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## *Artificial Intelligence in Inclusive Instruction for Braille-Using Students*

**Summary:** *The rapid integration of artificial intelligence (AI) in education has renewed interest in its role in inclusive teaching; however, disability-specific implementation pathways for Braille-literate learners remain underexplored. This conceptual paper examines how AI may support teachers in mainstream classrooms that include students who rely on Braille literacy. The analysis emphasises that accessibility in Braille-mediated learning depends not merely on modality substitution but on the structural organisation and navigability of instructional materials. Drawing on the Artificial Intelligence in Education (AIEd) literature, the paper frames AI as a teacher-governed accessibility support rather than an autonomous instructional agent. Three domains of potential contribution are identified: access to curricular materials, structured participation, and formative support. Key risks include structural distortion, overconfident AI outputs, and uneven language performance, which make systematic verification essential. The paper concludes that AI is most appropriately positioned as an accessibility co-pilot within teacher-led and blended instructional practices, warranting further empirical validation in real classroom contexts.*

**Keywords:** *Artificial intelligence in education; inclusive education; Braille literacy; accessibility*

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## **Introduction**

Inclusive education aims to ensure that all learners, regardless of disability or social background, can participate meaningfully in mainstream schooling (UNESCO, 2020). However, the physical placement of students with disabilities in regular classrooms does not, by itself, constitute inclusion (Edström et al., 2024). Inclusion requires instructional conditions in which learners are not prevented from demonstrating competence by barriers unrelated to the intended learning objectives (Dalton, 2019). Despite strong policy support, the implementation of inclusive education remains constrained by structural factors. Teachers often work with limited material resources, insufficient specialised training, and institutional cultures that adapt slowly to learner diversity (Zwane & Malale, 2018; Jardinez & Natividad, 2024; Motitswe, 2025). In addition, deficit-oriented perspectives that define learners primarily through limitations rather than participation opportunities may further reinforce marginalisation (Shukla, 2022; Nurdyansyah et al., 2022).

Against this background, recent developments in artificial intelligence (AI) have intensified debate about accessibility and instructional differentiation, as AI tools are being increasingly applied in learning analytics, assessment, lesson preparation, and digital communication (Stošić et al., 2025). Across literature, AI-supported environments are reported to enable more adaptive guidance than conventional whole-class instruction through differentiated feedback, flexible pacing, and task sequencing, although such effects remain context-dependent (Abbas et al., 2023; Akgun & Greenhow, 2022; Chen et al., 2020; Hwang et al., 2020; St-Hilaire et al., 2022; Vorobyeva et al., 2025). Nonetheless, educational value should not be presumed; it requires empirical support in terms of measurable gains in learning outcomes and accessibility, without adverse consequences (Castañeda & Selwyn, 2018; Ogunleye et al., 2024; Wu, Dang & Li, 2025).

Artificial Intelligence in Education (AIEd) encompasses intelligent, personalised, and conversational systems, including tools for automated assessment, adaptive feedback, and collaborative support (Tapalova & Zhiyenbayeva, 2022; Ercikan & McCaffrey, 2022; Alam, 2023; Wang et al., 2024; Garzón, Patiño & Marulanda, 2025). Intelligent Tutoring Systems (ITS), among the most extensively studied applications, have in some experimental and meta-analytic studies demonstrated learning gains comparable to one-to-one tutoring (Woolf, 2010; du Boulay, 2016). However, the evidence of the consistent, system-level impact in everyday classrooms remains uneven and contingent on local implementation conditions, including infrastructure and institutional capacity (Miao et al., 2021).

Within inclusive education debates, AI is most appropriately conceptualised as a conditional form of support. When implemented within clearly defined pedagogical frameworks, AI can reduce routine workload, facilitate differentiated instruction, and enable alternative content representations such as speech-to-text or automated image description (Wang, 2020; Melo-López et al., 2025). At the same time, reliance on AI-generated or AI-transformed materials introduces risks, particularly when such materials constitute the learner's primary route to curricular content. The educational value of AI in inclusive contexts therefore depends on deliberate alignment with accessibility requirements, learner diversity, and sustained teacher oversight and accountability (Song et al., 2024).

This paper is conceptual in scope and aims to clarify teacher-facing opportunities, constraints, and evaluation priorities for AI-supported Braille-inclusive practice. Braille-mediated literacy offers a particularly stringent test case for AI-supported accessibility, because understanding and independent navigation often depend on preserving structural relations that are typically encoded visually (e.g., tables, diagrams, symbolic layouts). For this reason, examining Braille-inclusive practice helps specify what “accessible transformation” should mean in

classroom conditions and where teacher verification remains indispensable.

### AI Support for Braille-Mediated Access in Mainstream Classrooms

Students with visual impairments, particularly those who rely on Braille literacy, face specific challenges in inclusive educational settings (Dimitrova-Radojičić & Petrovska Zimeski, 2020). These learners encounter barriers when instructional materials and assessment formats are not appropriately adapted. Empirical evidence links the availability of tactile materials and assistive technologies with higher levels of academic engagement and learner autonomy (Tanwar, 2019; Yektyastuti Sarwanto & Rasmitadila, 2026). The integration of assistive technologies should therefore be understood as a structural condition for equitable participation rather than as an optional enhancement.

Despite the expanding body of research on artificial intelligence (AI) in education, implementation pathways tailored to specific disabilities remain insufficiently specified. The literature frequently addresses accessibility in broad terms (e.g., captioning,

text-to-speech, simplified language), while comparatively less attention is given to modalities that require high representational fidelity, such as Braille-mediated access.

AI can assist teachers by accelerating lesson preparation, broadening access through alternative formats, enabling more interactive participation, and supporting more timely feedback. However, the pedagogical relevance of AI requires careful interpretation: the capacity of AI to generate or transform content does not guarantee preservation of the relational structure that Braille readers depend on for independent navigation and comprehension. The transition from traditional to AI-supported instruction should therefore be framed as a representational and governance challenge rather than merely a technological upgrade. Table 1 summarises key differences between traditional and AI-supported instruction, with particular attention to accessibility and personalisation, dimensions that directly affect Braille-literate learners.

The comparison in Table 1 is conceptual and focuses on teacher practices in a Braille-inclusive classroom. AI support is considered as assisting in the preparation of draft materials, while responsibil-

Table 1. Traditional vs AI-supported instruction for a Braille-literate student

Aspect	Traditional instruction	AI-supported instruction (teacher-governed)
Lesson planning	Manual planning; adaptations often added late	AI may draft structure/sequence; teacher aligns with Braille access needs
Accessible materials	Visually formatted materials; accessible versions often delayed	AI may speed up draft restructuring (headings, labels, steps); Braille-ready output still requires review and, where needed, transcription/embossing workflows (e.g., specialist support).
Tables & layout-dependent content	Visual tables/worksheets hard to navigate linearly	AI may support table linearisation and explicit keys; teacher verifies correctness
Diagrams/graphs	Often minimally described; meaning may be lost	AI may draft structured descriptions; verification is essential due to error risk
Representational fidelity	Relationships encoded in layout may be simplified away	AI can help make relations explicit, but may distort structure without systematic checking
Feedback	Typically delayed	Faster formative prompts are possible, moderated by the teacher
Quality assurance	Checks often informal	Explicit verification step recommended (structure, navigation, notation, tables/diagrams)

ity for validation and accessibility remains with the teacher (and, where necessary, with special educators and rehabilitation specialists).

### AI-Supported Personalisation for Braille-Inclusive Classrooms

AI is frequently associated with personalised learning, understood as the capacity of systems to adapt to how, when, and at what pace a learner engages with content (Bayly-Castaneda, Ramirez-Montoya & Morita-Alexander, 2024). In inclusive settings, this promise becomes pedagogically meaningful only when personalisation is understood as reducing barriers to participation rather than merely optimizing performance metrics. Recent scholarship indicates that adaptive feedback and tailored learning pathways may support learner motivation and progress, but only when embedded within responsible pedagogical strategies and ethical safeguards (Holmes et al., 2019; Castañeda & Selwyn, 2018). Within Braille-inclusive classrooms, AI-supported inclusion can be conceptualized across three practical domains:

1. Access to curricular materials through transformations that render content usable via refreshable Braille displays or embossed Braille;

2. Participation and engagement through interactive, structured tasks that do not depend on visual navigation;
3. Formative support through timely feedback that enables learners to self-regulate and address misunderstandings at an early stage.

These domains overlap but require different forms of AI support. For instance, text-to-speech may facilitate listening, yet it does not substitute for Braille literacy, which remains essential for spelling, punctuation, mathematical notation, and advanced academic work. Conversely, a well-structured braille-ready text can support independent study only when tables, cross-references, and diagrams are carefully re-represented to preserve relational meaning. To summarise the potential contribution of AI in inclusive settings while maintaining a teacher-centred perspective, Table 2 presents a conceptual mapping of benefits.

### AI Tools Potentially Deployable in Mainstream Macedonian Schools for Braille-Literate Students

A growing number of AI-enabled accessibility tools are currently available for learners with visual impairments. However, their practical usefulness in mainstream classrooms varies considerably across linguistic and infrastructural contexts. In particular,

Table 2. Potential contributions of AI to Braille-inclusive teaching

Domain	Contribution in Braille-inclusive classrooms
Instructional adaptation	AI may assist teachers in restructuring materials into clearer, linear, and Braille-compatible formats
Learner motivation and autonomy	Scaffolded tasks and timely prompts may support independent engagement for Braille users
Accessible communication	Structured prompts and guided responses may improve participation without reliance on visual navigation
Formative progress monitoring	Automated tracking may help teachers identify support needs and adjust instruction earlier
Teacher workload support	Routine formatting and drafting tasks may be partially automated, allowing more time for targeted pedagogical and socio-emotional support

not all tools provide reliable support for the Macedonian language, and some remain only partially compatible with Braille-oriented workflows. For teachers working in Braille-inclusive classrooms, the key question is therefore not only which tools exist, but which can be realistically deployed under local conditions. Table 3 summarises selected AI tools that may support instructional accessibility, with specific attention to their feasibility in the Macedonian educational context.

### Conclusion

In Braille-inclusive classrooms, AI may support access and participation, but it cannot replace the human and relational dimensions of teaching. Accessibility depends on intentional design, professional judgment, and continuous monitoring of learner experience rather than on automation alone (Castañeda & Selwyn, 2018). Practically, AI is best treated as a teacher-governed support: vision/OCR tools can provide rapid access to print; generative

Table 3. AI tools potentially usable in mainstream schools for Braille-literate students

Tool / Category	Primary function for Braille-literate students	Macedonian context feasibility	Key limitations	Practical classroom use-case
Google Lookout (Android)	OCR reading of printed text; rapid access to worksheets and handouts; may support immediate access when Braille versions are not yet available	Medium: widely usable on Android; Macedonian OCR performance should be locally pilot-tested	Not Braille transcription; OCR errors; sensitive to lighting/camera quality	Student scans worksheet for immediate access, teacher later prepares a verified Braille-ready version
Microsoft Seeing AI (iOS/Android)	Reads printed text and provides scene descriptions; supports rapid access to print and classroom environment	Medium-Low: Macedonian-language performance is not consistently documented; local validation required	Not Braille transcription; variable accuracy; language performance uncertain	Rapid access to printed text/scene cues during class; teacher later provides verified structured material
Generative AI (LLMs) for Braille-friendly restructuring	Draft restructuring of teacher materials into linear, Braille-compatible formats (headings, numbered steps, table linearisation, draft descriptions)	High (for text-based drafting): generally usable in Macedonian and English; suitability depends on task complexity and local validation	Hallucinations; possible distortion of diagrams/math; privacy considerations; mandatory human verification	Teacher inputs worksheet, AI produces structured draft, teacher verifies before Braille production
AI-powered translation tools	Translation into Macedonian to support accessible material preparation	High: Macedonian supported by major services; terminology requires checking	Terminological inaccuracies; not Braille-specific; requires teacher review	Teacher translates material, then restructures for Braille access
AI speech-to-text / captioning tools	Generates transcripts of spoken instruction that can later be edited and formatted for Braille use	Medium: depends on language models, device ecosystem, and classroom noise	Not direct Braille output; recognition errors in noisy environments	Teacher explanation transcribed, edited into structured Braille-compatible notes

systems can assist with drafting Braille-compatible restructurings; translation tools can support linguistic mediation; and speech-to-text can capture classroom talk for later Braille-oriented formatting. Across these uses, the key constraint is reliability (particularly the risk of structural distortion and overconfident errors) making verification non-negotiable. While AIED research reports learning gains in controlled settings (Woolf, 2010; du Boulay, 2016), effects in everyday classrooms are more variable and often incremental (Miao et al., 2021). In North Macedonia, feasibility is additionally shaped

by Macedonian-language performance, infrastructure, and compatibility with assistive technologies, which supports the case for small-scale local piloting, ideally within blended (hybrid) arrangements that combine the relational strengths of face-to-face teaching with the flexibility of targeted digital supports. Overall, AI is most plausibly positioned as an accessibility co-pilot within teacher-led practice; future work should prioritise evaluating the reliability and classroom impact of AI-assisted Braille adaptations.

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## ВЕШТАЧКА ИНТЕЛИГЕНЦИЈА У ИНКЛУЗИВНОЈ НАСТАВИ ЗА УЧЕНИКЕ КОЈИ КОРИСТЕ БРАЈЕВО ПИСМО

Инклузивно образование претставља једно од кључних полазишта савремених образовних система и подразумева стварање услова у којима сви ученици могу учествовати у наставном процесу на равноправни начин. У пракси се, међутим, показује да само укључивање ученика са оштећењем вида у редовне учионице не значи нужно и потпуну доступност наставних садржаја. Наставни материјали су у највећој мери обликовани визуелно, док њихово прилагођавање ученицима који користе Брајево писмо захтева додатно време, одговарајућу техничку подршку и специфична стручна знања. У том контексту, савремене дигиталне технологије, посебно оне засновани на вештачкој интелигенцији (ВИ), све чешће се размајрају као потенцијална подршка инклузивној настави.

У раду се размајра потенцијална улога вештачке интелигенције у подршци наставницима који раде у инклузивним учионицама у којима се образују и ученици који користе Брајево писмо. Посебна пажња посвећена је питању присутности наставних материјала и начину на који њихова структура утиче на разумевање садржаја код ученика који користе тактилни облици читања. За разлику од визуелног читања, Брајево писмо подразумева линеарну организацију информација, због чега распоред елемената, односи између појмова, као и структура табела и задатака имају важну улогу у процесу учења. Присутности наставних материјала зато не подразумева само техничку конверзију садржаја већ и очување њихове логичке организације.

Рад има концептуални карактер и усмерен је на размајрање могућности за примену вештачке интелигенције у инклузивној настави. У том оквиру издвајају се три области у којима се првенствено потенцијална улога ВИ: унапређење присутности наставним материјалима, подршка активнијем учењу ученика у наставним активностима и олакшавање формативне подршке у процесу учења. Савремени дигитални алати могу помоћи наставницима у ресруктурирању текста у прељепније и линеарније форме које су погодније за читање путем Брајевих дисплеја или за израду рељефних наставних материјала. Такође, поједини системи омогућавају генерисање описних визуелних садржаја, попут графика или дијаграма, чиме се олакшава присутност информација које су у оригиналу представљене визуелно. Осим тога, дигитални алати могу подржати диференциране наставне активности и омогућити бржу повратну информацију ученицима.

Истовремено, примена вештачке интелигенције у инклузивном образовању носи и одређене ризике. Аутоматски генерисани садржаји могу довести до поједностављивања или нарушавања структуре информација, што може онежати њихово разумевање у Брајевом

форми. Такође, постоји могућност за појаву нетачних или претерано сигурних одговора које генерише систем. Због тога наставник задржава кључну улогу у провери и прилагођавању материјала. Вештачка интелигенција се у овом раду посматра као подршка наставничкој пракси, а не као замена за педагошку процену и професионално искуство наставника.

Педагошке импликације односе се на приоритету за промишљеном интеграцијом дигиталних технологија у инклузивно образовање. Ефикасна примена ових алата захтева развој дигиталних компетенција наставника, али и сарадњу са стручњацима из области специјалне едукације и рехабилитације. Њихова примена зависи и од локалног образовног контекста, укључујући доступност технологија и подршку за македонски језик.

Разматрање указује на приоритетност вештачке интелигенције да допринесе унапређењу приступачности наставних материјала и подршци инклузивној настави за ученике који користе Брајево писмо. Истовремено, за одговорну и педагошки оправдану примену ових технологија неопходна су даља емпиријска истраживања која би испитала њихове стварне ефекте у свакодневној школској пракси.

**Кључне речи:** вештачка интелигенција у образовању, инклузивно образовање, Брајево писмо, приступачност