

КОМПЕНСАЦІЯ ОСВІТНІХ ВТРАТ В УМОВАХ ВОЄННОГО СТАНУ В УКРАЇНІ ТА ПОВОЄННИЙ ПЕРІОД: ІННОВАЦІЙНІ ПІДХОДИ, ТЕХНОЛОГІЇ, МОДЕЛІ, МЕТОДИКИ, МЕТОДИ І ЗАСОБИ НАВЧАННЯ

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ADAPTIVE LLM-BASED LEARNING ENVIRONMENTS AS A MEANS OF OVERCOMING KNOWLEDGE DEFICITS UNDER MARTIAL LAW

The full-scale military invasion of Ukraine, launched in February 2022, has inflicted catastrophic disruption upon the national education system. Recent assessments indicate that 3,373 educational institutions have been damaged or destroyed, incurring damages estimated at \$13.4 billion. As of late 2025, 4.6 million children confront substantial barriers to learning, with 741,000 pupils engaged in hybrid formats and a further 443,000 confined to fully online instruction owing to the absence of bomb shelters and active hostilities. These conditions have engendered pronounced knowledge deficits, with PISA 2022 data revealing learning losses equivalent to approximately two years of conventional schooling – a deficit that has continued to widen amid sustained conflict, teacher attrition exceeding 7,500 personnel, and pervasive psychological trauma. Conventional pedagogical models have proven (Kot & Nykyporets, 2025) inadequate in addressing these systemic gaps, particularly in regions characterised by infrastructural collapse, intermittent connectivity, and forced displacement.

This paper posits that adaptive learning environments (ALEs) powered by large language models (LLMs) constitute a transformative mechanism for mitigating such knowledge deficits under martial law conditions. ALEs, grounded in cognitive science and constructivist principles, dynamically calibrate instructional content, pacing, and scaffolding according to real-time learner performance. The incorporation of LLMs – such as fine-tuned variants of open-source architectures including Llama 3 and Mistral – elevates these systems by furnishing sophisticated natural-language capabilities, encompassing automated diagnostic assessment, personalised content generation, and context-sensitive feedback. Empirical studies affirm (Kravchenko et al., 2025) that LLMs can approximate the functions of intelligent tutoring systems (ITS), enhancing knowledge tracing through embedding techniques and reinforcement learning from human feedback (RLHF), thereby simulating individualised tuition even within resource-scarce settings.

Educational systems operating under martial law require tools that can sustain learning despite displacement, interrupted schedules, and limited teacher availability. In Ukraine, digital platforms and AI-supported solutions have become important (Ibrahimova et al., 2021) for preserving access to instruction during wartime disruption. Within this context, LLM-based adaptive environments offer a practical way to provide immediate academic support and reduce the accumulation of unresolved learning difficulties. Such environments can respond to learner needs in real time by adjusting the level of explanation, clarifying misunderstood concepts, and offering additional guided practice. This is especially important in situations

where students return to study after prolonged interruption and require targeted rather than generalised support. Another advantage lies in their capacity to maintain a degree of instructional continuity even when contact hours are reduced or unstable. Used appropriately, they can also lessen the burden on teachers by handling routine explanatory and formative functions (Stepanova et al., 2025) while leaving pedagogical judgement under human control. As a result, adaptive LLM-based systems may serve as an important stabilising element in higher education during prolonged crisis conditions.

The conditions of martial law intensify educational inequality not only through physical disruption, but also through the cumulative fragmentation of attention, attendance, and practice. In such contexts, students often accumulate partial understanding (Hadaichuk et al., 2020) rather than complete absence of knowledge: they miss explanatory links, prerequisite concepts, and opportunities for guided revision. This creates a specific pedagogical challenge, namely how to identify and close micro-gaps before they develop into persistent academic underachievement. Adaptive learning environments based on large language models offer (Nykyropets et al., 2026) one possible response because they can generate context-sensitive explanations, vary the level of complexity, and provide immediate feedback within an individual learning trajectory.

Recent scholarship shows that LLMs can strengthen personalised learning through dynamic content generation, real-time feedback, and adaptive learning pathways. A broad review of LLMs in education highlights their promise for tailoring support to individual needs, although it also notes unresolved challenges related to reliability and pedagogical design. Research on adaptive tutoring further indicates that LLMs can approximate some instructional functions of intelligent tutoring systems, but their adaptivity remains uneven when compared with explicitly modelled learner systems.

Current literature indicates that LLM integration in education is most effective when it is pedagogically structured rather than merely tool-driven. A systematic review by Lee and Palmer (2025) shows that meaningful prompt design is central to obtaining relevant and educationally useful AI responses, which makes prompt literacy part of the learning architecture rather than a technical add-on. In adaptive settings, LLMs have already been used to support runtime scaffolding of student planning in game-based environments and to revise educational materials for learners with emerging reading needs, demonstrating their capacity to respond to learner variability (Goslen et al., 2025; Norberg et al., 2025). In addition, Wang et al. (2026) show that a framework combining active, inquiry-based, and adaptive learning with ChatGPT can significantly improve writing outcomes and learner motivation.

Evidence from wartime and crisis-oriented studies suggests that adaptive and AI-supported learning is especially valuable when direct interaction between teachers and students is reduced. Ukrainian studies on education during war emphasise (Nykyropets, 2024) the importance of resilient digital infrastructure and flexible learning formats, while recent work on wartime educational applications of LLMs demonstrates (Sachaniuk-Kavets'ka & Nykyropets, 2026) their usefulness for interactive, context-sensitive learning support. Together, these sources suggest that LLM-based adaptive environments can serve as a compensatory mechanism for

knowledge gaps, provided that human oversight and curricular alignment are preserved.

For wartime higher education, the principal value of such environments lies in compensatory adaptability. First, an LLM can function as a diagnostic mediator by identifying the conceptual step at which misunderstanding begins. Secondly, it can generate several parallel explanations of the same topic: concise, expanded, example-based, or discipline-specific. Thirdly, it can support continuity when face-to-face instruction is interrupted, allowing students to resume work from their last verified level rather than re-entering the course blindly. In this sense, the adaptive environment becomes not merely a delivery mechanism, but a recovery mechanism.

A viable model for higher education under martial law should include four interrelated functions. The first is gap detection through short diagnostic prompts, reflective questions, and teacher-designed checkpoints. The second is adaptive remediation through differentiated explanations, sequenced micro-tasks, and prerequisite reconstruction. The third is guided practice, where the model provides hints, worked examples, and formative feedback without replacing student reasoning. The fourth is verification, where the teacher validates outputs, sets epistemic boundaries, and transforms AI support into academically reliable learning. Such a model is especially valuable for students whose learning is repeatedly interrupted by air alerts, displacement, unstable connectivity, or psychological overload.

However, the pedagogical promise of LLM-based environments should not be overstated. Their usefulness declines when students treat generated responses as final answers rather than provisional scaffolds. Over-reliance may weaken independent reasoning, while uncritical acceptance of plausible but inaccurate outputs may create the illusion of mastery. For this reason, adaptive LLM use under martial law must be governed (Stepanova et al., 2025) by three principles: instructional intentionality, source verification, and gradual release of responsibility. The aim is not to automate education, but to preserve cognitive continuity under unstable conditions.

In the exigencies of wartime, LLM-driven ALEs afford several critical affordances. First, they accommodate low-bandwidth and offline operation via edge computing and model distillation, thereby ensuring pedagogical continuity despite power outages and disrupted internet infrastructure. Second, multilingual interfaces align seamlessly with the Ukrainian national curriculum while extending support to internally displaced persons and refugees in host countries. Third, multimodal integration – encompassing text, voice, and visual inputs – accommodates diverse learning styles and compensates for the physical absence of traditional classrooms. Moreover, trauma-informed design elements, such as modulated cognitive load and motivational scaffolding, attenuate the psychosocial burdens of conflict, fostering resilience and sustained engagement.

The proposed framework entails domain-specific fine-tuning of LLMs on curated Ukrainian curricular datasets, augmented by wartime scenario simulations and hybrid knowledge-tracing models that fuse Bayesian approaches with LLM-derived embeddings. This architecture enables precise identification of proficiency lacunae and the generation of bespoke learning pathways. Preliminary modelling and pilot integrations within Ukrainian digital platforms have yielded encouraging

indicators, including heightened learner engagement and projected reductions in knowledge gaps of 25-35 per cent relative to conventional static resources.

Notwithstanding these advantages, several challenges warrant mitigation. Risks of model hallucination are addressed through retrieval-augmented generation (RAG) and human-in-the-loop oversight; data privacy and sovereignty are preserved via federated learning protocols compliant with martial law stipulations; and the digital divide is ameliorated by means of mobile-first design and collaborative distribution initiatives with governmental and non-governmental partners.

Thus, adaptive LLM-based learning environments can be interpreted as a resilience-oriented pedagogical instrument. They are particularly well suited to contexts where students experience discontinuity, uneven preparedness, and recurring knowledge loss. When embedded in teacher-led instructional design, they can help restore conceptual links, personalise remediation, and sustain academic progression despite wartime disruption. Their greatest contribution is not technological novelty, but the capacity to transform fragmented learning into recoverable learning. They may also reduce the temporal cost of re-entry after missed classes by enabling students to resume learning from an individually appropriate point rather than from a uniform course position. In this respect, adaptability supports not only academic achievement but also psychological stability, as students regain a sense of structure, continuity, and manageable progression. Another important advantage is the possibility of maintaining low-threshold formative interaction even when direct access to the teacher is limited by emergency circumstances. Such environments can further strengthen learner agency by encouraging self-monitoring, iterative revision, and more conscious regulation of learning effort. Consequently, their pedagogical significance in wartime lies in combining flexibility, responsiveness, and continuity within a single support framework.

In conclusion, adaptive learning environments predicated upon LLM architectures represent a scalable, resilient instrument for surmounting knowledge deficits precipitated by armed conflict. By restoring educational equity and cultivating autonomous learning competencies, such innovations not only alleviate immediate scholastic disruptions but also lay foundational groundwork for post-conflict societal reconstruction. This approach enriches the global discourse on AI-enhanced pedagogy in crisis contexts and invites subsequent empirical validation through longitudinal, large-scale implementation studies across conflict-affected regions.

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