

## OFFLINE-FIRST PWA З КОНТРОЛЬОВАНОЮ ПІДТРИМКОЮ ГЕНЕРАТИВНОГО ШІ ДЛЯ НАВЧАННЯ ІНФОРМАТИКИ У ПРИФРОНТОВІЙ ШКОЛІ

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## OFFLINE-FIRST PWA WITH CONTROLLED GENERATIVE AI SUPPORT FOR TEACHING INFORMATICS IN A NEAR-FRONTLINE SCHOOL

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### АНОТАЦІЯ

**Формулювання проблеми.** Освітній процес у прифронтових територіях має не лише організаційний, а й методичний виклик: нестабільні електропостачання та інтернет руйнують безперервність навчальних дій і спотворюють справедливість оцінювання, тоді як генеративний ШІ додатково знижує валідність перевірки, що спирається лише на кінцевий результат програмування. У статті перевіряється, чи здатний offline-first підхід зберегти навчальну дію та забезпечити доказовість виконання завдань за умов перебоїв без переходу до неконтрольованого використання ШІ.

**Матеріали і методи.** Запроваджено offline-first PWA «Edu Survival Kit» з локальним збереженням і відкладеною синхронізацією, модулем контрольованих підказок на основі GenAI та процесно орієнтованим оцінюванням через артефакти діяльності (версії, короткі пояснення, тести для перевірки). Пілотне дослідження охопило три групи стейкхолдерів (7, 10, 11 класи; доступ отримали 84 здобувачі освіти). Використано описові індикатори платформи, анонімне опитування (n = 33), відгуки вчителів (n = 2) та експертну оцінку (n = 1). Дані узагальнено описово та тематично.

**Результати.** Offline-first рішення забезпечило продовження роботи під час уроку за планового відключення та суттєво скоротило час доступу до завдань у мікропорівнянні з LMS-маршрутом (менше секунди проти десятків секунд). Здобувачі освіти високо оцінили зручність і підтримку за нестабільного зв'язку та стресу; найвищі оцінки отримали багаторівневі підказки і GenAI-помічник. Вчителі й експерт підтвердили придатність для прифронтових умов, але вказали на головний ризик – надмірну довіру до GenAI, що може призводити до поверхового розуміння.

**Висновки.** Offline-first архітектура працює як база інфраструктури навчання у прифронтовій школі, якщо оцінювання фіксує процес і перевірку, а не лише продукт. Використання GenAI є прийнятним за наявності правил прозорості, обов'язкової верифікації та мінімізації даних.

**КЛЮЧОВІ СЛОВА:** offline-first; прогресивний вебзастосунок; інформатика; освіта в умовах надзвичайних ситуацій; формувальне оцінювання; валідність оцінювання; генеративний ШІ; прифронтова школа.

**ДЛЯ ЦИТУВАННЯ:** Turchyn D. Offline-First PWA with controlled generative AI support for teaching informatics in a near-frontline school. *Фізико-математична освіта*, 2026. Том 41. № 1. С. 32-36. <https://doi.org/10.31110/fmo2026.v41i1-05>.

### ABSTRACT

**Formulation of the problem.** Near-frontline schooling faces a practical barrier that becomes methodological: learning continuity and assessment fairness are undermined when electricity and internet access are unstable, while generative AI can further weaken the validity of product-only grading in programming tasks. This study examines whether an offline-first learning design can preserve core learning actions and provide assessable evidence of work under disruption without normalizing unverified reliance on GenAI.

**Materials and methods.** The intervention was an offline-first Progressive Web App (“Edu Survival Kit”) with local persistence and deferred synchronization, complemented by controlled GenAI tutoring and a process-oriented assessment approach based on artifact traces (versions, short reflections, and verification tests). The pilot involved three school cohorts (Grades 7, 10, and 11; 84 learners received access). Evidence included descriptive platform indicators, an anonymous learner survey (n = 33), teacher feedback (n = 2), and external expert appraisal (n = 1). Data were summarized descriptively and thematically.

**Results.** The offline-first design sustained learning during planned outage conditions and markedly reduced task access time compared to an LMS route in a micro-comparison (sub-second versus tens of seconds). Learners reported high perceived usability and strong perceived support under unstable connectivity and stress; the GenAI hint layer received the highest usefulness ratings. Teachers and the expert confirmed crisis-fit and innovativeness but emphasized the main risk: over-trust in GenAI, which can mask shallow understanding.

**Conclusion.** Offline-first architecture can function as instructional infrastructure in near-frontline settings when paired with an assessment that foregrounds process evidence rather than final products. GenAI support is pedagogically acceptable only under explicit transparency and verification rules and with data minimization.

**KEYWORDS:** offline-first; Progressive Web App; informatics education; education in emergencies; formative assessment; assessment validity; generative AI; near-frontline schooling.

**FOR CITATION:** Turchyn, D. (2026). Offline-First PWA with controlled generative AI support for teaching informatics in a near-frontline school. *Physical and Mathematical Education*, 41(1), 32-36. <https://doi.org/10.31110/fmo2026.v41i1-05>.

### INTRODUCTION

Educational systems operating under crisis conditions face a shift from “access problems” to “continuity problems.” Even when learning remains formally available, unstable electricity and intermittent internet fragment participation, disrupt pacing, and make uniform assessment procedures inequitable. Equity concerns during remote learning were documented during the COVID-19 period, when the feasibility of continued learning depended on household resources and connectivity, rather than

solely on policy intent (Avanesian et al., 2021; The World Bank et al., 2021). In near-frontline settings, these constraints recur and intensify: connectivity is not merely low-quality but structurally unpredictable.

Informatics education is disproportionately affected. Learning tasks often require repeated micro-cycles (attempt, run, debug, revise). If learners cannot reliably open materials, access tasks, or submit evidence of their work, instructional time is lost before the content becomes relevant. Assessment is also destabilized: under intermittent connectivity, the “time of submission” can measure infrastructure rather than competence, and a single outage can erase evidence of progress. Emergency assessment guidance has therefore emphasized fairness, flexibility, and the careful use of evidence rather than rigid event-based testing (Allehaiby, 2021; Bawane & Sharma, 2020).

A second disruption is unfolding in parallel. Generative AI systems can now generate code, explanations, tests, and alternative solutions. In informatics, this can widen access to help and reduce “stuckness,” but it can also conceal shallow understanding and undermine the interpretability of product-only grading. Policy and governance documents increasingly stress that education must redesign tasks and assessment so that human reasoning, responsibility, and verification remain visible (Miao & Holmes, 2023; OECD, 2023, 2026; National Institute of Standards and Technology [NIST], 2023). In other words, the challenge is not simply whether GenAI is permitted, but whether assessment still measures what it claims to measure.

This paper presents a pilot study that integrates these two problem lines. We introduce an offline-first PWA for informatics learning (“Edu Survival Kit”) coupled with a process-oriented assessment framework and a controlled GenAI support module. The aim is not to “solve connectivity” but to remove connectivity as a hidden prerequisite for basic learning actions, and to shift assessment from single-point product checks toward accumulated evidence of process and verification.

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## CONCEPTUAL AND RESEARCH BACKGROUND

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### *Educational resilience under infrastructure instability*

Education in emergencies frameworks treat resilience as more than reopening access. The INEE Minimum Standards emphasize safe learning environments, community engagement, adaptation of curricula and assessment, and accountability mechanisms that remain workable under disruption (Inter-Agency Network for Education in Emergencies, 2024). The empirical lesson from global disruptions is that “remote learning availability” does not guarantee participation; reachability depends on devices, connectivity, and household conditions (Avanesian et al., 2021). This creates a methodological implication: measurement and grading must avoid conflating competence with infrastructure.

System-level perspectives on digital transformation also warn that connectivity is only one component of a broader cost structure: energy, maintenance, security, support, and user training shape whether digital schooling remains usable (Sepúlveda, 2020). For near-frontline regions, the operational conclusion is pragmatic. Instructional design needs fallback modes that preserve the core learning action when the network disappears.

### *Offline-first as an instructional design principle*

Offline-first originated in software engineering as a design priority: the application should remain functional without a network connection, with online features treated as enhancements rather than prerequisites (Kleppmann et al., 2019). In education, offline-first can be treated as a didactic principle: learning tasks should remain executable, progress should be locally preserved, and synchronization should be deferred until connectivity returns.

In web-based delivery, offline-first is implemented through PWA practices such as caching, service workers, and offline data management. Developer guidance describes the difference between a superficial offline mode (error messages) and a functional offline experience that preserves state and supports recovery after reconnecting (Google, 2014, 2021a, 2021b, 2022, 2024; Mozilla, 2024, 2025). From a pedagogical standpoint, the most relevant feature is not technical elegance but continuity: micro-cycles of learning can continue without being reset by network loss.

### *Assessment validity when the network and GenAI are unstable variables*

The classic argument for formative assessment is that learning improves when teachers and learners use evidence to adjust instruction and strategies (Black & Wiliam, 1998). In emergency contexts, formative cycles also buffer disruption: smaller, frequent evidence points reduce the impact of any single failed assessment event (Bawane & Sharma, 2020). Long-term learning perspectives further underscore the need for assessment aligned with durable competence rather than short-lived performance (Boud & Falchikov, 2006).

In higher-stakes remote assessment, OECD highlighted those technical conditions can directly threaten fairness and validity, and that assessment design must anticipate these risks rather than treat them as noise (OECD, 2020). In informatics, GenAI expands this validity problem: if a correct solution can be cheaply produced, the evidential value of the product decreases. Current governance discussions, therefore, stress transparency of AI use, the ability to verify outputs, and institutional rules that manage risk without forcing unrealistic bans (Miao & Holmes, 2023; OECD, 2023, 2026; NIST, 2023). Professional ethics norms are consistent with this direction: the ACM Code of Ethics emphasizes honesty, avoidance of harm, fairness, and responsible design (Association for Computing Machinery, 2018).

### *GenAI in programming education: promise and risk*

Recent empirical work suggests that learners’ interaction with GenAI in programming can shape behavior patterns, including debugging strategies and reliance on generated solutions (Stoyanova, 2025; Sun, 2024). These findings do not imply that GenAI is pedagogically harmful by default, but they reinforce the need for design constraints: scaffolding should support reasoning and verification, and assessment should demand evidence that is difficult to outsource fully.

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## PURPOSE AND RESEARCH QUESTIONS

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The purpose of the study was to theoretically justify and empirically pilot an integrated offline-first learning environment for informatics that includes controlled GenAI support and a process-oriented assessment framework, suitable for near-frontline infrastructure instability.

The study addressed three research questions:

(1) Does an offline-first PWA preserve continuity of learning actions under outages and unstable connectivity in a near-frontline school setting?

(2) How do learners, teachers, and an external expert appraise the usability, perceived learning support, and crisis-fit of the environment?

(3) What assessment and governance risks emerge when GenAI support is embedded, and what design constraints appear necessary?

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## RESEARCH METHODS

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### *Design and setting*

The pilot was conducted at a near-frontline Ukrainian secondary school (in the Shostka area), where outages and unstable internet repeatedly disrupt schooling. The study used a pragmatic, quasi-experimental, and descriptive mixed-evidence design, appropriate when randomization is not feasible, and the primary goal is to establish feasibility and stakeholder acceptability (Campbell & Stanley, 1963; Creswell & Creswell, 2018).

### *Participants*

Three cohorts participated: Grade 7 (n = 30), Grade 10 (n = 28), and Grade 11 (n = 26), totaling 84 learners granted access. The broader teaching and evaluation group included two teachers and one external expert. An anonymous end-of-pilot learner survey was completed by 33 respondents (39.3% of those with access). The Grade 10 cohort comprised the majority of survey respondents, with smaller shares from Grades 7 and 11.

### *Intervention: "Edu Survival Kit" (offline-first PWA with controlled GenAI support)*

The intervention was implemented as a PWA to prioritize local functionality. The offline core included access to tasks and materials, local persistence of progress and artifacts, and a learning flow structured into short cycles, each ending with a saved artifact. Online features were treated as add-ons: synchronization, teacher-facing monitoring, content updates, and AI services. This architecture follows standard PWA guidance emphasizing caching, service workers, offline data handling, and recovery after reconnecting (Google, 2014, 2021a, 2021b, 2022, 2024; Mozilla, 2024, 2025).

Deferred synchronization was used to separate "performed" from "uploaded." This distinction is essential for fairness: a learner who completes work offline should not be penalized for late synchronization due to connectivity issues (OECD, 2020). At the same time, data minimization principles were applied as a design requirement aligned with AI risk governance (NIST, 2023) and broader guidance on responsible GenAI use (Miao & Holmes, 2023).

The GenAI component was positioned as a tutor for explanation, diagnostic hints, test generation for self-checking, and brief reflection prompts. It was constrained by rules intended to preserve academic integrity: transparency of AI use, default verification via tests and artifact history, and avoidance of personal data sharing (Association for Computing Machinery, 2018; Miao & Holmes, 2023; NIST, 2023).

### *Process-oriented assessment framework*

Assessment was designed around accumulated evidence rather than a single product. For each task, learners were expected to produce a minimal evidence package: a final artifact, at least one intermediate version or a short change history, small test cases demonstrating verification, and a concise explanation of decisions or error correction steps. The logic is consistent with formative assessment theory (Black & Wiliam, 1998), crisis assessment guidance (Allehaiby, 2021; Bawane & Sharma, 2020), and alignment with long-term learning (Boud & Falchikov, 2006). The framework also responds to GenAI-related validity threats by making process evidence central rather than optional (OECD, 2023, 2026; Miao & Holmes, 2023).

### *Data sources and analysis*

Four evidence sources were used. First, descriptive platform indicators documented offline scenario functionality and access latency during a micro-comparison. Second, a learner survey used a five-point scale to capture perceived usability and support. Third, teacher feedback captured operational and pedagogical concerns. Fourth, an expert appraisal provided an external perspective on quality. Quantitative data were summarized descriptively. Qualitative open responses were thematically condensed with attention to credibility and consistency, following established principles for qualitative rigor (Patton, 1999).

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## RESEARCH RESULTS

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### *Continuity and latency under unstable connectivity*

Two objective observations were emphasized in the pilot. In a micro-comparison of task access, the conventional LMS-based route required approximately 40–60 seconds to reach tasks, whereas the offline-first solution provided access in under 1 second. In a near-frontline setting, this difference is pedagogically significant: it supports instructional pacing and reduces frustration before learners even engage with the content.

A second observation came from a planned outage lesson (a graded lesson on CSS Flexbox). The class continued work without connectivity, and progress was synchronized after the connection returned. This served as a functional test of offline-first continuity: learning actions did not collapse into "waiting for the internet," and assessment evidence persisted.

### *Learner perceptions*

Learner survey responses indicated generally positive perceptions across usability, motivation, and crisis-fit. Interface clarity showed a mean of 3.94, with 72.7% selecting the top two categories (4–5). Perceived usefulness of multi-level hints and the AI assistant was particularly high, with a mean of 4.70, and all respondents selected 4 or 5. Gamification showed a mean of 4.00, again with 72.7% selecting 4–5. Reported comfort under unstable internet or stress conditions reached a mean of 4.73, with all respondents selecting 4 or 5. These results suggest that the intervention was not merely tolerable but experienced as supportive under conditions of disruption.

Open comments converged on three motifs. Learners valued the ability to work offline, described the environment as fast and practical, and occasionally noted instability or uneven quality in AI hints. The last motif is analytically important: it

indicates that learners noticed non-determinism and that AI help is not automatically trusted as correct, which aligns with the need to institutionalize verification rather than assume it (Miao & Holmes, 2023; OECD, 2026).

#### *Teacher feedback and expert appraisal*

Teachers highlighted structured materials, monitoring of learning activity beyond mere logins, and the promise of GenAI for differentiated help. However, teachers also articulated a core pedagogical risk: AI hints may “switch off” independent reasoning if not constrained. They requested practical integration features, particularly a straightforward export of grades into spreadsheet formats, and tools to distinguish independent work from AI-generated text or solutions.

The external expert appraisal reported an overall average of around 4.15 (median 4, range 3–5). The highest ratings were assigned to near-frontline adaptability and innovativeness, while lower ratings were associated with technical aspects and scalability within routine school procedures. The central risk identified by the expert was over-trust in GenAI. The recommended condition for scaling was the presence of explicit transparency and verification rules, which aligns with governance guidance on GenAI in education and AI risk management (Miao & Holmes, 2023; NIST, 2023; OECD, 2026).

## DISCUSSION OF THE RESULTS

The pilot supports a pragmatic claim: offline-first architecture can protect the integrity of the learning action itself. When tasks open immediately, and progress persists offline, the instructional unit shifts from “connected session” to “learning cycle,” which is more robust under outages. This is consistent with PWA design guidance that treats offline capability and state persistence as core quality criteria rather than optional enhancements (Google, 2024; Mozilla, 2025). In near-frontline conditions, offline-first becomes a didactic principle because it directly shapes what counts as feasible pedagogy: shorter cycles, persistent artifacts, and deferred synchronization.

This also ties to equity. When connectivity is uneven, online-first systems implicitly reward households and time windows with stable connectivity. By separating performance time from upload time, deferred synchronization reduces one pathway through which infrastructure becomes an unacknowledged grading factor. Such design choices address fairness concerns raised in emergency assessment guidance and in discussions of remote exam policy (Allehaiby, 2021; OECD, 2020).

The pilot underscores the declining evidential value of the final product alone. Both teachers and the expert treated “AI replacing thinking” as the primary risk. This risk is not mitigated by prohibition alone in settings where learners can access GenAI on personal devices and where teachers cannot continuously supervise all interactions. A more defensible strategy is to redesign assessment so that evidence of reasoning, testing, debugging, and revision is required.

Formative assessment theory provides a robust rationale for this shift: frequent evidence and feedback cycles strengthen learning and make competence more observable (Black & William, 1998). Long-term learning alignment further supports assessments that value transferable practices, such as testing and explanation, rather than short-term output production (Boud & Falchikov, 2006). GenAI governance guidance strengthens the argument in a new way: when AI can generate outputs, assessment must foreground human verification and responsibility (Miao & Holmes, 2023; OECD, 2026). The “minimal evidence package” used in this pilot offers a concrete operationalization that can be scaled and standardized.

Learners perceived AI-supported hints as highly helpful, especially under stress and when limited to synchronous teacher assistance. This finding aligns with the broader premise that GenAI can support learning when positioned as scaffolding rather than outsourcing. Yet the stakeholder warnings indicate that the tutor role requires guardrails: transparency, verification, and data minimization. These principles align with AI risk management frameworks (NIST, 2023), education-sector guidance (Miao & Holmes, 2023; OECD, 2023), and professional ethics commitments to honesty and avoidance of harm (Association for Computing Machinery, 2018). In informatics, verification is especially tractable because tests can be demanded as routine evidence, turning “trust” into “check.”

Teachers’ requests for grade export and differentiation between “real activity” and superficial engagement show that adoption depends on operational compatibility. UNESCO’s framing of digital learning as a public good emphasizes systems thinking: tools must integrate into everyday governance and accountability, not remain isolated pilots (UNESCO, 2023). The expert’s lower ratings for scalability suggest that the next iteration should strengthen teacher-facing workflows, reporting, and standard operating procedures for the review of assessment evidence.

## LIMITATIONS

Three limitations shape interpretation. First, the learner survey covered 39.3% of those granted access, so perceptions may be biased toward more active or more satisfied participants. Second, the design included a micro-comparison and an offline control event but did not implement random assignment or a full controlled experimental structure; causal claims about learning gains cannot be made (Campbell & Stanley, 1963). Third, GenAI effects may vary by prior competence and by how learners use hints. Without fine-grained analysis of usage patterns and error profiles, the study can only describe feasibility and acceptability rather than differential effectiveness.

## CONCLUSION

This pilot study examined an integrated response to two simultaneous disruptions in informatics education: infrastructure instability and the availability of generative AI. The offline-first PWA “Edu Survival Kit,” combined with a process-oriented assessment framework and controlled GenAI tutoring, demonstrated feasibility in a near-frontline school setting. Objective observations indicated that an offline-first design preserved continuity during outages and reduced access latency compared to an LMS-based route. Learners reported high comfort and high perceived usefulness of hints and GenAI support, while teachers and an external expert emphasized both the promise of differentiated assistance and the central risk of over-reliance on AI. The findings support a practical conclusion: resilience and assessment validity improve when an offline-first design is paired with evidence-based formative cycles, explicit verification artifacts, and governance rules that make GenAI use

transparent and accountable. Future work should extend beyond feasibility to a stronger evaluation of learning outcomes and a systematic analysis of learner-AI interaction patterns.

#### CONFLICT OF INTEREST

The authors declare no financial, personal, or other interests that could be considered a potential conflict of interest regarding the publication of this article.

#### FUNDING SOURCES

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

#### DATA AVAILABILITY

This is a theoretical study and does not involve the use of any additional datasets.

#### USE OF ARTIFICIAL INTELLIGENCE (AI) TOOLS

AI tools were not used in the writing of this work.

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| Received: 29.11.2025 | Accepted: 15.01.2026 | Published: 02.03.2026 |



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