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Context matters: Why we must consider resources and context when implementing artificial intelligence tools in the teaching and learning of mathematics in South Africa

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Introduction

Artificial intelligence's promise meets South Africa's realities

Globally, the rapid diffusion of generative and learning analytics tools has sparked optimism for more personalised, feedback-rich mathematics learning. Yet leading scholars caution that the ethics, equity, and efficacy of artificial intelligence (AI) in education are not technology intrinsic; they are contingent on socio-technical context, governance, and pedagogy (Holmes et al., 2021). UNESCO (2025) likewise urges a human-centred and capacity-building approach that foregrounds inclusion, data governance, and teacher development, especially in low-resource settings.

South Africa's system exhibits extreme inequality in mathematics outcomes and opportunities, shaped by historical and ongoing structural factors (Eds. Spaull & Jansen, 2019). Policy ambitions for digital learning are not new, as the White Paper 7 (Department of Basic Education [DBE], 2004) envisioned universal school connectivity and teacher competence, but delivery has been uneven. These legacies mean that AI tools introduced without careful attention to infrastructure, teacher support, language, and regulation may falter in classrooms that lack stable internet, devices, relevant content, or guidance on safe data use (DBE, 2019).

Infrastructure and access: Necessary but still uneven

AI-supported mathematics learning such as adaptive practice, automated hints, and data-driven formative assessment requires dependable electricity, reliable connectivity, and learner access to devices. However, empirical reviews and system reports demonstrate persistent gaps.

Connectivity

National policy documents articulate the vision of 'internet in every school', yet by the early 2020s only an estimated 20% – 30% of South African schools had functional internet access suitable for teaching and learning, far below the goal of universal access (Education, Training and Development Practices Sector Education and Training Authority [ETDP SETA], 2020).

School infrastructure

Broader physical infrastructure deficits – especially in rural schools – continue to limit the feasibility of technology-dependent pedagogies. Issues include inadequate electricity supply, insufficient charging facilities for devices, insecure storage, and the lack of projectors or smartboards (Nkula & Krauss, 2014).

Household access

Remote or blended AI-supported learning presumes access to internet connectivity at home. Yet as of 2020, only a small proportion of households with learners reported home internet connections, with severe rural–urban divides; most households accessed the internet primarily via smartphones (Moyo, 2020).

These access constraints are highly consequential for mathematics education. Tools such as dynamic visualisations, automated feedback systems, and data-rich dashboards depend on bandwidth, uptime, and device availability. Where connectivity is intermittent, schools may require 'store-and-forward' or offline-first AI-adjacent tools (e.g., locally cached content, lightweight models). Importantly, education budgets must account not only for capital expenditures (capex) such as devices, but also for the ongoing operational expenditures (opex) of maintaining connectivity (Howell & Stols, 2021).

Teacher capacity and Technological Pedagogical Content Knowledge: Artificial intelligence is pedagogical, not plug-and-play

Effective technology use in classrooms depends heavily on teachers' Technological Pedagogical Content Knowledge (TPACK). This is especially critical in mathematics, where representations, common errors, and reasoning patterns are domain-specific (Mishra & Koehler, 2006). South African studies show uneven levels of TPACK and highlight persistent barriers to integrating digital tools into mathematics instruction, such as limited training, lack of time, and weak curricular alignment (Kola & Sunday, 2015; Mudaly, 2020).

National policy acknowledges these challenges. The Professional Development Framework for Digital Learning (DBE, 2018) sets competency targets and emphasises roles for sustained professional development rather than relying on one-off workshops. However, qualitative research continues to find gaps in enactment, particularly in rural and under-resourced schools where structural and contextual barriers undermine implementation (Hlalele, 2019).

Evidence from mathematics-specific digital tools further illustrates both the promise and the dependencies of effective integration. Studies on GeoGebra have reported measurable gains in learners' conceptual understanding and increased teacher confidence, provided that adequate training and curricular integration are present (Bansilal, 2015; Ngubane, 2022). Yet, in South African classrooms, teacher experiences with GeoGebra often hinge on access to professional training, time to design tasks, and sustained peer or institutional support (Govender, 2021). These enabling conditions are precisely the ones that AI tools will also require.

The implication is that AI initiatives must be embedded in multi-year, subject-specific professional learning programmes that are directly aligned with the Curriculum and Assessment Policy Statement (CAPS). For mathematics, this includes embedding AI use in teaching functions, geometry, and algebra, with a focus on coaching teachers in prompt design, error analysis, and understanding the limitations of automated feedback. Without such structured support, the novelty of AI risks overshadowing the central goal of fostering mathematical sense-making (Setati & Adler, 2020).

Language and curriculum: Designing for multilingual classrooms

Mathematics learning in South Africa is inherently multilingual. Research has consistently shown that language-in-education policies, code-switching practices, and the dominance of English significantly shape learner participation and understanding (Adler, 2001; Setati, 2005). Studies in *Pythagoras* and the *Eurasia Journal of Mathematics, Science and Technology Education* affirm that the linguistic medium of instruction influences not only access to mathematical discourse but also learner confidence and performance (Msimanga & Shiza, 2014; Nkambule & Mukuna, 2019).

Reviews across African contexts highlight that multilingual classrooms require deliberate scaffolding strategies rather than simple translation. Scaffolding includes providing learners with opportunities to use home languages for sense-making, while gradually building capacity in the language of instruction (Planas, 2018; Probyn, 2009). Without such strategies, learners risk disengagement and fragmented understanding of mathematical concepts.

For AI applications, this has three important implications:

- Comprehensive language coverage and accuracy for all 11 official South African languages.
- Culturally and linguistically relevant task design that reflects learners' real-world linguistic repertoires.
- Support for translanguaging, enabling learners to move fluidly across languages during mathematical reasoning (Heugh, 2015).

If these elements are neglected, AI tutors may misinterpret learner input, provide inappropriate hints, or default to prestige English registers, thereby marginalising learners in linguistically diverse classrooms. UNESCO's (2021) policy guidance on AI in education explicitly emphasises inclusion, equity, and linguistic diversity as cornerstones of ethical AI deployment. In South Africa, this means AI design must embed multilingual capability and empower teachers to adapt outputs for their specific linguistic contexts.

Equity and algorithmic bias: Why data and models matter

International research in machine learning has documented persistent disparities in model performance across demographic groups, including intersectional accuracy gaps in facial analysis and natural language processing tasks (Buolamwini & Gebru, 2018; Raji & Buolamwini, 2019). While these examples do not involve mathematics education directly, they underscore the risk of biased data sets and unequal error rates when AI systems are deployed in contexts already marked by inequality.

Within education, scholars caution that AI systems can reproduce and amplify systemic biases unless they are carefully governed, continuously audited, and subjected to

transparent accountability measures (Holmes et al., 2021; Ed. Selwyn, 2019). This is particularly salient in high-stakes areas such as mathematics assessment, where subtle errors can disproportionately disadvantage learners from marginalised groups.

For South Africa, applying an *equity lens* is non-negotiable, given the historical disadvantage in mathematics attainment and persistent performance gaps across socio-economic quintiles (Spaull, 2013; Taylor, 2019). Developers and procurers of AI-driven educational tools must therefore require bias assessments, representativeness checks (including linguistic, regional, and device-related dimensions), and rigorous error-profiling across quintiles and languages both before and after classroom deployment. Embedding these practices is central to ensuring that AI contributes to closing – rather than widening – the equity gap in mathematics education.

Policy and regulation: *Protection of Personal Information Act* compliance and ethical use

The *Protection of Personal Information Act (POPIA), Act 4 of 2013*, governs the processing of personal data in South Africa, including the sensitive processing of children's data in schools. Guidance from the DBE emphasises obligations around lawful processing, informed consent, purpose limitation, and data security – requirements that are directly implicated when AI tools log learner interactions, errors, and progress (DBE, 2021).

Recent legal scholarship highlights unresolved questions about AI-specific risks under *POPIA*, such as automated profiling, algorithmic decision-making, and data minimisation in educational settings (Botha, 2020; Roos, 2021). These studies stress the importance of explicit consent procedures and robust governance frameworks to safeguard learners.

Within the higher education sector, institutional guidelines also call for proactive compliance. Universities such as Wits recommend aligning AI use with *POPIA* obligations and conducting regular privacy and ethical reviews to ensure accountability in data-driven teaching and learning (Mhlambi, 2022).

At the international level, UNESCO (2021) foregrounds principles of transparency, accountability, and human oversight in its global guidance on AI in education. These principles converge with South Africa's *POPIA* framework, emphasising the ethical responsibility of schools and higher education institutions to safeguard learner data.

Practical takeaway: any AI deployment in South African schools should include: (1) a data-protection impact assessment, (2) transparent and accessible consent processes for learners and guardians, (3) local data-retention schedules, and (4) procurement clauses mandating privacy-by-design.

From ambition to action: Principles for context-aware artificial intelligence in mathematics

Drawing across the literature and policy landscape, the following principles emerge for implementing AI in South African mathematics classrooms:

- **Infrastructure-first sequencing:** Stable electricity, classroom-level Wi-Fi, or robust offline modes and adequate devices must be prioritised before relying on always-online AI features. Evidence on persistent connectivity gaps suggests the need for phased roll-outs based on school readiness (ETDP SETA, 2020).
- **Subject-specific professional learning:** Professional development should be multi-year and anchored in TPACK for mathematics. This includes task design, diagnosing misconceptions, effective prompt use, and alignment with CAPS, rather than generic tool trainings (Mishra & Koehler, 2006; Mudaly, 2020).
- **Multilingual design and translanguaging:** AI tools must support South Africa's 11 official languages and classroom code-switching practices. Teachers should retain the capacity to curate and correct language outputs to ensure mathematical precision (Adler, 2001; Nkambule & Mukuna, 2019).
- **Curriculum alignment and pedagogy:** AI integration should focus on strengthening reasoning, modelling, and proof, rather than limiting activities to drill-and-practice. Embedding tasks that prompt explanation, multiple representations, and error analysis aligns with international cautions against over-claiming the benefits of automation (Williamson & Eynon, 2020).
- **Equity and bias audits:** Any AI product should undergo mandatory bias testing and reporting by language, province, and school quintile, with locally curated data sets and continuous monitoring (Buolamwini & Gebru, 2018).
- ***POPIA*-aligned governance:** Implementation must include data-protection impact assessments, guardian consent for minors, specification of storage locality, access controls, and deletion protocols, alongside staff training on privacy responsibilities (DBE, 2021; Republic of South Africa, 2013).
- **Iterative evaluation:** Independent research in South African mathematics classrooms should be commissioned to track learning effects, teacher workload, and unintended consequences, building on prior Information and Communication Technology (ICT) evaluations and white paper reflections (Czerniewicz & Brown, 2014).
- **Costing for sustainability:** Long-term budgeting must cover connectivity and device maintenance, not just initial procurement. Zero-rated or low-bandwidth deployments, in partnership with telecommunications providers, are essential for equitable access (ETDP SETA, 2020).

Conclusion

The integration of AI tools into mathematics education in South Africa holds great promise but demands a careful,

context-sensitive approach. Persistent inequalities in infrastructure, teacher capacity, language diversity, and regulatory frameworks cannot be overlooked if AI is to advance rather than hinder equity. For AI to be a meaningful driver of learning, implementation must prioritise foundational resources, align with CAPS, strengthen teacher professional development, and embrace multilingualism. Equally, ethical governance under *POPIA* and continuous bias auditing are essential to protect learners and promote fairness. Long-term sustainability requires not only procurement but also the budgeting of maintenance and operational costs. Ultimately, AI's role in mathematics education will be transformative only if it is guided by equity, inclusivity, and pedagogical integrity. By embedding these principles, South Africa can ensure that AI contributes to improving mathematical reasoning, problem-solving, and access – while narrowing, not widening, educational divides.

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