practices (Rofiudin et al., 2025). The synthesis of 10 articles (40% of the total) indicates that SOLE consistently has a positive impact on students' critical thinking skills through big questions that stimulate analysis, evaluation, and collaborative presentation of findings (Tsamago & Bayaga, 2023; Yanti et al., 2024). This model aligns with the educational paradigm that prioritizes learner-cantered approaches while fostering students' metacognition (Angelelli et al., 2023).

In the context of digital education, the application of SOLE supported by e-learning has been shown to strengthen learning independence and foster student creativity. Rohman

(2024) study confirms that integrating SOLE into online learning supports students' active engagement in solving complex problems. Husni (2023) research further demonstrates that SOLE enhances the quality of digital learning interactions among pre-service teachers, particularly through collaboration in joint projects. This is reinforced by Tang & Hare (2023) study, which combines SOLE with gamification, leading to a more adaptive and engaging learning experience. Furthermore, SOLE is also relevant in educational contexts that require real-world problem solving. Widoyoko (2023) study demonstrates the model's effectiveness in enhancing students' work readiness through project-based learning.

Meanwhile, Rahmat (2023) indicates that integrating SOLE with augmented reality fosters the development of higher-order thinking skills in applied science learning. This context is reinforced by Mahalingam (2024) research, which underscores the role of school–industry collaboration in optimizing SOLE implementation to enhance curriculum relevance. However, the literature review highlights several limitations. Muaziyah (2023) found that critical thinking skill assessment instruments in the SOLE context remain varied and lack standardization. Indahwati (2023) adds that a key challenge lies in teachers' capacity to design meaningful big questions, which sometimes results in suboptimal SOLE implementation. Furthermore, Setiawan (2024) highlights cultural resistance in educational contexts that remain predominantly teacher-centered, indicating that adapting this model requires a gradual approach.

Overall, the literature findings confirm that SOLE contributes significantly to strengthening students' critical thinking skills. SOLE's approach is relevant not only from elementary to higher education but also in contexts that demand adaptive and collaborative problem solving. With the integration of digital technology and support from industry collaboration, SOLE has the potential to foster more contextual, innovative, and critical learning experiences.

c. Integration of Progressive Web Apps (PWA) Self-Organized Learning Environments (SOLE) for Strengthening Critical Thinking

The integration of Progressive Web Apps (PWA) with Self-Organized Learning Environments (SOLE) represents a pedagogical paradigm that combines the advantages of digital technology with an independence-based approach. From 7 articles (28% of the total), a synthesis of recent literature indicates that the combination of the two can significantly enhance critical thinking skills. PWA offers flexibility of cross-device, offline, and multiplatform access to learning resources, while SOLE emphasizes the exploration of big questions that engage students in analysis, evaluation, and collaboration. Together, their integration creates an adaptive learning ecosystem that fosters active participation and competency development (Herman & Frederick, 2023; Kusmiyati, 2023).

Recent research confirms that the integration of PWA–SOLE not only enhances student engagement but also broadens access to more inclusive learning opportunities. Eunike (2023) study shows that the use of PWA in digital environments supports the achievement of SOLE objectives by providing responsive digital media. Similarly, Hudianti (2023) found that PWA applications in community-based learning contexts strengthen collaborative interactions among students. Meanwhile, Ghufron (2023) revealed that SOLE-based collaborative learning, when combined with digital platforms, enhances critical thinking skills in academic writing.

In education, this integration is relevant for preparing students to adapt to technological changes in industry. Yulastri (2023) emphasized that a project-based approach reinforced by PWA–SOLE enhances students' entrepreneurial readiness and problem-solving skills. Hariyanto (2023) added that project-based learning with digital media integration strengthens students' analytical, collaborative, and adaptive skills in vocational schools. Research by Yuan & Mengmeng (2023) further highlights that the integration of critical and technology-based learning models can strengthen the social recognition of education. However, the literature also notes limitations in implementation. Wulandari (2023) found that although PWA facilitates material distribution, the success of its integration with SOLE is strongly influenced by the quality of learning media design. Long (2023) adds that user interaction factors such as video design and facilitator involvement play a critical role in determining integration effectiveness. Furthermore, Alfarizi (2023) notes that technical challenges related to usability and user experience must still be addressed for PWA–SOLE integration to reach its full potential. Even so, PWA–SOLE integration represents a new direction in learning design by emphasizing digital literacy, creativity, and adaptive problem solving. This integration holds potential as a pedagogical framework to strengthen students' critical competencies. This pattern is consistent with the model in Section 3.5 where offline access and notifications support exploration and self-regulation during SOLE.

3.5 Integrated Conceptual Model: Bridging PWA, SOLE, and Critical Thinking

The integrated model positions technology as a scaffold for inquiry rather than a neutral carrier of content. It specifies three linkages:

a. PWA affordances to SOLE phases: offline access and caching support exploration; install ability and responsiveness stabilize collaboration and presentation across devices; notifications and background sync cue planning, monitoring, and timely feedback.
b. SOLE phases to critical-thinking dimensions: big questions trigger interpretation and problem framing; exploration and collaboration drive analysis, evaluation, and inference through evidence gathering and argumentation; presentation consolidates explanation and self-regulation via reflection on product and process.
c. Equity and inclusion: data-light PWA delivery and device-agnostic access broaden participation, enabling diverse learners to engage in SOLE with minimal bandwidth constraints, as shown in Table 7.

Table 7. Mapping of PWA features, SOLE phases, and critical-thinking dimensions

PWA feature	Supported SOLE phases	Targeted critical-thinking dimensions
Offline access and caching	Exploration	Analysis; Evaluation
Install ability and device-agnostic access	Collaboration; Presentation	Explanation; Analysis
Responsiveness and performance	Collaboration; Presentation	Analysis; Evaluation; Explanation
Background synchronization and notifications	Exploration; Presentation	Self-regulation; Analysis
Lightweight UI and low-bandwidth delivery	Exploration; Collaboration	Analysis; Evaluation

Taken together, these linkages show how specific technological features can be orchestrated into pedagogical routines that elicit higher-order thinking, providing a coherent basis for implementation and assessment.

3.6 Implications

Starting from the integrated model in Section 3.5, implications are derived in four mutually reinforcing domains.

a. Theoretical. The model extends technology–pedagogy frameworks by specifying which PWA affordances align with SOLE processes that elicit higher-order thinking, offering a theory-driven crosswalk rather than a tool-oriented checklist.
b. Pedagogical practice. Instructors can use a design checklist: formulate assessable big questions; map each SOLE phase to one or two PWA features; plan prompts for self-regulation (notifications, progress cues); ensure low-bandwidth delivery; and embed short explanation and argumentation routines during collaboration and presentation.
c. Assessment. Adopt standardised instruments for critical thinking with multi-dimensional rubrics; combine product-based evidence with process data from PWA logs to capture planning, monitoring, and revision.
d. Policy and infrastructure. Prioritise device access programs, campus or school Wi-Fi plus offline-first content bundles, and lightweight authentication to reduce access friction; support professional development for big-question design and facilitation of SOLE.

These four domains form a unity that serves as a basis for discussing the limitations and directions of further research.

3.7 Limitations and Directions for Future Research

The evidence base remains limited by heterogeneity of instruments for measuring critical thinking, uneven technical reporting of PWA implementations, and a concentration of studies in specific regions and education levels. The 2020–2025-time window and the focus on journal articles may exclude relevant design reports or earlier groundwork. Classification into PWA, SOLE, or PWA-SOLE categories can be sensitive to reporting quality. Future work should employ pre-registered protocols, multi-site quasi-experimental or design-based studies, and standardised critical-thinking measures with reliability reporting. Richer analytics are recommended, including alignment of PWA usage logs with SOLE facilitation events to test the hypothesised pathways in the conceptual model. Cross-context replications and cost–benefit analyses will strengthen external validity and practical adoption.

4. CONCLUSION

The synthesis shows that integrating Progressive Web Apps (PWA) and Self-Organized Learning Environments (SOLE) strengthens critical thinking. Across the corpus, 32% of studies emphasized PWA contributions to flexibility, motivation, and project-based engagement, 40% highlight SOLE effects on independence, collaboration, and inquiry, and 28% examine their integration with promising results. Beyond aggregation, this review advances theory by explaining how specific PWA affordances function as scaffolds for SOLE processes that elicit higher-order cognition: offline access and install ability reduce access friction, responsiveness stabilizes collaborative work, and notifications support self-regulation; aligned with big questions,

exploration, collaboration, and public presentation, these supports map to interpretation, analysis, evaluation, inference, explanation, and self-regulation in a staged, inquiry-oriented workflow.

Practical implications follow directly. Educators can adopt a design checklist: formulate assessable big questions, align each SOLE phase with one or two PWA features, schedule prompts for planning and reflection, ensure low-bandwidth delivery, and embed brief explanation and argumentation routines. Curriculum developers should align outcomes and multidimensional rubrics with this model, package offline-first content bundles, and integrate learning analytics to capture process evidence. Policymakers should prioritize device access, reliable school Wi-Fi with offline options, lightweight authentication, and professional development for SOLE facilitation and media design. Limitations remain, including heterogeneous instruments, uneven technical reporting, and context concentration. Future research should include multi-site empirical validation with comparison groups, development and validation of standardized critical thinking instruments tailored to PWA–SOLE implementations, and longitudinal studies that examine durability, scalability, and cost-effectiveness while linking platform logs to facilitation events to test the proposed mechanism.

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