Adaptive Learning for Inclusive Algebra Instruction in Resource-Constrained Secondary Schools: Implications for Special and Inclusive Education in the Eastern Cape, South Africa

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ABSTRACT:
This qualitative case study examines how adaptive learning can support inclusive algebra instruction for learners with diverse learning needs in resource-constrained secondary schools in the Eastern Cape, South Africa. Guided by Universal Design for Learning, the Zone of Proximal Development and adaptive teaching, the study explored teacher and learner experiences of algebra support in ordinary inclusive classrooms. Data were generated through semi-structured interviews, learner focus group discussions, and classroom observations with 10 mathematics teachers and 20 Grade 10 learners across 4 schools. Thematic analysis found that algebraic difficulty operates as a barrier to participation when learners receive limited feedback, differentiated practice and accessible representations. Adaptive feedback was perceived as useful for step-by-step scaffolding, but its value depended on teacher mediation, digital-pedagogical readiness, accessible design, reliable infrastructure and equitable access to devices. The paper argues that adaptive learning is not a standalone solution but a support ecology for strengthening inclusive conceptual mastery in algebra.

Keywords: Adaptive learning, inclusive education, algebra, Universal Design for Learning, barriers to learning

1. Introduction

Inclusive education requires teaching systems that recognise learner diversity and remove barriers to participation, achievement and belonging. In South Africa, this concern is especially important in mathematics classrooms, where learners may experience overlapping barriers linked to disability, language, poverty, prior learning gaps, limited digital access, and low confidence in abstract topics. Contemporary inclusive education research emphasises that inclusion is not achieved solely by placing learners in the same classroom; it also requires access to the curriculum, responsive pedagogy, accessible resources, and fair opportunities to demonstrate learning (OECD, 2023; European Agency for Special Needs and Inclusive Education, 2022; CAST, 2024).

This paper speaks directly to that scope by examining how adaptive learning can support learners who experience barriers to algebra learning in ordinary inclusive secondary

classrooms. The paper does not treat adaptive learning as a simple technological solution. Instead, it examines whether digital feedback, personalised tasks and teacher mediation can reduce learning barriers while avoiding new forms of exclusion for learners with diverse support needs (Fitas, 2025; Dumitru et al., 2026).

Adaptive learning platforms use data generated through learner responses to adjust task difficulty, provide hints, sequence activities and offer immediate feedback. In mathematics education, these systems are increasingly viewed as a way of supporting differentiated practice in large classes where teachers cannot always provide individual feedback to every learner. Recent reviews show that adaptive systems can support mathematics learning when they are pedagogically integrated, aligned with curriculum goals and accompanied by teacher readiness rather than introduced as stand-alone digital products (Benkhalfallah et al., 2024; Naseer & Khawaja, 2025; Nurhayati et al., 2026).

The Eastern Cape provides an important context for such inquiry. Many schools in the province serve rural or peri-urban communities affected by poverty, long travel distances, uneven infrastructure and limited digital resources. These conditions matter for special and inclusive education because digital tools can support access only when electricity, devices, connectivity, teacher training and school-level support are reliable. In resource-constrained settings, technology integration is therefore a sociotechnical issue rather than a purely classroom-based decision (Aruleba & Jere, 2022; Dzimba & van der Poll, 2024; Ngoasong, 2022).

This study was guided by four objectives: (1) to identify inclusive learning barriers that affect conceptual mastery of algebra among Grade 10 learners in resource-constrained secondary schools; (2) to examine how teachers and learners perceive adaptive learning tools as scaffolds for learners with diverse learning needs; (3) to analyse contextual conditions that enable or constrain equitable and disability-responsive use of adaptive learning; and (4) to propose a context-responsive model for inclusive adaptive algebra instruction. The central research question was: How can adaptive learning support inclusive conceptual mastery of algebra in resource-constrained secondary schools in the Eastern Cape? Four sub-questions asked what barriers learners encounter, how adaptive feedback is experienced, what support teachers require, and what conditions are necessary for equitable implementation.

1.1 Literature review: Algebra, learner diversity and inclusion

Algebra is conceptually demanding because it requires learners to coordinate symbols, relationships, generalisation and abstract reasoning. Learners who rely mainly on memorised procedures may solve routine examples but struggle when equations, variables or representations change. Recent studies on algebra learning and mathematics learning difficulties show that learners benefit from explicit scaffolding, multiple representations, worked examples, concrete-representational-abstract approaches and opportunities to explain reasoning rather than only reproduce procedures (Klee-Schramm et al., 2026; Namkung & Bricko, 2021; Prosser & Bismarck, 2023; Satsangi et al., 2021).

Universal Design for Learning (UDL) is useful because it asks teachers to plan multiple means of engagement, representation, and action and expression before learners fail. In algebra, this may include visual representations of variables, oral explanations, step-by-step worked examples, opportunities to use manipulatives or digital tools, and different ways of demonstrating understanding. The 2024 UDL Guidelines foreground learner agency, accessibility and barriers rooted in systems of exclusion, which makes UDL appropriate for studying adaptive learning in inclusive mathematics classrooms (CAST, 2024; Dumitru et al., 2026).

The Zone of Proximal Development (ZPD) adds a second theoretical lens. Learners develop new competence when support is pitched between what they can do independently and what they can do with guidance. In algebra, this means that learners require hints, prompts, examples and

feedback that are neither too easy nor too difficult. Current research on adaptive feedback and self-regulated digital learning shows that support is most powerful when learners receive timely guidance while teachers remain involved in monitoring progress and interpreting learner needs (Gallagher et al., 2022; Jin et al., 2023; Naseer & Khawaja, 2025).

Adaptive teaching literature also emphasises that effective instruction depends on teachers' capacity to notice learners' thinking and adjust tasks, explanations and feedback accordingly. Technology may extend this capacity by producing learner data, but teachers still need to interpret that data and connect it to classroom explanation. In inclusive classrooms, this is important because learner difficulty may reflect misconceptions, language barriers, disability-related support needs, anxiety, poor attendance or limited prior exposure to digital tools (Gallagher et al., 2022; Fitas, 2025; Dumitru et al., 2026).

The literature on digital inequality cautions that educational technologies can widen gaps when implementation assumes equal access. Learners who have smartphones, data, electricity, quiet study spaces and digitally confident family support are more likely to benefit from online or adaptive tools. Learners without these resources may be further excluded unless schools provide structured access, assistive options and teacher-guided use. This concern is particularly significant for special and inclusive education because barriers to learning often interact with socioeconomic and infrastructural barriers (Helsper, 2021; OECD, 2023; European Agency for Special Needs and Inclusive Education, 2022).

1.2 Theoretical and conceptual framework

The study integrates UDL, ZPD and adaptive teaching into an inclusive adaptive learning framework. UDL foregrounds curriculum access and proactive barrier reduction; ZPD foregrounds guided progression from assisted to independent performance; and adaptive teaching foregrounds teacher judgement in responding to learner evidence. Together, these ideas position adaptive learning as a mediated support system rather than a replacement for teachers (CAST, 2024; Gallagher et al., 2022; Nurhayati et al., 2026).

Figure 1 presents the model used to guide the study. It places the adaptive learning platform between inclusive design and classroom ecology. This positioning is intentional: adaptive feedback can support conceptual mastery only when the classroom provides accessible tasks, teacher mediation, reliable infrastructure, learner self-regulation support and fair access to devices. The model therefore treats inclusion as an interaction among pedagogy, technology and context (Aruleba & Jere, 2022; European Agency for Special Needs and Inclusive Education, 2022).

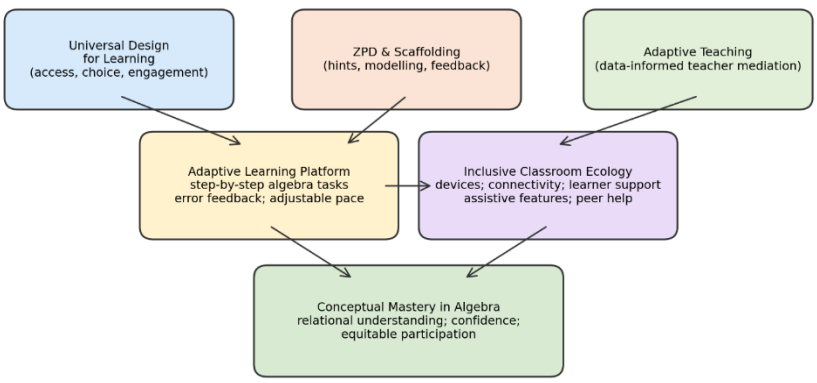

Figure 1. *Inclusive adaptive algebra learning support model.*

The figure illustrates how Universal Design for Learning, ZPD-based scaffolding and adaptive teaching interact to support inclusive algebra instruction. The adaptive learning platform provides step-by-step algebra tasks, immediate error feedback and adjustable pacing, while the inclusive classroom ecology ensures access to devices, connectivity, learner support, assistive features and peer collaboration. Together, these elements promote conceptual mastery in algebra through relational understanding, learner confidence and equitable participation.

This framework shows that adaptive learning can only support conceptual mastery when it is embedded within an inclusive classroom environment. Technology alone is not sufficient; it must be guided by teacher mediation, accessible learning design, scaffolded feedback and equitable access to digital resources. In this study, the framework positions adaptive learning as a supportive pedagogical tool that can help learners overcome algebraic misconceptions, participate meaningfully in mathematics learning and develop confidence when appropriate infrastructure, teacher support and inclusive practices are in place.

2. Methodology

Design. The study adopted a qualitative case study design located within the interpretivist paradigm. This design was appropriate because the purpose was to understand how teachers and learners made sense of adaptive learning in real classroom conditions, rather than to measure impact through a controlled experiment. Qualitative case study research is suitable when the researcher seeks contextual depth, participant voice and a holistic understanding of a bounded educational phenomenon (Lim, 2025; Mtisi, 2022).

Participants and sampling. Participants were selected purposively because they were directly involved in Grade 10 mathematics teaching and learning. The sample comprised ten mathematics teachers and twenty Grade 10 learners from four secondary schools in the Eastern Cape. Purposive sampling was suitable because the study required participants who could provide information-rich accounts of algebra learning barriers, adaptive feedback and inclusive classroom support (Ahmad & Wilkins, 2024; Dahal, 2024).

Instruments. Data were generated through semi-structured teacher interviews, learner focus-group conversations and classroom observations. The interview guide explored algebraic misconceptions, support needs, technology access, teacher readiness and perceptions of adaptive feedback. Classroom observations focused on learner engagement, teacher mediation, available resources and accessibility conditions. These qualitative tools were appropriate because they enabled the study to capture both reported experiences and observed classroom practices (Lim, 2025; Mtisi, 2022).

Procedure. Permission was sought from the relevant institutional and school authorities. Teachers were first briefed about the study, after which interviews were scheduled at times that did not interrupt teaching. Learner focus groups were conducted only after parental consent and learner assent were obtained. Observations were conducted during ordinary mathematics lessons, with attention to naturally occurring teaching and learning practices rather than external evaluation. Participants were coded as teachers or learners, and direct identifiers were removed from transcripts and field notes.

Data analysis. Data were analysed thematically using a reflexive and systematic process of familiarisation, initial coding, theme generation, theme review, theme definition and reporting. Coding was both deductive and inductive: UDL, ZPD and adaptive teaching informed the initial analytic lens, while participant accounts allowed additional themes to emerge. NVivo was used to organise transcripts, observation notes and coded extracts. Reflexive thematic analysis was suitable because it supported interpretation of patterns across teacher and learner experiences while preserving contextual meaning (Braun & Clarke, 2021; Lim, 2025).

Trustworthiness. Credibility was strengthened through triangulation of interviews, focus groups and observations, as well as member checking of selected interpretations with participants. Transferability was supported through detailed

contextual description of schools, participants and classroom conditions. Dependability was enhanced through an audit trail of research decisions, while confirmability was supported through reflexive notes that recorded assumptions and analytic choices. These procedures are consistent with current qualitative research guidance on rigour and transparency (Adler, 2022; Lim, 2025).

Ethical considerations. The study involved human participants and therefore followed principles of voluntary participation, informed consent, assent for minors, confidentiality, anonymity and the right to withdraw without penalty. Particular care was taken because learners were minors and because digital learning data can raise privacy and fairness concerns. The study therefore treated ethical practice as both a research obligation and a condition for responsible use of AI-supported educational technologies (Miao & Holmes, 2023; UNICEF, 2021; UNESCO, 2021).

Table 1. *Methodological overview.*

Element	Description
Research approach	Qualitative, interpretivist case study focused on lived experiences and contextual meanings.
Sites	Four Eastern Cape public secondary schools representing rural, semi-rural and urban/peri-urban contexts.
Participants	Ten mathematics teachers and twenty Grade 10 learners studying algebra.
Data sources	Semi-structured interviews, learner focus groups and classroom observations.
Analytical method	Thematic analysis using deductive and inductive coding.
Inclusive education boundary	The study examined barriers to learning and diverse support needs; it did not diagnose or categorise learners by impairment.

3. Results

The analysis produced five interrelated themes. The findings are presented descriptively in this section, with participant quotations used to show how teachers and learners experienced adaptive learning, algebraic barriers and inclusive support conditions.

Table 2*. Theme matrix.*

Theme	Summary finding	Inclusive/special education relevance
1. Algebraic difficulty as a barrier to learning	Learners struggled with variables, factorisation, equations and word problems, especially when lessons moved quickly from demonstration to practice.	Algebra difficulty was linked to differentiated support needs rather than learner inability.

2. Adaptive feedback as conceptual scaffolding	Participants valued immediate feedback, hints and step-by-step guidance when platforms worked reliably.	Adaptive feedback can provide reasonable instructional support for learners who need repetition and low-stigma correction.
3. Teacher readiness and mediation	Teachers reported limited training and uncertainty about using adaptive platforms pedagogically.	Inclusive technology requires teacher competence in accessibility, data interpretation and learner support.
4. Infrastructure and digital exclusion	Connectivity, electricity, device shortages and home access differences shaped who could benefit.	Without equitable access and assistive design, adaptive learning can reproduce exclusion.
5. Learner engagement and self-regulation	Some learners were motivated by interactive tasks, while others clicked through activities or became distracted.	Learners with diverse needs require explicit guidance, structured routines and teacher/peer support.

3.1 Theme 1: Algebraic difficulty as a barrier to learning

Teachers and learners described algebra as a point where many learners lost confidence. Participants reported that learners often memorised procedures without understanding the meaning of symbols or why steps were taken. Difficulties were most visible in factorisation, solving equations, substitution and translating word problems into algebraic expressions. Learners who missed earlier concepts were unable to keep pace when lessons moved rapidly to new procedures.

Participants linked these difficulties to large classes, limited feedback and uneven foundational knowledge. Teachers reported that they could identify struggling learners but could not always provide individual support during a single lesson. One teacher explained that learners with repeated errors often remained silent because they feared embarrassment. This silence made it difficult to know who understood and who was copying steps without conceptual grasp.

> *"Some learners write the steps from the board, but when you ask them why they moved a term or changed a sign, they cannot explain. They are afraid to show that they are lost." (Teacher participant)*

> *"I can do it when the teacher shows us, but when the numbers change, I get confused. I need more examples before I understand." (Learner participant)*

3.2 Theme 2: Adaptive feedback as conceptual scaffolding

Participants saw potential in adaptive learning because it could provide immediate feedback and additional practice at a learner's own pace. Teachers noted that feedback during ordinary lessons was delayed or uneven because one teacher had to support many learners. Adaptive platforms were valued when they showed errors immediately, broke problems into smaller steps and allowed learners to retry without public judgement.

The strongest positive comments related to algebra topics that require step-by-step reasoning. Teachers believed that adaptive hints could help learners see where a misconception occurred instead of simply marking an answer wrong. Learners who had used digital practice activities said they liked knowing immediately whether they were on the right track.

> *"If properly managed, I think learners would finally grasp algebra concepts like factorisation because the system gives step-by-step guidance." (Participant 10)*

"The feedback from the programme helps some learners realise their mistakes immediately, something I cannot always do in a crowded class." (Participant 9)

3.3 Theme 3: Teacher readiness and inclusive mediation

Teacher readiness emerged as a decisive condition. Participants did not reject adaptive learning in principle, but many expressed uncertainty about how to integrate it into lessons. They described a gap between the expectation that schools should innovate digitally and the limited professional development available to mathematics teachers in under-resourced schools. Teachers also raised the need to understand accessibility features, learner data, differentiated task selection and how to combine digital feedback with classroom discussion.

The findings show that adaptive learning requires teacher mediation. Teachers wanted practical training that models how to use adaptive tasks before, during and after instruction; how to group learners; how to support learners who struggle with self-paced work; and how to prevent the technology from becoming a distraction.

"We are not trained to use these digital systems; most of us just rely on chalk and talk, so the adaptive learning idea feels too advanced for us." (Participant 3)

"If workshops are offered consistently, we may slowly adopt these tools, but without that, it will remain a dream." (Participant 2)

3.4 Theme 4: Infrastructure, accessibility and digital exclusion

Infrastructure was the most frequently reported barrier. Participants mentioned unreliable internet, electricity interruptions, limited devices, shared computer laboratories and insufficient technical support. In some schools, the computer laboratory was shared by hundreds of learners, making regular adaptive practice unrealistic. Teachers therefore hesitated to plan lessons around platforms that might not be available when needed.

Learners' home access also differed. Some learners could practise on phones after school, while others had no device, data or quiet space. Participants were concerned that adaptive learning might benefit learners who were already better resourced unless schools provided structured in-school access. Accessibility was also raised indirectly through concerns about screen size, language, reading load and the need for teacher explanation.

"Even if you bring us the best system, without internet and electricity, it will just gather dust in the storeroom." (Participant 5)

"Learners from better-off families practise on their phones at home, but those without devices fall behind." (Participant 5)

3.5 Theme 5: Learner engagement and self-regulation

Learner engagement was uneven. Some learners were excited by interactive tasks, instant feedback and opportunities to repeat activities privately. Others struggled with independent work, became distracted or clicked through tasks without reflection. Teachers interpreted this as evidence that adaptive platforms should not be introduced as unsupervised individual work. Learners need routines, goals, teacher check-ins and opportunities to discuss mathematical reasoning.

This theme is important for inclusive education because learners who experience attention, confidence, language or self-regulation barriers may require explicit support to benefit from adaptive learning. Participants reported that the most promising use occurred when the teacher structured the digital activity, explained the purpose, monitored progress and used the results to guide follow-up teaching.

"Most of our learners get lost quickly when they have to work independently on the system; they just click randomly without understanding." (Participant 6)

"Those who are serious benefit because they get instant feedback that we as teachers cannot always provide." (Participant 10)

4. Discussion

4.1 Adaptive learning as inclusive scaffolding, not a replacement teacher

The findings indicate that adaptive learning has inclusive potential when it operates as a scaffold within a teacher-mediated learning environment. Participants valued immediate feedback and graduated support because these features address a persistent problem in large mathematics classes: one teacher cannot provide continuous individual explanation to every learner. Recent evidence on adaptive feedback and adaptive learning systems supports this finding, showing that adaptive tools can improve conceptual engagement when they are instructionally purposeful and when learner interaction is sustained (Naseer & Khawaja, 2025; Nurhayati et al., 2026; Benkhalfallah et al., 2024).

However, the findings also show that adaptive systems cannot replace teacher judgement. Teachers must decide when to use the platform, which learners need additional explanation, when a hint is mathematically adequate, and how feedback should be connected to classroom discussion. This supports adaptive teaching research, which positions teacher noticing, explanation and responsive adjustment as central to mathematics learning (Gallagher et al., 2022; Klee-Schramm et al., 2026).

The results align with UDL because participants valued features that reduce barriers: multiple attempts, immediate feedback, stepwise progression and reduced public exposure of errors. Yet UDL also requires proactive accessibility. Adaptive platforms must therefore include accessible language, visual clarity, audio options where possible, flexible pacing and culturally relevant examples. Without these features, adaptive learning may support some learners while excluding others who experience language, sensory, attention or confidence-related barriers (CAST, 2024; Dumitru et al., 2026; Fitas, 2025).

4.2 The risk of digital exclusion in special and inclusive education

A central contribution of the study is its warning that adaptive learning can both support and undermine inclusion. When platforms are available only to learners with home devices and data, they can widen achievement gaps. This is particularly concerning in special and inclusive education because exclusion is rarely caused by one barrier alone; it is often produced by the interaction of disability, poverty, language, geography and institutional under-support (Helsper, 2021; OECD, 2023; European Agency for Special Needs and Inclusive Education, 2022).

The Eastern Cape context demonstrates why inclusive technology must be understood as a system. A platform cannot compensate for unreliable electricity, insufficient devices, lack of teacher training or inaccessible content. For adaptive learning to become an inclusion strategy, it must be connected to school leadership, district support, teacher professional development, data privacy safeguards and assistive technology planning (Aruleba & Jere, 2022; Dzimba & van der Poll, 2024; Miao & Holmes, 2023).

4.3 Implications for practice

First, mathematics teachers should integrate adaptive learning into structured lesson cycles rather than treating it as extra practice. A lesson cycle may begin with teacher modelling, move to adaptive practice with clear goals, include teacher monitoring of platform feedback and end with a whole-class discussion of misconceptions. Such cycles connect formative feedback to purposeful instruction and are consistent with evidence on feedback and adaptive teaching.

Second, adaptive algebra tasks should be selected according to accessibility and conceptual value. Tasks should offer representations of variables, equations and functions, not only symbolic drills. Teachers should look for platforms that provide hints, explanations, worked examples and opportunities for learners to explain their reasoning. This is consistent with UDL's emphasis on multiple means of representation and action, as well as mathematics research on tutoring systems and conceptual feedback.

Third, teachers need sustained professional development. Once-off workshops are unlikely to change practice. Training should include

hands-on use of platforms, inclusive lesson planning, interpretation of learner data, ethical handling of data, classroom management in device-based lessons and strategies for supporting learners with barriers to learning. AI education guidance similarly stresses that teacher capacity is central to safe and equitable implementation.

Fourth, learner self-regulation should be taught explicitly. Learners need to know how to read feedback, when to request help, how to retry a problem, how to record misconceptions and how to avoid non-academic device use. This is especially important for learners who experience attention, confidence, language or executive-function barriers. Self-regulated learning literature supports explicit attention to goal setting, strategy use, monitoring and reflection.

4.4 Implications for policy and school leadership

Policy support should connect inclusive education, digital transformation and mathematics improvement. Provision of devices without learner support will not be sufficient. District and school leaders should prioritise reliable electricity, low-cost connectivity, teacher training, assistive technology compatibility, learning-support referral pathways and ethical data governance. These priorities align with national inclusive education commitments, the SIAS support framework and broader development goals for equitable quality education.

School leadership also has a role in preventing digital inequality. Timetables should provide regular access to devices for all learners, not only those in better-resourced classes. Learning support teams should use adaptive data carefully to identify learners who need additional support, while avoiding labelling or surveillance practices that undermine dignity. This approach is consistent with inclusive education principles and ethical guidance on AI and children.

4.5 Limitations and future research

The study has limitations. It was qualitative and conducted in four schools; therefore, the findings should be interpreted cautiously rather than generalised statistically. The study also focused on ordinary inclusive classrooms and did not collect diagnostic disability data. Future research should include learners with identified support needs, learners using assistive technologies and specialist support staff to deepen the special education evidence base. Such work would respond to international calls for stronger evidence on inclusion, disability and equitable educational support.

Future studies should also use mixed-methods designs to combine qualitative accounts with learning outcome data. Longitudinal research is needed to determine whether adaptive algebra support improves conceptual mastery, retention, confidence and progression over time. Studies should also examine offline adaptive tools, mobile-friendly platforms, low-bandwidth designs and privacy-preserving learning analytics, especially in rural contexts where infrastructure remains uneven.

5. Conclusion

This study examined adaptive learning as a possible support for inclusive algebra instruction in resource-constrained secondary schools in the Eastern Cape. The findings show that algebraic difficulty functions as a barrier to participation and achievement when learners receive limited feedback, narrow representations and insufficient individual support. Adaptive feedback can help by providing step-by-step scaffolding, repeated practice and immediate correction, which reflects principles from UDL, ZPD and adaptive teaching.

At the same time, the study concludes that adaptive learning is not automatically inclusive. Its value depends on teacher mediation, accessible platform design, learner self-regulation, ethical data use, reliable infrastructure and equitable access. For the International Journal of Special Education audience, the main contribution is the argument that adaptive learning should be evaluated through an inclusive education lens: not only whether it raises mathematics scores, but whether it reduces barriers, protects dignity and expands

participation for learners with diverse support needs.

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8. Author Declaration

Originality: The author declares that this manuscript is original, has not been published previously and is not under consideration elsewhere in the same form.

Competing interests: The author declares no competing financial or non-financial interests.

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Ethics approval and consent to participate: The study involved human participants. Institutional and school-level permissions were sought before data generation. Informed consent was obtained from teachers, and parental consent and learner assent were obtained for participating minors. Participants were informed of voluntary participation, confidentiality and the right to withdraw.

Studies involving animals: This study did not involve animals.

Data availability: The qualitative data are not publicly available because they contain context-specific participant narratives, but anonymised extracts are reported in the manuscript.

Author contribution: Thabisa Maqoqa conceptualised the study, developed the methodology, analysed the data and wrote the manuscript.