African Journal of Teacher Education and Development
ISSN: (Online) 2958-0986, (Print) 2958-8650

Promoting equitable early mathematics learning: Enacting cognitive justice in childhood classrooms

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Dates:
Received: 12 Jan. 2026
Accepted: 15 Mar. 2026
Published: 04 Sept. 2026

How to cite this article:
Selepe, M.A., Bawani, L.E. & Mphahlele, R.S., 2026, 'Promoting equitable early mathematics learning: Enacting cognitive justice in childhood classrooms', *African Journal of Teacher Education and Development* 5(1), a182. https://doi.org/10.4102/ajoted.v5i1.182

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Background: Internationally, teachers are not equipped to promote equitable and cognitive justice in early mathematics classrooms. Cognitive justice and Vygotsky's sociocultural theories underpinned this study, as they argue that equitable mathematics aligns with mediated tools and cultural practices, contributing to cognitive justice.

Aim: This article examines adaptable approaches that support equitable teaching and learning of early mathematics.

Setting: Twelve early childhood mathematics teachers from four rural schools in Limpopo, South Africa, participated in this study.

Methods: Hermeneutic phenomenological research was employed in this qualitative study to elicit participants' lived experiences with adaptable approaches that support equitable teaching and learning of early mathematics. Data were collected through semi-structured interviews and non-participant observations.

Results: The findings indicated that teachers are aware of the significant integration of technologies and culturally responsive play-based pedagogies to promote equitable early mathematics education. However, there are inconsistencies in their classroom practices as a result of unclear curricula, inadequate professional development, and limited access to digital tools in under-resourced schools. The study contributes analytically to teacher education by showing how teachers navigate tensions between equity-oriented pedagogical intentions and structural constraints when implementing cognitive justice in early mathematics classrooms.

Conclusion: Considering the findings, the article suggests continuous professional development, the use of accessible digital resources and lesson exemplars that integrate technology, cultural practices and play-based pedagogies for cognitive justice.

Contribution: This research contributes to the growing literature on equitable education and cognitive justice in early childhood mathematics.

Keywords: cognitive justice theory; early childhood; equitable mathematics; mathematical concepts; Vygotsky's sociocultural theory.

Introduction

Mathematics is a foundational discipline that shapes cognitive development and problem-solving abilities from an early age. In the context of early childhood education (ECE), teaching mathematical concepts is not merely about imparting knowledge, but also about promoting an equitable learning environment that acknowledges and values diverse cognitive approaches (Schoenfeld 2022). This notion of equitable mathematics learning is increasingly recognised as essential for promoting cognitive justice, an idea rooted in the belief that all learners, regardless of their sociocultural backgrounds, should have equal opportunities to engage with and understand mathematical concepts. Vithal, Brodie and Subbaye (2024) argue that mathematics education must be responsive to the realities of learners in diverse contexts. Their work emphasises that cognitive justice is not a mere theoretical ideal but a practical imperative for transforming classrooms into spaces of equity and inclusion. They draw examples from Africa and beyond to illustrate how inclusive pedagogies can empower marginalised learners and enrich mathematical discourse.

Research in mathematics education has increasingly focused on the disparities in learning outcomes that arise from systemic inequities. Mariyono (2024) and Laksana et al. (2025) corroborate that children from low socioeconomic backgrounds in Indonesian classrooms perform poorly in mathematics and reading because strategies for multiculturalism, multilingualism and equity in

education are not adequately addressed. In Africa, the complexity of educational challenges is compounded by historical factors, socioeconomic disparities and varying cultural understandings of mathematics. Studies from Kadonsi, Kenneth and Magdalene (2023) and Anderson et al. (2024) have shown that traditional approaches to mathematics teaching often overlook the rich mathematical practices embedded in local cultures, which can alienate learners and hinder their engagement. In South Africa, the legacy of apartheid continues to influence educational access and quality, resulting in significant disparities in mathematics proficiency among different demographic groups (Department of Basic Education [DBE] 2022). Recent research has pointed to the importance of culturally relevant pedagogy in addressing these inequities, suggesting that integrating local knowledge and experiences into mathematics teaching can enhance learner engagement and understanding (Mthethwa 2023).

Despite the growing body of literature advocating for equitable mathematics education, a significant gap remains in understanding how cognitive justice can be effectively operationalised in early childhood settings, particularly in the African context. The existing literature mainly focuses on secondary and tertiary education, often neglecting the foundational years when attitudes and perceptions toward mathematics are formed. Furthermore, although there is recognition of the need for culturally responsive teaching, there is a lack of empirical research that explores specific pedagogical strategies to promote cognitive justice in early childhood mathematics education. This gap is particularly concerning given the critical role that early mathematical experiences play in shaping lifelong attitudes and competencies in mathematics.

The purpose of this study was to examine adaptable approaches that support equitable teaching and learning of early mathematics. By examining current pedagogical practices and identifying effective strategies for integrating diverse knowledge systems into mathematics teaching, this research aims to contribute to a more equitable framework for mathematics education. This study is relevant as it addresses critical issues of equity and inclusion in mathematics education at a stage where foundational skills are developed. By focusing on ECE, this research not only seeks to enhance pedagogical practices but also aims to inform policy discussions around educational equity in South Africa and other similar contexts. Ultimately, this study aspires to contribute to a transformative approach to mathematics education that recognises and values the diverse cognitive frameworks of all learners.

While this study engages with related concepts such as equity, inclusion, social justice and culturally responsive pedagogy, these concepts are not used interchangeably. Vithal et al. (2024) explain that equity in mathematics education refers to ensuring that all learners have fair access to learning opportunities and resources, particularly those from historically marginalised communities. Inclusion focuses on enabling all learners to participate meaningfully in classroom learning regardless of their backgrounds or abilities. Xenofontos et al. (2021) emphasise that social justice in education addresses broader systemic inequalities that influence learners' access to knowledge and educational opportunities. In contrast, Leyva and Joseph (2023) and Zhang, Li and Disney (2024) describe culturally responsive pedagogy as teaching practices that recognise learners' cultural identities, languages and lived experiences as valuable resources for learning. Cognitive justice differs from these related concepts because it focuses specifically on recognising the legitimacy of diverse knowledge systems. Odora Hoppers (2021) and Sefotho and Letseka (2024) argue that cognitive justice requires education systems to acknowledge indigenous and community knowledge alongside formal academic knowledge. In this study, cognitive justice serves as the central analytical lens, while equity, inclusion and culturally responsive pedagogy represent related goals and pedagogical strategies that support equitable mathematics learning.

Research question: *How can teaching be adapted to ensure equitable mathematics learning in early childhood?*

Literature review

Promoting equitable mathematics learning in early childhood through cognitive justice involves recognising diverse knowledge systems and ensuring all children have access to quality mathematical education. This approach emphasises the importance of culturally responsive teaching and the integration of indigenous knowledge, which can enhance learning experiences for disadvantaged groups. Guided by the problem statement and research question, the following themes were generated for this study's review.

The importance of early mathematics education

Early childhood mathematics education is pivotal in shaping children's cognitive abilities and attitudes towards mathematics. Avcİ and Akman (2023) assert that early exposure to mathematics concepts significantly influences children's future academic success. The National Council of Teachers of Mathematics (NCTM 2022) emphasises that early mathematics experiences are essential for promoting numeracy skills, problem-solving abilities and logical reasoning. These foundational skills not only prepare children for formal schooling but also equip them with critical thinking skills necessary for navigating an increasingly complex world. Moreover, studies such as Clements, Lizcano and Sarama (2023) and Siller and Ahmad (2024) have both argued that competencies in early childhood mathematics contribute to a child's future academic achievements, including proficiency in mathematics itself. This means that children who engage in rich mathematical conversations and activities during preschool years tend to outperform their peers later in their educational journey. This emphasises the need for teachers to prioritise mathematics in early childhood curricula, ensuring

that all children, regardless of their background, have equitable access to quality mathematics education.

Effective teaching strategies for promotion of cognitive justice in early mathematics teaching

There is a need for teaching strategies with cognitive processes to enhance early childhood mathematics learning. Aragón et al. (2024)'s literature revealed that different approaches engage distinct cognitive skills. In the same view, Suh et al. (2021) suggested that mathematical modelling, when integrated with deliberate equitable teaching practices, can promote deeper mathematical understanding, student agency and 21st-century skills in diverse elementary classrooms. In a separate study, Svane et al. (2023) suggest that teachers require intervention approaches to enhance mathematics skills in preschools. Promoting cognitive justice can be addressed by integrating diverse cultural and linguistic backgrounds of mathematics in teaching and learning activities (Leyva & Joseph 2023). Zhang et al. (2024) argue that Chinese children's learning activities need to be culturally contextualised and integrated with play-based pedagogies. Similarly, South African teachers are encouraged to use culturally responsive and play-based activities when teaching mathematics (DBE 2011). However, the South African curriculum is not explicit about this view, as there are no clear guidelines to make mathematics equitable and accessible to learners in both rural and urban schools. Despite Young and Young (2024) not focusing on early childhood, they agree that there is still a gap in equitable mathematics in rural areas across all European countries. The analogy of equitable and accessible supports the need for inclusive, developmentally appropriate and culturally responsive strategies that reach all children, including those at risk. This early intervention focus is crucial for cognitive justice, as it addresses disparities before they widen in formal schooling.

Strategies to promote cognitive justice in early childhood mathematics include incorporating local and indigenous mathematical practices (Sata 2024), using translanguaging to support conceptual understanding (Escamilla, Alanís & Meier 2024), and facilitating learner-centred learning where learners share multiple problem-solving approaches (DBE 2011). Philosophers such as D'Ambrosio (2018) agree that indigenous games, storytelling and play-based activities can develop learners' mathematics skills while making their everyday lives meaningful. The critique from Escamilla et al. (2024) shows that translanguaging can promote cognitive justice in early mathematics by validating learners' home languages and cultural ways of knowing as legitimate tools for thinking and learning. Lastly, critical reflection on curriculum content that aligns with the local communities' values, equity and inclusivity in mathematics education. As such, linking early mathematics curriculum with the knowledge and skills integrated in the community can promote cognitive justice.

Challenges faced by teachers in early childhood math teaching for promotion of cognitive justice

Teachers face complex challenges when trying to ensure all learners' ways of thinking and learning are respected and included in early childhood mathematics lessons. These challenges manifest in various ways, including pedagogical gaps, systemic constraints and cognitive demands. These challenges hinder the creation of equitable learning environments that affirm diverse mathematical identities and knowledge systems. Concerning pedagogical gaps, teachers may lack sufficient training, resources or methods to teach mathematics in a way that honours different cultural perspectives or learning styles. A study conducted by Payadnya et al. (2024) in Indonesia and Thailand revealed that teachers have limited resources and professional development opportunities to incorporate different cultural perspectives and contextual realities into their teaching and learning of mathematics.

Additionally, Xenofontos et al. (2021) highlight that many teachers struggle to incorporate social justice perspectives as a result of a lack of training and exposure to such pedagogical approaches. This backdrop suggests a need for robust pre- and in-service professional development for teachers in teaching mathematics from the early grades. Suh et al. (2024) affirm that despite the effectiveness of culturally responsive mathematical modelling in early mathematics classrooms, many teachers remain untrained in employing such tasks, limiting their ability to connect learning with learners' lived experiences and social contexts. It is against this background that the reviewed literature indicates a need for expanded research and systemic support to implement equity-oriented approaches in diverse educational settings, particularly in early mathematics.

There are significant challenges in implementing social justice within early childhood mathematics education, arising from multiple underlying factors (Svane et al. 2023). This situation calls for researchers to examine these challenges and contribute to the development of policies aimed at addressing them. In relation to cognitive demands, Parrish and Bryd (2022) found that cognitively demanding tasks are linked to higher student achievement, especially when these tasks incorporate multiple representations, which enhance problem-solving skills. However, simply increasing cognitive demand or offering multiple solution strategies does not automatically lead to better outcomes. The authors emphasise that teachers need targeted support and professional development to sustain the complexity of these tasks and to engage learners effectively. This implies that the decline in cognitive demand during implementation suggests that more research is needed on teacher practices and classroom dynamics that sustain or undermine task complexity, hence situating our study.

Lastly, the synthesis of literature by Vithal et al. (2024) indicates that research on equity in mathematics education is expanding and diversifying. However, persistent systemic

constraints, such as socioeconomic disparities, institutional biases and curriculum limitations, continue to challenge the realisation of equitable mathematics learning, especially for marginalised groups. There is a pressing need for more inclusive research, pedagogy and policy. In the same vein, Xenofontos et al. (2021) found that systemic constraints significantly hinder efforts to promote equitable mathematics learning. There is ambiguity in the conceptualisation of social justice within mathematics education. Lack of clarity and agreement on the concept of social justice, leading to inconsistent implementation and weak policy support (Cairney & Kippin 2022). This background highlights the necessity for researchers to explore how teachers can be supported to enact cognitive justice and culturally sustaining pedagogies in early childhood mathematics skills development. Hosseini et al. (2025) corroborate that systemic constraints, such as policy, institutional structures and entrenched social norms, pose significant challenges to equitable early childhood mathematics learning. This calls for research that explicitly focuses on cognitive justice, integrating recognition, representation and redistribution within early childhood mathematics education.

Theoretical framework

This study is grounded in the principles of cognitive justice theory, which advocates for the recognition and validation of diverse epistemologies in educational contexts (Visvanathan 2009). Cognitive justice, as articulated by Sefotho and Letseka (2024), means that all forms of knowledge, particularly those arising from marginalised communities, should be acknowledged and integrated into the learning process. This is particularly pertinent in ECE, where foundational mathematical concepts are introduced and where cultural and contextual factors profoundly influence learning outcomes. While equity and inclusion support access to quality education for all individuals, cognitive justice goes further to promote balanced knowledge systems that are complemented by African epistemologies alongside dominant Western knowledge traditions (Odora Hoppers 2021).

In this study, cognitive justice provides the primary conceptual lens for understanding how mathematics teaching can recognise and validate diverse ways of knowing in early childhood classrooms. The concept is operationalised by examining how teachers integrate cultural practices, digital tools and play-based pedagogies to support equitable mathematics learning. Cognitive justice theory closely aligns with Vygotsky's sociocultural theory, which emphasises the role of social interactions and cultural context in cognitive development (Vygotsky 1978). Vygotsky's notion of the Zone of Proximal Development (ZPD) is particularly relevant, as it highlights the potential for learning when children engage with more knowledgeable peers and/or adults. This interaction supports the development of mathematical reasoning and conceptual understanding. Recent studies have reinforced Vygotsky's assertions by demonstrating that collaborative learning experiences improve children's mathematical reasoning and problem-solving abilities (Ndebil & Ali 2024; Siller & Ahmad 2024).

In this study, sociocultural theory explains how cognitive justice can occur in the classroom through learning processes. While cognitive justice focuses on recognising diverse knowledge systems, sociocultural theory explains how learners develop mathematical understanding through social interaction, mediated tools and guided participation. Ethnomathematics further strengthens this theoretical perspective by emphasising the mathematical knowledge embedded within cultural practices and everyday activities. D'Ambrosio (1985) argues that indigenous games, cultural practices and community activities contain mathematical ideas that can support meaningful learning. This perspective supports the argument that culturally relevant games and community practices can serve as legitimate pedagogical resources for teaching early mathematics.

Integrating cognitive justice, sociocultural theory and ethnomathematics enables a comprehensive approach to mathematics education that respects and incorporates the diverse cultural backgrounds of all learners. Mathematical concepts can be taught using culturally relevant contexts that resonate with children's lived experiences, thereby promoting deeper engagement and understanding (Acharya et al. 2021). This approach not only validates learners' cultural identities but also challenges the dominant narratives that often marginalise alternative ways of knowing. Together, these theoretical perspectives guide the analysis of this study. Cognitive justice provides the normative goal of equitable recognition of diverse knowledge systems, sociocultural theory explains how learning occurs through interaction and mediation, and ethnomathematics illustrates how cultural practices can function as mathematical learning resources. This combined framework allows the study to analyse how teachers attempt to translate these theoretical principles into everyday classroom practices.

Moreover, the intersection of these theories underscores the importance of teacher training and curriculum development in promoting equitable practices. Teachers must be equipped with the skills to recognise and address the diverse mathematical knowledge that children bring to the classroom. Professional development programmes should focus on fostering cultural competence and understanding the implications of cognitive justice in their teaching practices (Hosseini et al. 2025). This aligns with the call for a more inclusive curriculum that reflects the multiplicity of mathematical experiences and knowledge systems present in contemporary classrooms.

Research methods and design

This study adopted an interpretivist paradigm to interpret the participants' experiences of adaptable approaches that support equitable teaching and learning of early mathematics. Supported by Paudel (2024), the views and experiences of individuals are influenced by cultural, social and historical backgrounds. This view from Paudel (2024)

aligns with the research from Dawadi, Shrestha and Giri (2021), which shows a complementarity between the interpretivist paradigm and qualitative research, as it requires rich and in-depth data from a social setting within a specific real-life context. It is against this belief that a qualitative approach was employed to collect data from human participants, aiming to gain more insight into the subject under study (Cleland, MacLeod & Ellaway 2021; Lim 2025). Hermeneutic phenomenology was employed to explore teachers' lived experiences of adapting to ensure equitable mathematics learning in early childhood. To contextualise the reader, a hermeneutic phenomenological research design is sought to understand the meaning of human experience by interpreting the rich descriptions of that experience (Alsaigh & Coyne 2021). As advised by Akkaş and Meydan (2024), this study selected 12 early childhood teachers from four primary schools in Limpopo, South Africa. These participants were selected using homogeneous purposive sampling based on their professional experience of teaching mathematics in the early years. One of the inclusion criteria required participants to have a minimum of 3 years' experience teaching mathematics in the foundation phase. This requirement ensured that the teachers had adequate classroom experience and curriculum familiarity to engage meaningfully during data collection processes. Three teachers (from Grade 1 to Grade 3) from each school participated; however, there could be potential bias arising from having these teachers from the same district. These teachers they as they receive the same teacher training workshops and mathematics materials, which could influence the generalizability of the findings (Hays & McKibben 2021; Selepe & Phala 2025). Data triangulation was used to reduce potential bias as this study combined semi-structured interviews with non-participant observations (Bentalha & Alla 2024). In addition, member checking in qualitative research was ensured by sharing the preliminary interpretations with teachers to validate that their lived experiences are authentically not overly shaped by district training influences.

One-on-one interviews were conducted to elicit each teacher's lived experiences on adaptable approaches that support equitable teaching and learning of early mathematics. An interview schedule consisting of open-ended questions, derived from the research questions, was used to guide the conversations. This ensured that the authors, as interviewers, posed relevant questions to the teachers and employed probing techniques to elicit deeper responses in early mathematics teaching. An audio recorder was used to capture the conversations during the interview sessions. Non-participant observations were conducted, observing the participants teaching mathematics in their classrooms. This was done to corroborate the teachers' responses from the interviews and validate how teaching can be adapted to ensure equitable mathematics learning in early childhood. The observations were conducted with each Grade 3 teacher from four schools, assuming that they implemented mathematics activities in the same way in each school. The rationale for observing Grade 3 teachers specifically represents a critical transition in the foundation phase where learners consolidate early mathematics skills before progressing to the intermediate phase. Each lesson took 45 min, as stipulated by the Curriculum Assessment and Policy Statement (CAPS). As argued in Li (2023) and Selepe and Phala (2025)'s work, a single observation session was conducted to minimise disruption to teaching and learning activities while capturing authentic, real-time classroom practices. While multiple observations could provide deeper insights, the study prioritised teachers' reflective accounts of their lived experiences during interviews, with observations serving as complementary data to contextualise these experiences. An observation schedule was employed to address the research questions and investigate the phenomenon under study. The study was conducted over a period of 1 month. This duration covered all data instrument collections.

Before the data collection processes, the ethical certificate was approved by the 'information redacted to maintain the integrity of the review process'. Each teacher signed the consent form, which informed them about the exit clause that allows withdrawal of participation at any time without penalty. The interview verbatim transcripts were reviewed multiple times and cross-checked against the audio recordings to detect and correct any discrepancies (Battaglia 2024). Pseudonyms such as School 1, Foundation Phase, Educator 1 (S1, FP, E1) to School 4 Foundation Phase Educator 3 (S4, FP, E3) were used to protect the identities of schools and participants in qualitative research. Before the data analysis, the data was prepared for the actual analysis.

Data analysis

The recorded data was transcribed into text to align with the qualitative approach. Furthermore, the data was cleaned to facilitate the collection of notes and reflections, aiming to understand the lived experiences of the participants. Interpretive phenomenological analysis was used to analyse the data (Ismail & Kinchin 2023). The data analysis was informed by principles of cognitive justice, particularly the recognition of diverse epistemologies and equitable access to knowledge. The codes were generated from the keywords of the research questions.

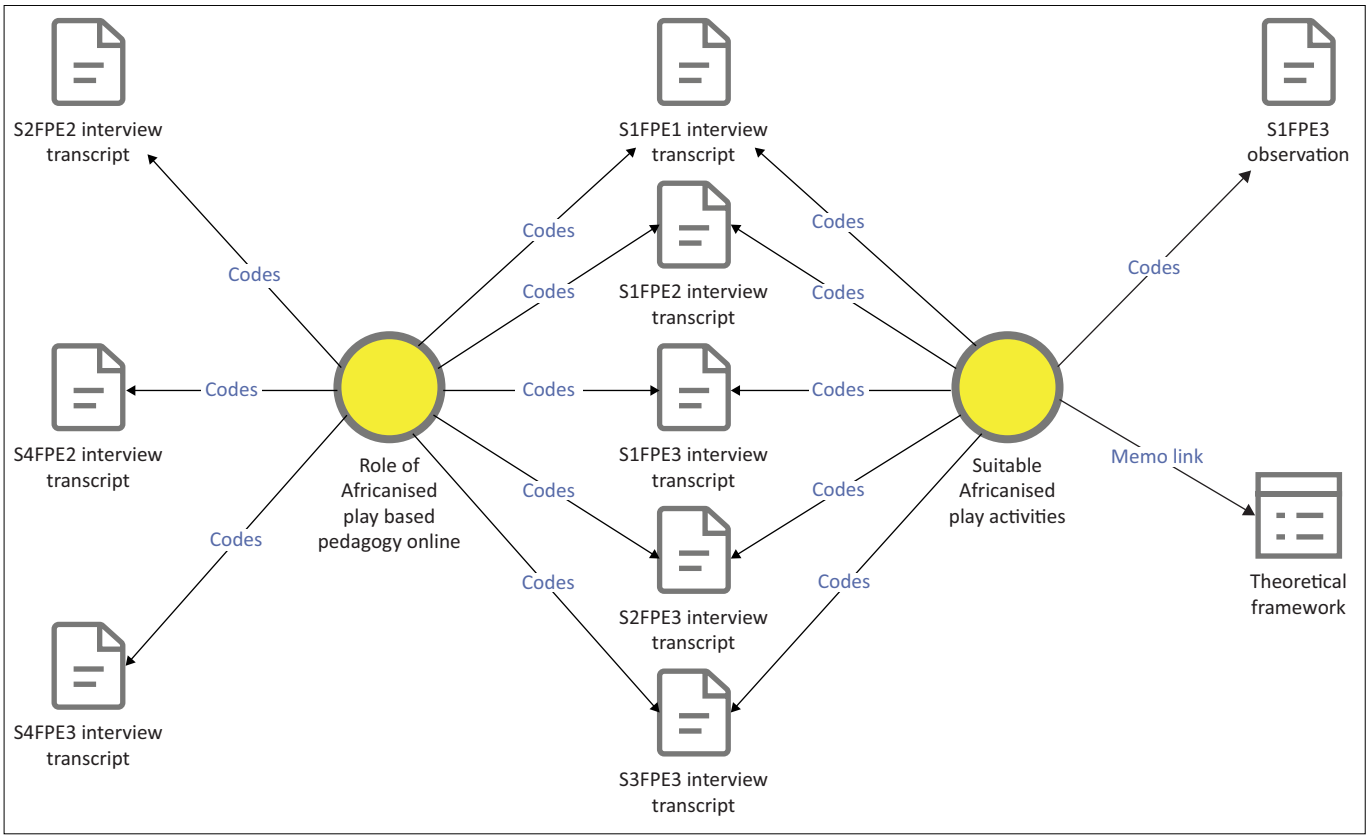
To operationalise cognitive justice in the analysis, the study translated the concept into observable analytical indicators derived from the theoretical framework. Odora Hoppers (2021) and Sefotho and Letseka (2024) explain that cognitive justice requires the recognition of diverse knowledge systems within educational contexts. Guided by this perspective, three indicators informed the coding process. Firstly, the recognition of diverse knowledge systems referred to classroom practices where teachers incorporated cultural practices, indigenous games, or learners' everyday experiences into mathematics teaching. Secondly, equitable learner participation referred to opportunities for learners to actively engage in mathematical reasoning through collaborative activities, guided play or discussion.

This indicator aligns with Vygotsky's (1978) sociocultural theory, which emphasises learning through social interaction and mediation, and with Siller and Ahmad's (2024) findings that collaborative learning improves learners' mathematical reasoning. Thirdly, the use of mediating cultural or technological tools referred to teaching resources that supported learners' conceptual understanding of mathematics, such as digital resources, culturally meaningful games or visual learning materials.

During coding, segments of interview and observation data were examined in relation to these indicators. Instances were coded as evidence of cognitive justice when teaching practices recognised diverse knowledge systems and enabled learners to participate meaningfully in mathematical learning through appropriate mediating tools. Conversely, the absence of cognitive justice was identified when classroom practices relied mainly on conventional instructional approaches that did not integrate learners' cultural knowledge, limited learner participation or lacked supportive mediating resources. By applying these indicators during coding, the study used cognitive justice as an analytical lens to interpret how teachers' practices enabled or constrained equitable mathematics learning.

An independent coder collaborated in co-coding the dataset to enhance the transparency, credibility, consistency and reliability of the data analysis (Friedman, Owen & VanPuymbrouck 2024). Secondly, similar codes were grouped to develop categories that align with the literature review. Lastly, categories were grouped to identify emerging themes, which were then used to discuss the findings. Although the analysis involved coding procedures supported by NVivo, the study remained grounded in a hermeneutic phenomenological orientation. Alsaigh and Coyne (2021) explain that hermeneutic phenomenology focuses on interpreting participants' lived experiences rather than merely categorising data. In this study, coding served as an organising strategy to identify patterns across the data, while the interpretation focused on understanding the meaning of teachers' lived experiences of adapting mathematics teaching to promote equitable learning. Thus, the themes were not treated as simple categories but as interpretive representations of how teachers experience and enact equitable mathematics teaching in their classroom contexts.

To ensure rigour and trustworthiness, the authors employed data triangulation within an interpretive paradigm (Bentalha & Alla 2024), enabling the inclusion of multiple perspectives and a richer understanding of teachers' lived experiences of the phenomenon under investigation. Figure 1 illustrates a coding network exported from NVivo during the data analysis. To strengthen credibility, the study used multiple qualitative strategies. Data triangulation was achieved by comparing evidence from semi-structured interviews and classroom observations to identify converging patterns in teachers' practices (Bentalha & Alla 2024). Member checking was conducted by sharing preliminary interpretations with



S, school; FP, foundation phase; E, educator.

FIGURE 1: A coding network on adaptable approaches to support equitable early mathematics.

selected participants to confirm that the interpretations accurately reflected their experiences. The involvement of an independent coder enhanced dependability by ensuring that coding decisions were discussed and refined collaboratively (Friedman et al. 2024). The researchers also provided detailed descriptions of the research context and participants to support transferability by enabling readers to assess the relevance of the findings to similar educational settings.

Figure 1 illustrates a coding network that demonstrates the interconnection of adaptable approaches, including technology integration, play-based pedagogy and cultural practices, to support the equitable teaching and learning of early mathematics. Simply put, S1, FP, E1; S1, FP, E2; S1, FP, E3; S2, FP, E3 and S3, FP, E3 expressed their lived experiences with these approaches during the semi-interviews, while S1FPE3 used a Sudoku game during the classroom observations. The coding network is linked to the theoretical framework, guiding the analysis and presentation, which in turn relates to cognitive justice because it emphasises culturally rooted ways of knowing. However, participants face challenges such as limited access to digital tools and insufficient professional training, which hinder their ability to implement these approaches in mathematics classrooms effectively.

Ethical considerations

Before the data collection processes, the ethical certificate was approved by the University of South African Ethics Committee with reference 2023/10/11/64019209/38/AM. Each teacher signed the consent form which informed them about the exit clause that allows withdrawal of participation at any time without penalty. The verbatim transcriptions were repeatedly read and checked against the audio recordings to identify and correct anomalies (Battaglia 2024).

Results

The presentation of results reflects the analytical criteria used in this study. Classroom practices were interpreted in relation to whether they recognised diverse knowledge systems, supported meaningful learner participation, and used mediating cultural or technological tools to enhance mathematical understanding. These dimensions enabled the study to examine how teachers enacted, or struggled to enact, cognitive justice in their everyday teaching practices.

Teachers' lived experiences on adapting mathematics approaches

The results reveal that teachers understand that integrating digital technologies into mathematics teaching enhances accessible and equitable learning for learners. The transcripts from the semi-structured interviews indicate that participants have lived experiences in using online teaching platforms and digital tools to teach early mathematics in their classrooms. The emphasis is that acquiring mental mathematics knowledge through adaptive approaches is socially constructed and can be adopted in their teaching and learning activities. Two participants articulated:

> 'Our school is equipped with Wi-Fi and smartboards. We can play the games on the smartboards with the learners. Even at home, learners have smartphones and smartboards.' (S2, FP, E3)

> 'I use Google videos that link to the mathematics topic of the week … Songs that relate to mathematics can be implemented.' (S3, FP, E1)

More interestingly, a participant explained how Google videos can be used to teach children mathematics:

> '… Learners can use tablets to view videos and ... to play the games, to learn counting and multiplication …' (S1, FP, E3)

S1, FP, E3's response reflects on incorporating play-based pedagogies to make mathematics teaching adaptable and equitable in early childhood. To contextualise the readers in relation to this presentation of results, play-based pedagogy is a teaching strategy that develops learners' holistic skills and can be meaningful and significant in teaching mathematics and other subjects in early childhood (Yeng & Tatsi 2024).

The non-participants' observations validate the responses from the participants' interviews, which show that technology integration in early mathematics teaching. S2, FP, E3 utilised technological tools, including a laptop, smartboard and projector, to digitally display mathematical songs and numbers during the mathematics lesson, aligning with her claims about using digital tools to enhance mathematical understanding in young learners. Similarly, S3, FP, E3's practices combined digital and physical teaching activities to teach early mathematics skills. This was observed when learners began by watching a Google video via projector and later went outside to play physical games, developing mathematics concepts through hands-on activities, which linked to S3, FP, E3's responses during the interviews. However, a challenge of limited access to technological devices in the classrooms was evident in S1, FP, E3's classrooms, where the cultural game Sudoku was used for remedial counting practice. A probing response from a participant was:

> 'We have limited tablets, and I could not access our smart classrooms during my lesson.' (S1, FP, E3)

In S4, FP, E3 classrooms, technological tools were not used, as she noted that they have few tablets that are shared across all grades in the early childhood. These data from the observations show that teachers understand the significant role of technology in promoting equitable learning of early mathematics. Nevertheless, infrastructure constraints, such as resource availability, negatively affect its implementation in classrooms.

Culturally responsive play-based pedagogy in early mathematics

The participants highlighted the meaningful and fundamental use of culturally relevant play-based pedagogy for promoting equitable learning experiences in early mathematics. To clarify the setting in which this study unfolds, Iyabode et al. (2024) explain culturally responsive play-based pedagogy as play activities that integrate culture, identity, and indigenous knowledge to teach early mathematics. These results align well with the ethnomathematics practices that encourage the use of indigenous concepts to teach mathematics in the classroom (D'Ambrosio 1985). These approaches develop young learners' cognitive, social and physical skills in mathematics learning. Two participants remarked:

> 'Since culture broadens learners' comprehension of mathematics, it would be beneficial to incorporate it into mathematics teaching … It helps our children to rediscover their African identity and culture.' (S1, FP, E3)

> 'We can also set up activities that feature cultural elements that young children can play and learn mathematics.' (S2, FP, E3)

S3, FP, E3 explained how the Morabaraba game can be used to teach early mathematics as it integrates aspects of culture and play-based pedagogies. To anchor the discussion in context, Livingstone and Wallis (2019) note that Morabaraba is a two-player strategy board game in which players place and move 'cows' (pieces) to form a row of three, aiming to capture the opponent's pieces. This game can be used to teach counting, addition and subtraction through managing pieces, as well as logical deduction for strategic moves, geometry, patterns and problem-solving skills in an early childhood classroom. A participant narrated:

> 'Morabaraba engages learners in problem-solving skills … To win this game, learners must have algebraic and mathematical thinking skills.' (S3, FP, E3)

They explained the social and cognitive benefits of play:

> 'Since they are part of physical activities, they help to maintain their holistic skills … Education knowledge is then constructed as learners converse and interact.' (S3, FP, E3)

The classroom observations revealed both opportunities and gaps in using culturally responsive play-based pedagogies to promote equitable early mathematics learning, as reflected in participants' interview responses. During the classroom implementation, S3, FP, E3 successfully integrated technology and culturally responsive play-based pedagogy. The participants watched a video of young children playing with pebbles and developing number counting skills on the projector. As explained by Bilton (2025), pebbles can be used as counters or mathematics resources to teach mathematics in early childhood. In S3, FP, E3 classrooms, after watching the video on projectors, learners were asked to use bottle tops to play a game of pebbles to enhance their counting skills. During this mathematics activity, the development of counting, number patterns, problem-solving and social skills was evident and demonstrated. Similarly, S2, FP, E3 used a Hopscotch game to teach learners number and geometric patterns. S1, FP, E3 used Sudoku to teach addition, subtraction and counting skills during the assessment. The outcome of the assessment was to enhance learners' mathematics skills while integrating culturally responsive play-based pedagogy. In contrast, S4, FP, E3 did not incorporate culturally responsive play-based pedagogy during the lesson despite her responses from the interviews highlighting the participants' understanding of promoting cultural identity, cognitive development and equitable mathematics in early childhood. These results suggest that while participants are aware of the benefits of using culturally responsive play-based pedagogy for equitable learning in early mathematics, challenges such as knowledge of lesson planning and the availability of resources may limit its actual classroom implementation.

Discussion

This article's results reveal that adaptable teaching practices in early mathematics require teachers to integrate technology and culturally responsive play pedagogies. The integration of technology and culturally responsive play accommodates diverse learning styles, reinforces cultural identity and provides equitable opportunities for all learners to engage meaningfully with mathematical concepts. Participants' lived experiences show that teachers value pedagogical flexibility and contextualised teaching practices. However, classroom observations reveal that contextual challenges, such as limited resources and insufficient professional support, often constrain their implementation.

Interpreting these findings through the lens of cognitive justice theory highlights how equitable mathematics education requires recognising diverse knowledge systems and ensuring that learners have fair access to learning opportunities (Sefotho & Letseka 2024). While equity and inclusion focus on fair access and participation in learning, this study uses cognitive justice as the analytical lens to examine how teachers recognise and integrate diverse knowledge systems through culturally responsive pedagogies and technological tools in early mathematics classrooms. The following themes explain how teachers attempt to enact these principles in practice and where challenges emerge.

Theme 1: Using technologies for equitable and cognitive development of early mathematics

This theme addresses the article's research question by examining how digital technologies support equitable teaching and learning in early mathematics. Cognitive justice theory emphasises that equitable education requires expanding access to knowledge and recognising multiple ways of learning and knowing (Sefotho & Letseka 2024). In this study, digital tools function as mediating resources that can broaden learners' access to mathematical knowledge and support different learning styles. The findings show that teachers believe technology can enhance learners' engagement and understanding of mathematics concepts. The findings show that teachers believe technology can

enhance learners' engagement and understanding of mathematics concepts. For example, participants such as S1, FP, E3 reported limited access to tablets and smart classrooms, while S4, FP, E3 highlighted the scarcity of shared devices across grades. These practices illustrate how teachers use digital tools to create interactive and visually rich learning environments that help young learners grasp mathematical concepts more easily.

From a cognitive justice perspective, these digital resources can support equitable learning by allowing learners to access mathematical knowledge through multiple representations, including visual, auditory and interactive forms. In this way, technology can reduce barriers to understanding and enable learners with different learning preferences to participate meaningfully in mathematics learning.

The findings corroborate Vygotsky's tenets of mediation, scaffolding and ZPD, as participants such as S2, FP, E3 and S3, FP, E3 articulated their lived experiences with technological devices, including smartboards, projectors and Google videos, which served as mediated tools to enhance learners' mathematical understanding in guided play activities. The literature from Suh et al. (2021) and Svane et al. (2023) supports this statement, as they explain that technology is one of the key enablers of equity and conceptual understanding of mathematics concepts. However, the observations reveal an important gap between teachers' intentions and their classroom practices. While teachers recognise the benefits of digital tools, many classrooms experience limited access to technological resources. For instance, S1, FP, E3 explained that she could not access the smart classroom during the lesson and had only a limited number of tablets available to learners. Similarly, S4, FP, E3 indicated that the few available tablets were shared across multiple grades. These constraints limited teachers' ability to consistently integrate technology into mathematics lessons.

These challenges are confirmed by Fauzi and Suryadi (2020) and Xenofontos et al. (2021), who asserted that teachers often lack resources and professional training to integrate technologies meaningfully in the classrooms. Interpreting these findings through cognitive justice theory highlights that equitable mathematics learning cannot be achieved through pedagogical innovation alone. Structural support, including access to technological resources and professional development opportunities, is necessary to ensure that all learners can benefit from these tools. Therefore, while digital technologies show strong potential to support equitable mathematics learning, the findings suggest that their contribution to cognitive justice remains uneven unless schools receive adequate resources and support.

Theme 2: Valuing diverse epistemologies through culturally relevant mathematics pedagogies

Theme 2 emerged from the aim of this article to support an examination of adaptable approaches to equitable teaching and learning in early mathematics. Cognitive justice theory, as highlighted by Shizha (2025) emphasises that education should recognise multiple knowledge systems and validate indigenous and local knowledge alongside formal academic knowledge. The findings show that teachers attempt to integrate culturally relevant play-based pedagogies into their mathematics teaching. Activities such as Hopscotch, Morabaraba, pebbles and Sudoku were used to help learners develop mathematical concepts through familiar cultural games and everyday experiences. These practices demonstrate how teachers draw on learners' cultural backgrounds to make mathematics learning more meaningful and accessible.

Kadonsi et al. (2023) emphasise that learners enter classrooms with diverse cultural and linguistic knowledge systems that influence how they understand and engage with new knowledge. In this study, teachers attempted to build on these existing knowledge systems by incorporating culturally familiar activities into mathematics teaching. For example, S3, FP, E3 explained how the Morabaraba game supports the development of problem-solving, pattern recognition and logical reasoning skills. Research on ethnomathematics also supports this approach. D'Ambrosio (1985) argues that indigenous practices and cultural activities often contain embedded mathematical ideas that can support meaningful learning. Similarly, Leyva and Joseph (2023), Zhang et al. (2024), and Acharya et al. (2021) advocate integrating cultural practices into mathematics education to make learning more inclusive and contextually relevant.

However, interpretation of the findings reveals a tension between teachers' understanding of culturally responsive pedagogy and their classroom practices. While participants expressed strong support for integrating cultural games into mathematics teaching during interviews, classroom observations showed that these practices were not always consistently implemented. In some cases, culturally responsive play-based activities were used primarily as remedial strategies rather than as core instructional approaches. From a cognitive justice perspective, this pattern suggests that cultural knowledge is sometimes positioned as supplementary rather than as an equally valid source of mathematical knowledge. Although teachers recognise the value of cultural games in supporting learning, they may still view them as informal activities rather than legitimate ways to teach mathematics.

This challenge is also linked to curriculum structures. Policies such as the CAPS and international frameworks like the Common Core State Standards provide limited guidance on integrating diverse epistemologies into mathematics teaching (DBE 2011; Hosseini et al. 2025). As a result, teachers may struggle to consistently incorporate culturally responsive pedagogies into formal lesson planning. As a result, achieving cognitive justice in early mathematics requires more than recognising cultural practices in principle. Teachers need clearer curriculum guidance and professional

development support to integrate indigenous knowledge and cultural practices meaningfully into mathematics instruction.

Contribution and recommendations on equity and cognitive justice in early mathematics

This study contributes to teacher education research by providing an interpretive understanding of how teachers attempt to enact cognitive justice in early mathematics classrooms. Rather than only describing classroom practices, the findings highlight the presence of an intention–practice gap in equity-oriented teaching, variations in how teachers enact cognitive justice across classrooms, and identifiable patterns in how teachers combine technological and culturally responsive pedagogical approaches. However, limited access to digital resources often prevents teachers from integrating these tools effectively. Similarly, teachers value culturally responsive play-based pedagogies that reflect learners' cultural identities and lived experiences, yet these approaches are sometimes used only as supplementary or remedial strategies.

Beyond describing teachers' experiences, this study advances understanding of teacher development by showing how teachers navigate tensions between equity-oriented pedagogical intentions and structural constraints in their classrooms. The findings demonstrate that teachers possess emerging knowledge of equitable mathematics teaching, but they require stronger pedagogical support to translate this knowledge into sustained classroom practice. The study, therefore, contributes analytically to teacher education by identifying three areas of teacher learning necessary for promoting cognitive justice in early mathematics. Firstly, teachers need pedagogical knowledge to integrate digital tools meaningfully into mathematics lessons rather than treating technology solely as a supplementary teaching resource. Secondly, teachers need professional learning opportunities that help them view culturally responsive play-based pedagogies as legitimate mathematical learning approaches rather than remedial activities. Thirdly, teachers require curriculum guidance that helps them connect indigenous cultural practices with formal mathematical concepts during lesson planning.

Highlighting these gaps, this study provides a deeper understanding of how structural conditions influence the realisation of cognitive justice in early mathematics education. The findings suggest that achieving equitable mathematics learning requires both pedagogical innovation and systemic support. Based on these findings, the study recommends that policymakers and education authorities provide continuous professional development programmes that integrate digital technologies and culturally responsive play-based pedagogies into mathematics teaching. These training programmes should demonstrate practical strategies for combining cultural games and digital tools with mathematics concepts.

For example, professional development initiatives could show teachers how to adapt cultural games such as Morabaraba and Sudoku for digital platforms and use them to teach mathematical concepts. In addition, curriculum developers could design exemplar lesson plans and resource materials that explicitly demonstrate how teachers can integrate digital technologies with culturally responsive activities in early mathematics classrooms. Schools should receive support to access affordable and offline technological tools that can be distributed equitably across classrooms, particularly in under-resourced contexts. Such support would help ensure that all learners benefit from teaching approaches that recognise diverse knowledge systems and promote equitable participation in mathematics learning. Because the study involved teachers from four schools within a single district in Limpopo province, the findings should be interpreted as context-specific insights rather than generalisable conclusions about early mathematics teaching across South Africa.

Conclusion

The findings revealed that participants' intentions and partial practices in teaching early mathematics are evident in the interviews and observations. However, they cannot yet be considered entirely equitable nor fully aligned with cognitive justice. The article extends the theoretical orientations of cognitive justice in early mathematics, acknowledging cultural practices, digital innovation and diverse epistemologies that extend beyond equity, inclusion, and pedagogical strategies.

Importantly, the study contributes to teacher education research by demonstrating that teachers' understanding of equitable mathematics pedagogy develops unevenly when professional learning opportunities and curriculum guidance are limited. The findings show that teachers often recognise the importance of culturally responsive and technology-supported teaching, but they require structured professional learning to transform these ideas into consistent classroom practices. The study, therefore, highlights that promoting cognitive justice in early mathematics is not only about adopting inclusive pedagogies but also a process of teacher learning that requires sustained professional development, curriculum support and access to appropriate teaching resources.

The emerging findings indicate that teachers recognise the value of technology and culturally responsive play-based pedagogy; however, their actual implementation in the classroom remains inconsistent. As such, this research emphasises the critical need for professional development to support teachers in their classroom practices. Policymakers are encouraged to promote equitable early mathematics education to bridge the gap between intentions and cognitive justice in the classroom. The findings are based on a small sample of teachers in Limpopo province, which restricts the generalisability of the results to a broader context. Future

researchers can focus on longitudinal studies to explore sustained professional development and improved access to digital tools, and how these factors shape teachers' practical implementation and learners' achievement in early mathematics.

Acknowledgements

The authors acknowledge all the participants who were able to share their insights related to the subject matter of this study.

This article is based on research originally conducted as part of Mmakgabo A. Selepe's doctoral thesis titled 'Using Africanised play-based pedagogy in the online teaching of mental mathematics to foundation phase learners', submitted to the Department of Early Childhood Education and Development, University of South Africa in 2024. The thesis was supervised by Ramashego S. Mphahlele. The thesis was reworked, revised and adapted into a journal article for publication. The original thesis is available at: https://ir.unisa.ac.za/handle/10500/6419/browse?type=subject&value=Africanised+play-based+pedagogy.

Competing interests

The authors, Mmakgabo A. Selepe; Leungo E. Bawani and Ramashego S. Mphahlele, declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

CRediT authorship contribution

Mmakgabo A. Selepe: Conceptualisation, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. Leungo E. Bawani: Conceptualisation, Writing – original draft, Writing – review & editing. Ramashego S. Mphahlele: Supervision, Writing – review & editing. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication, and take responsibility for the integrity of its findings.

Funding information

The authors received no financial support for the research, authorship and/or publication of this article.

Data availability

The data that support the findings of this study are not openly available and are available from the corresponding author, Mmakgabo A. Selepe, upon reasonable request.

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