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ВІДОМОСТІ ПРО АВТОРІВ

ВАРГАНИЧ Галина – старший викладач кафедри вокально-хорової підготовки вчителя Харківської гуманітарно-педагогічної академії.

Наукові інтереси: музично-педагогічна практика – важлива форма здобуття професійної педагогічної підготовки майбутнього педагога-музиканта.

РОЩЕНКО Ольга – викладач-методист кафедри музично-інструментальної підготовки вчителя Харківської гуманітарно-педагогічної академії.

Наукові інтереси: музично-педагогічна практика – важлива форма здобуття професійної педагогічної підготовки майбутнього педагога-музиканта.

ЖИЛКИНА Олена – старший викладач кафедри вокально-хорової підготовки вчителя Харківської гуманітарно-педагогічної академії.

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INFORMATION ABOUT THE AUTHORS

VARGANICH Galina – Senior Lecturer, Department of Vocal and Choral Teacher Training Kharkiv Humanitarian and Pedagogical Academy.

Scientific interests: music-pedagogical practice is an important form of obtaining professional pedagogical training of a future teacher-musician.

ROSCHENKO Olga – Teacher-methodologist, Department of Musical and Instrumental Teacher Training Kharkiv Humanitarian and Pedagogical Academy.

Scientific interests: music-pedagogical practice is an important form of obtaining professional pedagogical training of a future teacher-musician.

ZHYLKINA Olena – Senior Lecturer, Department of Vocal and Choral Teacher Training Kharkiv Humanitarian and Pedagogical Academy.

Scientific interests: music-pedagogical practice is an important form of obtaining professional pedagogical training of a future teacher-musician.

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ГЕРЕГА Богдан –

аспірант кафедри фізики та астрономії
Карпатського національного університету

імені Василя Стефаника

ORCID: <https://orcid.org/0009-0006-2964-3298>

e-mail: bohdan.hereha.23@pnu.edu.ua

ВІД ТЕОРЕТИЧНИХ МОДЕЛЕЙ ПЕРСОНАЛІЗОВАНОГО НАВЧАННЯ ДО ВИМОГ ДО ОСВІТНЬОГО ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ НА ОСНОВІ ШТУЧНОГО ІНТЕЛЕКТУ В ІНКЛЮЗИВНІЙ ОСВІТІ

Персоналізоване навчання дедалі частіше розглядається не лише як педагогічна мета, а і як конкретне завдання для проектування освітнього програмного забезпечення, особливо в інклюзивних класах. Грунтуючись на аналітичному синтезі дев'яти нещодавніх публікацій, ця стаття систематизує чотири теоретичні основи – адаптивне навчання, технологію повного засвоєння знань, компетентнісний підхід та універсальний дизайн навчання – і трансформує їх у систему вимог до освітнього програмного забезпечення на базі ШІ. У роботі роз'яснюється, як педагогічні наміри співідносяться з функціоналом, що підлягає реалізації, зокрема: діагностикою та моделюванням профілю учня, генерацією динамічних освітніх трасекторій, адаптивним поданням

контенту, а також підтримкою зворотного зв'язку та оцінювання, що допомагає виявляти прогалини у знаннях, зберігаючи критерії прогресу чіткими. Крім того, структура вимог визначає інструменти моніторингу для вчителя, журнали аудиту рекомендацій, а також механізми коригування або скасування рішень системи. Нефункціональні вимоги розглядаються як пріоритетні обмеження: конфіденційність на етапі проектування, безпечна обробка чутливої інформації про учнів, прозорість та інтерпретованість, стійкість і надійність, а також захист від упереджених або дискримінаторів результатів. Архітектурні аспекти розглядаються через призму модульних сервісів, що забезпечують масштабованість, зручність та інтеграцію з інституційною інфраструктурою. Особлива увага приділяється компонентам генеративного ШІ, які можуть розширити можливості створення контенту та зворотного зв'язку, але вимагають суворішого регулювання та нагляду з боку педагогів. Результати дослідження свідчать на користь моделі, де вчитель залишається ключовою ланкою, а ШІ підсилює його фахову експертізу й допомагає долати бар'єри в освітньому процесі. Стаття завершується окресленням того, як оцінювати інклюзивний вплив у реальних умовах та як узгодити алгоритмічну оптимізацію з ключовими освітніми цілями, такими як розвиток суб'ектності та компетентностей учнів.

Ключові слова: персоналізоване навчання, інклюзивна освіта, освітнє програмне забезпечення, штучний інтелект, інженерія вимог, універсальний дизайн навчання

HEREHA Bohdan –

a PhD student of the Physics and Astronomy Department

at Vasyl Stefanyk Carpathian National University

ORCID: <https://orcid.org/0009-0006-2964-3298>

e-mail: bohdan.hereha.23@pnu.edu.ua

FROM THEORETICAL MODELS OF PERSONALISED LEARNING TO REQUIREMENTS FOR ARTIFICIAL INTELLIGENCE-BASED EDUCATIONAL SOFTWARE IN INCLUSIVE EDUCATION

Personalised learning is increasingly treated not only as a pedagogical aspiration but as a concrete design problem for educational software, especially in inclusive classrooms where learner variability is structural rather than exceptional. Based on an analytical synthesis of nine recent publications, this article systematises four theoretical anchors – adaptive learning, mastery learning, competency-based education and Universal Design for Learning – and translates them into a requirements framework for AI-based educational software in inclusive settings. The paper clarifies how pedagogical intentions map to implementable functions, including learner diagnostics and modelling, dynamic trajectory generation, adaptive content presentation with accessible alternatives, and feedback and assessment support that helps identify learning gaps while keeping progression criteria explicit. In addition, the framework specifies teacher-facing monitoring tools, audit trails of recommendations and interventions, and mechanisms for adjusting or overriding system decisions. Non-functional requirements are treated as first-order constraints: privacy by design with data minimisation, secure processing of sensitive learner information, transparency and interpretability, robustness and reliability, and safeguards against biased or discriminatory outcomes. Architectural implications are considered through a modular service perspective that supports scalability, maintainability and integration with institutional infrastructure. Particular attention is given to generative AI components, which can expand content creation and feedback but require stronger governance, verification and educator oversight. The findings support a teacher-in-the-loop model in which AI augments professional judgement and reduces barriers to participation. The article concludes by outlining directions for evaluating inclusive impact in authentic classrooms and aligning algorithmic optimisation with broader educational goals such as learner agency and competency development.

Key words: personalised learning, inclusive education, educational software, artificial intelligence, requirements engineering, UDL.

Statement and justification of the relevance of the problem. The relevance of personalised learning in inclusive education is grounded in a simple empirical observation: contemporary classrooms include learners who differ markedly in prior knowledge, pace of learning, communication modes, and support needs. In such contexts, a single instructional pathway can inadvertently privilege students who align with “average” assumptions and marginalise those who do not. Research on AI-enabled personalised learning argues that the core promise of these systems is the ability to adjust learning content and support in response to learner-specific evidence, but also stresses that benefits depend on careful design choices and on the educational goals against which “personalisation” is defined [1, 5].

At the same time, inclusive education introduces additional constraints that are not peripheral but structural: accessibility needs, language barriers, and the requirement that technological support strengthens – rather than displaces – teachers’ professional work [7, 8]. Therefore, the problem is not whether AI can personalise learning in principle, but what requirements AI-based educational software must satisfy to operationalise pedagogical models of personalisation while remaining safe, transparent, and usable for teachers and diverse learners.

Analysis of recent research and publications.

Across the studies included in this review [1-9], several recurring patterns can be identified.

First, the systematic review of AI-based personalised learning in education [1] classifies contemporary applications into three broad groups: (i) personalised content recommendation, (ii) personalised tutoring and learner support, and (iii) personalised feedback and assessment systems. This typology is important for requirements engineering because it indicates what “personalisation” looks like in implemented systems – not only adaptive content, but also adaptive support and evaluation.

Second, reviews focusing on higher education [2] highlight that implementation is often constrained by governance, ethics, and methodological limitations in evaluation, leading to a recurring call for more robust evidence and clearer frameworks for deployment decisions. This is relevant for inclusive education as well, because students with special educational needs (SEN) may be exposed to higher risks if data practices, accountability, or system limitations are poorly specified.

Third, Artificial Intelligence in Education (AIEd) research on personalised learning pathways [3] treats pathway construction as a design problem involving sequencing, monitoring, and adaptation, rather than a single recommendation step. This aligns with the pedagogical view that learning trajectories should be

dynamic, revisable, and sensitive to learner progress.

Fourth, the systematic review on AI in inclusive education [4] describes AI as potentially supportive for personalisation, accessibility, and learner engagement, while also emphasising recurring challenges such as ethical risks and implementation barriers. In parallel, work directly addressing inclusive education and language barriers [7] reinforces that accessibility and communication supports are not optional “add-ons”, but central functions in inclusive contexts.

Fifth, Laak and Aru [5] argue that “bridging the gap” requires aligning AI-enabled personalisation with contemporary educational goals (e.g., broad competencies), not only with short-term performance metrics. This is a caution against narrow optimisation: a system may improve test performance yet fail to support autonomy, inclusion, or long-term learning aims.

Sixth, the microservice architecture study [6] makes the technical dimension explicit: a personalised learning system is described as needing accurate learner profiling, adaptive path generation, real-time behavioural analysis, multi-dimensional evaluation, and specified non-functional targets such as availability and response time. In reported comparative experiments, the authors present improvements for learners using the AI-based system relative to a traditional system, while also documenting performance optimisation at the system level.

Seventh, the generative AI-focused paper [9] reframes personalisation as an end-to-end workflow that may include multimodal perception, learning analytics-driven diagnosis, and personalised generation with feedback loops; it also stresses value alignment, secure data practices, and interpretability to reduce risks such as hallucination and to increase trustworthiness.

Taken together, these sources justify a requirements-oriented synthesis: pedagogical models define what personalisation should mean, while AI/architecture research clarifies how it is operationalised and what constraints must be engineered into the system.

The purpose of this article is to (i) systematise key theoretical models of personalised learning that are relevant to inclusive education, and (ii) derive a coherent set of functional and non-functional requirements for AI-based educational software that can implement these models in practice while meeting the ethical, accessibility, and teacher-oversight demands highlighted in recent research [4, 6, 9].

Presentation of the main research material. The present study synthesises four commonly cited theoretical models of personalised learning – adaptive learning, mastery learning, competency-based education, and Universal Design for Learning (UDL) – and translates them into requirements for AI-based educational software in an inclusive setting. This translation cannot be “purely technical”: as emphasised in the literature, AIEd should start from educational goals and then select technologies that meaningfully support those goals, rather than allowing tooling to dictate pedagogy [5].

1) From pedagogical models to software functions: a requirements logic

Across the reviewed works, personalised learning

is described less as a single method and more as a system of decisions about (i) what to teach next, (ii) how to teach it, and (iii) how to support a learner when progress becomes uneven. In practice, AI-based systems operationalise these decisions through a cycle: diagnose → model the learner → adapt instruction → monitor outcomes → refine the trajectory. This cycle is visible in systematic reviews of AI-driven personalised learning, where the application landscape includes learning-path recommendation, tutoring/feedback mechanisms, and learner modelling approaches that infer profiles and affinities from interaction data [1].

To keep the requirements traceable to pedagogy, it is useful to map each theoretical model to the minimum system capabilities it implies:

- Adaptive learning requires the system to (i) capture learner state from ongoing activity, (ii) update a learner model, and (iii) adjust content difficulty, sequencing, and feedback in response to that state [1].
- Mastery learning requires (i) diagnostic assessment, (ii) mastery criteria (thresholds, indicators), (iii) targeted remediation when mastery is not met, and (iv) reliable progress monitoring over time (so “mastery” is not guessed but evidenced) [1].
- Competency-based education requires (i) an explicit competency framework, (ii) assessment aligned with competencies (not only task completion), and (iii) reporting tools that allow educators to interpret competency evidence and intervene [5].
- UDL requires (i) multiple means of representation, (ii) multiple means of engagement, and (iii) multiple means of action/expression – implemented through accessible formats and flexible interaction patterns rather than a single “standard” interface [4], especially important for students with SEN and for multilingual contexts [7].

This mapping is not merely conceptual: it is a practical checklist that prevents “personalisation” from collapsing into a vague promise. The same point appears indirectly in discussions of modern educational aims: technology-led individualisation may increase efficiency in domain-specific knowledge acquisition, yet still fail to support broader goals such as learner agency and self-regulated learning unless the system is designed to scaffold them intentionally [5].

2) Learner modelling in an inclusive context: what the system must know (and what it must not assume)

A consistent theme across the articles is the centrality of the learner model: AI can only personalise what it can represent. At the same time, inclusive education raises a methodological and ethical constraint: learner modelling must avoid turning differences into deficits, and must not create hidden “labels” that follow a student without pedagogical justification.

In a practical architecture, learner modelling is implemented as a set of interrelated profiles:

- Knowledge and skill state (topic mastery, misconceptions, competency attainment).
- Learning process indicators (pace, persistence, error patterns, response latency).

- Support needs and accessibility preferences (formats, interaction modes, assistive features).
- Contextual constraints (language barriers, availability of assistive technologies, classroom organisation).

Inclusive education papers emphasise that AI tools supporting special needs or real-time translation must be built with strong safeguards and privacy considerations, because such systems can process highly sensitive educational and behavioural data [7]. The same literature also notes persistent concerns about opacity in AI decision-making and the risk of algorithmic bias affecting assessment outcomes – concerns that are especially damaging in inclusive settings where trust and fairness are foundational [7].

Therefore, a functional requirement in inclusive AI-based systems is not only “profile the learner”, but also:

- provide teacher-visible explanations of why the system inferred a state or made a recommendation (so the educator can accept, reject, or revise it) [7];
- implement privacy-preserving protocols and user-centric controls (particularly where minors and SEN data are involved) [7].

3) Personalised learning pathways: sequencing, feedback, and the role of evidence

Personalised learning pathways can be understood as a structured sequence of learning opportunities that is continuously updated based on evidence. The systematic review literature explicitly documents learning-path recommendation as an application area within AI-based personalisation [1].

However, in a human classroom, pathways are rarely only about “the next task”. They are also about feedback quality, motivation, and the learner’s sense of progress – dimensions that are easily flattened in automated systems. Recent work on GenAI and personalised learning states that GenAI may reshape the construction of learning resources and evaluation systems, but also faces limitations in understanding individual differences across static characteristics and dynamic learning processes [9]. In other words, content generation alone is not equivalent to pedagogically valid personalisation.

For this reason, pathway generation should be treated as an evidence-based mechanism with at least three connected subsystems:

- Diagnostic subsystem: identifies current misunderstandings and readiness signals (including early warning signs of learning difficulties).
- Adaptation subsystem: selects tasks, examples, and representations aligned with the learner model and the instructional intent.
- Monitoring and validation subsystem: checks whether the adapted route actually improves outcomes, and whether the system’s inferences remain consistent with new evidence.

A practical implication from higher-education review literature is that, while AI-driven personalisation often shows potential for efficiency and engagement, the broader body of evidence can be methodologically heterogeneous, motivating a need for clearer evaluation frameworks and more robust research designs [2]. This is relevant here not as a

methodological digression, but as a design requirement: AI-based educational software should embed evaluation hooks (logging, interpretable metrics, teacher feedback loops) so that personalisation can be audited and improved rather than asserted.

4) Generative AI as a component, not the whole system

The reviewed GenAI-focused article frames GenAI-empowered personalised learning as relying on fine-tuning and prompt engineering, diagnosing needs from personal and process data, and generating customised learning content; it also highlights multimodal processing and interdisciplinary integration as enabling richer learning experiences [9]. At the same time, the same paper emphasises gaps: weak autonomy/controllability, insufficient understanding of learning processes, and deficiencies in safety and ethical regulation [9].

For requirements engineering, this leads to a balanced formulation:

- GenAI can be used to generate tasks, explanations, and feedback variants, and to support flexible interaction.
- But GenAI outputs must be bounded by (i) curriculum constraints, (ii) the learner model, and (iii) safety/ethics policies, with teacher oversight as a normal operating mode rather than an emergency mechanism [7, 9].

Technically, the GenAI paper describes implementation strategies such as retrieval-augmented approaches that pull personalised features from a student feature database to support customised teaching plans [9]. In an inclusive context, this approach strengthens personalisation only if the underlying student feature store is itself ethically governed, transparent to educators, and protected against leakage or misuse [7].

5) Architectural implications: why “microservices” is not simply a buzzword

The architectural article on AI-based personalised learning systems argues for a microservice approach to balance performance and scalability while meeting quality requirements such as availability and response time [6]. In inclusive and large-scale deployments, this matters for a concrete reason: personalisation is computation-heavy and interaction-sensitive, and delays or instability do not affect only “user satisfaction” – they affect learning continuity and, in SEN contexts, may undermine accessibility supports that students rely on.

Translating the microservice approach into functional structure, an AI-based personalised learning platform can be conceptualised as a set of services/modules that correspond to the pedagogical cycle:

- Data collection and learning record service (events, attempts, timing, assistive feature usage).
- Learner modelling service (profiles, mastery indicators, competency evidence).
- Recommendation and pathway service (sequencing, difficulty adjustment, remediation selection).
- Content/format adaptation service (UDL-

aligned representation, multimodal delivery).

- Teacher dashboard and oversight service (interpretability, decision review, intervention tools).
- Governance and compliance service (privacy controls, auditing, bias monitoring).

The microservice argument is not, therefore, an abstract engineering preference; it offers a way to keep pedagogical responsibilities separable, testable, and governable – especially when some components (e.g., GenAI generation) require stricter monitoring than others [6, 9].

6) The teacher's position: central, interpretive, and professionally supported

Several inclusive-education analyses note that teacher perceptions of usefulness and ease of use strongly affect whether AI tools are accepted, and that professional development is necessary to address gaps in experience and knowledge – particularly when AI tools risk being perceived as interfering with curriculum coverage or undermining professional judgement [7]. This reinforces a non-functional requirement that is often under-specified in AI system descriptions: the system must be legible to educators.

Legibility includes:

- interpretability (why the system recommends an action),
- controllability (how the teacher can adjust or override it), and
- accountability (how decisions are recorded and reviewed).

This is aligned with broader concerns about transparency and human control raised in ethical discussions of educational AI, especially where privacy, consent, and data minimisation become legally and morally non-negotiable [7].

Findings and perspectives for further research. The nine analysed sources [1-9] converge on a shared conclusion: personalised learning in inclusive education requires a shift from generic “AI features” to explicit, testable requirements grounded in pedagogical models and bounded by ethical and usability constraints. The literature indicates that AI-based personalisation is implemented through recommendation, tutoring/support, and feedback/assessment functions [1], but that inclusive contexts require additional accessibility and teacher-oversight expectations [4, 7]. Technical studies show that these requirements can be translated into concrete system functions (profiling, adaptive pathways, real-time analytics) and explicit non-functional targets (availability, response time, security) [6]. Finally, generative AI expands what can be personalised (e.g., dynamically generated explanations or tasks) but simultaneously raises the bar for interpretability, secure data handling, and controllability to reduce risks such as hallucinations and low-trust outputs [9].

Future work should prioritise:

- Evaluation designs that reflect inclusive goals, not only short-term achievement, consistent with arguments that personalisation must align with broader educational objectives rather than narrow metrics [5].
- Teacher-in-the-loop interaction models that specify when the system recommends, when it defers, and how educators can inspect and override decisions

– an implementation priority for inclusive adoption [7, 8].

• Privacy-preserving and trustworthy GenAI personalisation, including transparent decision logic and secure personalised learning data pipelines, as a prerequisite for responsible scaling [9].

• Accessibility-sensitive learner modelling, especially for learners whose observable interactions differ due to SEN or language barriers, to prevent biased inference and exclusionary adaptation patterns [4, 7].

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ВІДОМОСТІ ПРО АВТОРА

ГЕРЕГА Богдан – аспірант кафедри фізики та астрономії Карпатського національного університету імені Василя Стефаника.

Наукові інтереси: агенти штучного інтелекту та агентні системи для освітніх сценаріїв, застосування штучного інтелекту для проектування персоналізованих навчальних траєкторій, інклюзивна освіта та підтримка учнів з особливими освітніми потребами засобами штучного інтелекту.

INFORMATION ABOUT THE AUTHOR

HEREHA Bohdan – PhD student, Physics and Astronomy Department Vasyl Stefanyk Carpathian National University.

Scientific interests: artificial intelligence agents and agent-based systems for educational use cases, artificial intelligence for designing personalised learning trajectories, inclusive education and artificial intelligence support for learners with special educational needs.

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КУЯВЕЦЬ Дмитро –
аспірант Уманського державного педагогічного
університету імені Павла Тичини
ORCID: <https://orcid.org/0009-0006-0986-3648>
e-mail: dmytro.kuiavets@gmail.com

ОГЛЯД ТРЕНДІВ ЗА 2025 РІК ПО ТЕМІ «ФОРМУВАННЯ ЗДОРОВ'ЯЗБЕРЕЖУВАЛЬНОЇ КОМПЕТЕНТНОСТІ У МАЙБУТНІХ ВЧИТЕЛІВ» ЗАКОРДОННИЙ ДОСВІД

У статті здійснено комплексний аналіз сучасних зарубіжних підходів до формування здоров'язбережувальної компетентності у майбутніх учителів у контексті розвитку концепції *health-promoting education* та глобальних освітніх трансформацій. Актуальність дослідження зумовлена зростанням психоемоційного навантаження на педагогів, цифровізацією освітнього процесу та посиленням ролі закладів вищої освіти у забезпеченні благополуччя учасників освітнього середовища. У сучасному міжнародному освітньому дискурсі здоров'я та благополуччя дедалі частіше розглядаються не як допоміжний компонент, а як системоутворювальний чинник якості педагогічної освіти та професійної стійкості вчителя, що потребує переосмислення змісту його професійної підготовки.

Метою статті є виявлення концептуальних засад і провідних тенденцій формування здоров'язбережувальної компетентності у майбутніх учителів у зарубіжних системах педагогічної освіти, а також обґрунтування можливостей їх системної інтерпретації в контексті сучасних освітніх викликів.. Методологічну основу дослідження становлять аналіз і синтез зарубіжних наукових джерел, порівняльний аналіз, узагальнення результатів оглядових та емпіричних досліджень у сфері *health-promoting education*.

У результаті дослідження виокремлено провідні глобальні тренди 2025 року, серед яких посилення уваги до ментального здоров'я та психоемоційного благополуччя, розвиток навичок саморегуляції та професійного самозбереження педагога, інтеграція фізичної активності й здорового способу життя в освітній процес, а також активне впровадження цифрових та інноваційних підходів до здоров'язбережувальної освіти. Обґрунтовано переосмислення професійної ролі педагога як активного суб'єкта здоров'язбережувальної діяльності та фасилітатора благополуччя.

На основі узагальнення зарубіжного досвіду запропоновано авторську модель формування здоров'язбережувальної компетентності майбутніх учителів, що поєднєє когнітивний, ціннісно-мотиваційний і діяльнісний компоненти та орієнтована на інтеграцію здоров'язбережувальних підходів у зміст і організацію педагогічної освіти.

Ключові слова: здоров'язбережувальна компетентність, педагогічна освіта, *health-promoting education*, ментальне здоров'я, професійне благополуччя педагога, саморегуляція та стресостійкість, фасилітація благополуччя, глобальні освітні тренди, підготовка майбутніх учителів.