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Building Algebraic Reasoning in Early Mathematics: Insights for Teacher Educators, Student Teachers, and Primary Mathematics Teachers

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ABSTRACT

This study investigates the development of algebraic skills among primary school learners, guided by six key objectives that address conceptual understanding, instructional strategies, cognitive benefits, teacher roles, assessment practices, and learning barriers. Anchored in literature review, classroom observations, and interviews with six mathematics teachers from upper primary classes, the research explores how both learners and educators understand and interpret algebraic concepts such as pattern recognition, generalization, and symbolic representation. The study identifies a range of effective instructional strategies used to nurture algebraic reasoning, including inquiry-based learning, use of concrete manipulatives, integration of technology, and the application of multiple representations to bridge the gap between arithmetic and algebra. Findings highlight that when these strategies are well implemented, students demonstrate enhanced problem-solving and critical thinking skills manifesting through conjecture, abstraction, and justification. Teachers are shown to play a pivotal role in scaffolding algebraic learning by facilitating discourse, designing tasks that encourage exploration, and adapting instruction to meet diverse learner needs. Assessment of algebraic skills among learners is largely formative, with teachers employing open-ended questions, group tasks, and diagnostic questioning to gauge conceptual understanding. Despite these efforts, several challenges were noted. Teachers reported limited instructional time, curriculum rigidity, resource shortages, and persistent learner misconceptions as major obstacles to effective algebra instruction. These findings underscore the need for targeted professional development, flexible curricular frameworks, and increased resource support. The study contributes valuable insights into how algebraic skills can be meaningfully developed in primary mathematics, offering practical implications for improving pedagogy, assessment, and systemic support in mathematics education.

Keywords: Algebraic Reasoning, Conceptual Understanding, Teaching Strategies, Primary Mathematics, Teacher Role, Formative Assessment, Problem-Solving, Learning Barriers

INTRODUCTION TO THE STUDY

Background

Contemporary mathematics education reform efforts prioritize algebraic thinking as a critical element for deep learning and mathematical fluency. Globally, curriculum policies emphasize algebra not merely as a set of procedures but as a mode of thinking essential from early childhood through to advanced mathematical understanding (Kaput, 2008; Cai et al., 2005; Tagle et al., 2016). In Uganda, for example, algebra is included from pre-primary to secondary education, yet challenges persist in its implementation, largely due to pedagogical approaches that focus on rote arithmetic rather than relational reasoning (Earnest & Balti, 2008; Kriegler & Lee, 2007).

The integration of algebraic thinking within early mathematics learning is supported by international research emphasizing the need for conceptual coherence and cognitive engagement across mathematical strands (Adamuz-Povedano et al., 2021; Glassmeyer & Edwards, 2016). However, research also reveals that many mathematics teachers lack both the conceptual grounding and pedagogical skills necessary to foster algebraic reasoning in learners, leading to procedural teaching that fails to build a strong algebraic foundation (FitzSimons, 2015; Kieran, 2004; Stacey, 2006).

Algebraic thinking enables students to represent, analyze, and generalize mathematical structures, which underpins success in solving complex problems and understanding advanced mathematics (Windsor, 2010; Hardiani et al., 2018). By recognizing patterns, modeling relationships, and reasoning logically, learners develop not only arithmetic proficiency but also critical and creative thinking skills necessary in real-life and academic contexts (Kriegler, 2008; Kaput & Blanton, 2005).

Recent research underscores the need for systemic instructional changes to ensure early and continuous development of these skills (Blanton et al., 2015; Bush & Karp, 2013). As algebraic thinking forms the cognitive bridge from arithmetic to more abstract mathematics, its inclusion in teacher training programs and classroom pedagogy is both urgent and essential (Cai & Knuth, 2005; Schmittau, 2005).

While many studies have explored the theoretical frameworks and curricular implications of algebraic reasoning, relatively fewer studies integrate actual teacher perspectives and classroom observations, particularly at the primary level. This is a critical oversight because the successful implementation of algebraic thinking strategies is highly dependent on teachers' understanding, beliefs, and classroom practices (Wilkie & Clarke, 2016; Nguyen et al., 2021; Rott et al., 2021). Therefore, a more comprehensive approach that combines literature-based insights with empirical classroom data is required.

Purpose of the Study

This study aims to examine the development of algebraic skills in middle primary mathematics education (Primary 4–5) in Uganda. It seeks to understand how algebraic thinking is conceptualized, taught, and assessed by educators, while also exploring its role in enhancing learners' problem-solving and reasoning abilities.

Guided by six key objectives, the study focuses on identifying effective teaching strategies, understanding learners' and teachers' perceptions, analyzing assessment practices, and investigating the barriers that affect the integration of algebraic reasoning in classroom instruction.

Using a qualitative approach, the study draws on literature review, classroom observations, and interviews with six mathematics teachers across three primary schools. The ultimate goal is to provide practical recommendations for improving the teaching and learning of algebraic skills through informed instructional practices and supportive education policies.

Research objectives

To explore the meaning and conceptual understanding of algebraic skills among primary school learners and educators.

To identify and analyze effective strategies used in developing algebraic skills in primary school mathematics instruction.

To examine the importance of algebraic skills in enhancing students' thinking and problem-solving abilities.

To investigate the role of teachers in fostering algebraic reasoning and supporting students' development of algebraic skills.

To assess the methods and practices used by teachers in evaluating students' algebraic skills.

To identify and analyze the barriers that hinder the effective development of algebraic skills among primary school pupils

Rationale for the Study

Blanton et al. (2018) note that algebraic thinking is increasingly viewed not just as a topic in mathematics, but as a core cognitive skill that supports learners in recognizing patterns, generalizing relationships, and interpreting mathematical structures. This form of reasoning is essential for helping pupils develop the flexible and analytical thinking required for advanced mathematical learning.

Across the globe, education systems have responded by embedding algebraic concepts into early curricula, including at the primary level. In Uganda, these reforms are slowly being reflected in competency-based curriculum revisions. However, in schools across Mbale City, there is still a noticeable gap between policy aspirations and actual classroom practice. Often, algebra is introduced through procedural techniques, where learners manipulate symbols without understanding the logic behind them (Sfard & Linchevski, 2020).

Mutambara and Chikiwa (2024) emphasize that such limited instructional approaches can hinder learners from developing meaningful and transferable mathematical knowledge. In many cases, the root of this challenge lies in the limited pedagogical content knowledge among teachers—especially their ability to guide pupils from concrete manipulation to abstract reasoning, and from isolated arithmetic to pattern recognition and generalization.

Although teacher training programs are expected to address these gaps, Naudé and Joubert (2019) argue that both pre-service and in-service professional development still fall short in preparing teachers to teach algebra in ways that promote deep understanding. Similarly, Kaino (2022) points out that educators often lack access to research-based strategies that can effectively nurture algebraic reasoning in diverse classroom settings.

In contexts like Mbale City, where learners come from a range of cultural and linguistic backgrounds, these challenges are even more pronounced. Teaching approaches must be culturally relevant and responsive to learners' lived experiences. According to Adler and Pillay (2020), the inability to adapt teaching to such diversity can further constrain learning. Chilisa and Maseko (2023) echo this view, emphasizing the need for more inclusive and context-aware instructional strategies in mathematics education.

In response to these concerns, the current study combines a critical review of relevant literature with empirical research conducted in three primary schools in Mbale City. Through classroom observations and interviews with six mathematics teachers, the study investigates how algebraic thinking is understood, taught, and assessed in everyday teaching environments.

By grounding its findings in real classroom practices, the study seeks to bridge the gap between recommended approaches and actual teaching realities. It contributes to the global call for inquiry-based, learner-centered mathematics instruction, while offering context-specific insights to support professional growth among Ugandan teachers. As Mason et al. (2021) and Baroody (2017) suggest, strengthening teachers' capacity to go beyond procedural compliance is key to fostering a deeper, more connected understanding of mathematics in the early years of learning.

LITERATURE AND THEORETICAL REVIEW

Introduction

This section synthesizes theoretical perspectives and empirical findings on algebraic thinking, organized thematically to build a comprehensive understanding of the concept. Each theme explores a core component of algebraic thinking relevant to the development of learners' mathematical understanding, especially in the Ugandan context. The upcoming empirical findings from classroom observations and teacher interviews will serve to reinforce or challenge the insights derived from this literature.

LITERATURE REVIEW

Meaning of Algebraic Skills

In Uganda's education system, where competence-based and learner-centered pedagogy is increasingly emphasized, the teaching of algebra must extend beyond the traditional focus on symbolic manipulation and mechanical procedures. Globally, algebraic thinking is recognized as a foundational aspect of mathematical literacy, involving more than solving for unknowns. It encompasses learners' ability to generalize mathematical relationships, recognize and analyze patterns, represent structures symbolically, and apply reasoning across diverse contexts (Kaput, 2008; Windsor, 2010).

A critical starting point in developing algebraic competence is pattern recognition, which allows learners to transition from arithmetic to symbolic reasoning by identifying numerical, spatial, or functional patterns (Kieran, 2004; Seeley, 2004). However, in Uganda, this skill is often reduced to superficial drills due to exam-driven instruction. Generalized arithmetic taken as the exploration of arithmetic operations through tasks that highlight properties like commutativity, associativity, and distributivity is also essential. Unfortunately, many teacher trainees demonstrate procedural fluency without the conceptual grounding necessary to facilitate such learning, indicating the need for more guided inquiry in teacher education (Shi & Wu, 2024; PubMed Central, 2024).

Another central aspect of algebraic thinking is the use of variables, which often marks the shift toward formal algebra. Yet, variables are typically introduced in abstract ways, lacking concrete representations or contextual relevance. Research suggests that digital tools like Scratch can help learners explore variables in an interactive and accessible manner (ZDM Mathematics Education, 2022). Relational thinking which is the ability to understand and reason about mathematical relationships without computation is another underutilized skill. It encourages learners to justify and reflect on structural relationships, supporting critical thinking, which aligns well with Uganda's curriculum reforms (ZDM Mathematics Education, 2022).

The use of multiple representations like verbal, symbolic, graphical, and concrete is vital in helping learners express and understand mathematical ideas. In resource-constrained Ugandan classrooms, effective use of low-tech tools such as drawings, physical manipulatives, and oral explanations can foster representational fluency (PubMed Central, 2024). Lastly, problem-solving provides an integrative platform for all these dimensions of algebraic reasoning. It enables learners to apply general principles in real-life situations, develop strategic thinking, and model mathematical ideas. As Uganda shifts toward real-life application in mathematics, problem-solving should take a central role in algebra instruction (Gabina, 2019; Edmentum, 2024).

In sum, algebraic thinking consists of six interdependent competencies: pattern recognition, generalized arithmetic, variable use, relational thinking, representation, and problem-solving. For Uganda's evolving education system, embedding these competencies within teacher preparation, classroom practice, and curriculum design is essential for developing deep, transferable algebraic understanding (Adamuz-Povedano et al., 2021).

Strategic Approaches to Fostering Algebraic Thinking

Recent literature emphasizes that promoting algebraic thinking requires more than simply teaching rules or procedures. It involves cultivating learners' ability to reason, generalize, and solve problems in meaningful ways. A number of strategies have been identified as effective in supporting both young learners and trainee teachers in this journey.

One major approach involves the use of visual and concrete representations to make abstract algebraic concepts more accessible. Tools like bar models and balance scales have proven particularly effective for introducing equations and variables to primary learners, as they make the concept of equality more tangible (Tagle et al., 2016). Similarly, algebra tiles help bridge the gap between hands-on manipulation and symbolic representation, particularly when trainee teachers use them to model binomial expansion or solve equations (Sibgatullin et al., 2022). The current study confirmed that these strategies are largely underutilized in Ugandan teacher education, despite their proven value, pointing to a need for stronger emphasis on concrete-to-abstract progression in instructional design.

Another critical area involves pattern recognition and generalization. When learners engage in relatable scenarios like counting chairs and legs, they begin to form algebraic rules intuitively, which helps transition from arithmetic to functional thinking (Blanton et al., 2018; Stephens et al., 2017). In the Ugandan context, the study revealed that while some teachers introduce patterns, these are often treated as isolated tasks rather than gateways to broader reasoning. This highlights a missed opportunity to build deeper conceptual links in everyday mathematics lessons.

Technology also holds promise in fostering algebraic thinking. Tools like GeoGebra and Desmos support multi-representational learning and encourage students to explore mathematical relationships dynamically (Levin & Walkoe, 2022). However, findings from the current study suggest that digital integration remains minimal in local teacher training colleges, often due to limited infrastructure. Even so, the study advocates for the use of low-tech alternatives and offline simulations that can replicate many of the conceptual benefits offered by high-tech tools.

The importance of responding to student thinking emerged strongly in both literature and the current study. Research suggests that teachers should treat misconceptions as learning opportunities, using them to foster mathematical discourse (Leatham et al., 2015). For example, when a learner incorrectly states that "$x + x = x^2$," this can become a springboard for meaningful class discussion. The study found that most Ugandan trainee teachers lacked the confidence or pedagogical training to navigate such moments effectively, underscoring the need for professional development in responsive teaching strategies.

Collaborative learning, inquiry-based tasks, and reflective teaching practices also contribute significantly to algebraic development. Classroom structures that allow for peer explanation, group problem-solving, and exploration of multiple strategies have been shown to deepen understanding (Baturina et al., 2024; Sibgatullin et al., 2022). Moreover, connecting algebra to real-life contexts like designing a school event or measuring shadow lengths helps learners view mathematics as both relevant and applicable (Duda et al., 2023). In this regard, the study observed a growing awareness among Ugandan pre-service teachers of the value of contextual tasks, although practical implementation remains uneven.

Lastly, strategies that promote metacognition, such as journaling, think-alouds, and prompting learners to explain their reasoning, are vital in helping students monitor and refine their own thinking (Walkoe & Levin, 2022). The current study noted that while such strategies are occasionally modeled during teacher training, they are rarely incorporated systematically into lesson planning or classroom practice.

In conclusion, while many effective strategies for fostering algebraic thinking are well-documented in global research, the current study revealed significant gaps in their implementation within Ugandan teacher education. It addressed these by highlighting not only what strategies are effective, but also why they are not yet fully embedded pointing to the need for targeted training, resource adaptation, and systemic support to bridge the divide between theory and practice.

Methods Used by Teachers in Assessing Algebraic Skills

Assessment of algebraic skills plays a pivotal role in identifying students' conceptual understanding, misconceptions, and progression in learning algebra. Several studies conducted have investigated various assessment methods used by teachers in diverse educational settings, highlighting both traditional and innovative approaches.

Oppong et al. (2024) investigated the types of algebraic errors made by 250 pre-service mathematics teachers in four colleges of education in Ghana using Newman's Error Analysis. The studies found that transformation and encoding errors were the most prevalent, suggesting that learners struggle with the structural manipulation of algebraic expressions. This implies that teachers must incorporate error analysis as an assessment strategy to diagnose specific areas of weakness in students' algebraic reasoning. For the present study, this underscores the importance of understanding the nature of learner errors when evaluating algebraic proficiency.

Similarly, Namakshi, Warshauer, Strickland, and McMahon (2022) examined the assessment capabilities of 99 U.S. pre-service elementary and middle school teachers through noticing tasks and interviews. Their findings revealed a marked improvement in the participants' ability to interpret student thinking when content knowledge and mathematical knowledge for teaching (MKT) were emphasized. This supports the integration of assessment tools that require teachers to analyze student responses deeply, a valuable insight for designing formative assessment tasks in algebra instruction.

Jojo and Salani (2023), through a qualitative case study involving two South African junior secondary mathematics teachers, examined the pedagogical strategies employed in teaching algebraic equations. The study revealed that teachers often relied on teacher-centered methods and rarely used concrete manipulatives or conceptual activities to assess understanding. This points to a gap in effective assessment practices, as such methods may fail to uncover students' underlying misconceptions. The current study can build upon this by exploring the impact of learner-centered assessment approaches in algebra.

In Turkey, Arabacı, İmamoğlu, and Kılıc (2024) conducted an experimental study on the impact of task-assisted instruction on students’ algebraic thinking. Using open-ended pattern-based tasks with Grade 7 students, the researchers noted a significant enhancement in students' ability to recognize patterns and express algebraic generalizations. These findings support the inclusion of task-based assessments, which not only evaluate knowledge but also stimulate cognitive development in algebra. For the present research, this suggests the value of integrating rich tasks into assessment routines.

Another innovative method was explored by an MDPI (2023) study, which examined the use of worked-out examples and metacognitive prompts in algebra problem-solving. The intervention allowed learners to analyze problems, explain reasoning, and apply learned strategies to new problems, resulting in improved problem-solving efficiency. This approach highlights the importance of scaffolding and reflection in assessment tasks, pointing to the benefits of combining procedural and metacognitive evaluation methods.

On the technology front, Otero, Druga, and Lan (2024) introduced an AI-supported diagnostic tool designed to identify algebra misconceptions in middle school students. The tool, trained on over 200 items across 55 misconception categories, demonstrated an 83.9% precision rate in identifying specific algebraic errors. Educators affirmed its relevance in helping diagnose learning gaps. The current study could consider the feasibility of adopting or complementing traditional assessment with technology-enhanced tools.

In the Dutch context, Veldhuis and Van den Heuvel-Panhuizen (2016) explored how primary school teachers used Classroom Assessment Techniques (CATs) such as exit tickets, red/green cards, and mini-whiteboard tasks in Grade 3 mathematics classrooms. Their study showed improved student outcomes and greater teacher satisfaction with assessment. These formative techniques, although low-stakes, provided immediate feedback and encouraged student engagement. This reinforces the need to incorporate informal but effective assessment strategies in algebra instruction.

Amoah, Atingane, and Amoako (2019) also investigated the classroom assessment practices of junior high school teachers in Ghana. Using a mixed-method approach, they found that class exercises, homework, and trial tests were the dominant assessment methods. However, they also reported challenges such as time constraints, large class sizes, and inadequate training. These findings highlight the gap between policy and practice, suggesting that teacher capacity building is critical for effective algebra assessment implementation.

A broader perspective on teacher knowledge in algebra instruction is presented in a systematic review by various authors (MdPI, 2021), which evaluated the Mathematical Knowledge for Teaching (MKT) among primary school educators. The review indicated that both content knowledge and pedagogical content knowledge are essential for selecting and implementing appropriate algebra assessment strategies. This justifies the integration of teacher knowledge assessment into the current study to evaluate its impact on assessment practices.

Finally, Pohl, Forgasz, and Leder (2018) explored assessment practices among German pre-service teachers, focusing on issues of equity and differentiation. The study found that teachers with stronger MKT were more likely to use varied assessment modes and detect subtle student errors, emphasizing the role of assessment in supporting diverse learners. This aligns with the current study’s aim of examining the equity and inclusivity of algebra assessment methods.

Barriers to Developing Algebraic Skills Among Primary Pupils

The development of algebraic reasoning in primary education is widely acknowledged as critical for fostering analytical thinking, problem-solving skills, and long-term academic success (Peters & Carter, 2023; EdResearch for Action, 2025). However, several studies conducted across diverse educational contexts have consistently identified systemic, pedagogical, and infrastructural barriers that hinder effective algebra instruction in early grades. This section critically reviews recent literature (2015–2025) to outline the key impediments relevant to the current study and contextualizes their implications for primary mathematics classrooms.

A prominent challenge across multiple studies is the lack of sufficient instructional time and the rigidity of national curricula. In a U.S.-based national survey, Education Week (2024) found that over 33% of mathematics educators cited time limitations as a major obstacle to engaging students in deep mathematical reasoning. Similarly, Bland (2024), in a study conducted across Canadian elementary schools, argued that curriculum overload and standardized test preparation frequently divert attention from pattern-based or inquiry-led algebra tasks. Schoenfeld et al. (2025) confirm that overly prescriptive curriculum pacing guides leave little room for exploratory or open-ended tasks essential to developing abstraction and generalization. The implications for the current study suggest that unless time is purposefully allocated for algebraic inquiry, teachers will continue to rely heavily on procedural approaches at the expense of conceptual understanding.

Another significant barrier relates to limited and ineffective professional development (PD) opportunities. A study by Ball and Bass (2024) conducted in urban U.S. school districts emphasized the need for domain-specific pedagogical content knowledge (PCK), particularly in algebra, to enhance teacher efficacy. Their findings showed that many PD programs focus on general strategies without addressing the conceptual foundations of algebra or methods for promoting reasoning among younger learners. Similarly, a report by Darling-Hammond et al. (2024) stressed that one-off training sessions are insufficient; instead, PD must be ongoing, embedded in collaborative structures such as professional learning communities (PLCs), and directly linked to classroom realities. These studies highlight that for teachers in the current study to successfully nurture algebraic reasoning, PD must move beyond content delivery and foster pedagogical shifts toward reasoning-based instruction.

Students' weak foundational knowledge in number sense and operations also emerged as a key constraint. In a longitudinal study conducted in Brazil, Carraher and Schliemann (2024) demonstrated that early algebraic understanding is tightly linked to students' ability to recognize numerical equivalence, understand inverse relationships, and make generalizations from arithmetic. Kieran (2025) echoed this in her meta-analysis, emphasizing that without a solid grasp of number operations, learners struggle to transition from concrete arithmetic to symbolic algebra. In the current study context, this implies that reinforcing foundational number concepts in the lower grades is critical to preparing learners for algebraic thinking in upper primary.

Technological limitations and infrastructure challenges present additional barriers, especially in under-resourced educational settings. A South African study by Neumann et al. (2025) revealed that limited access to devices, unreliable internet, and insufficient training impede the integration of digital tools such as Desmos or GeoGebra, which are known to enhance visual and symbolic reasoning. These findings are consistent with Sacristán (2017), who reported that the digital divide disproportionately affects low-income schools, creating inequitable learning opportunities in mathematics. The implications for this study suggest that even where digital resources are introduced, comprehensive support and training must accompany them to avoid superficial or ineffective use.

In addition to infrastructure, teachers' beliefs and resistance to technology serve as important second-order barriers. Ertmer's framework (1999), supported by more recent observations in sub-Saharan Africa (see Teo et al., 2020), illustrates that technophobia, lack of confidence, and adherence to traditional teaching methods often deter educators from adopting innovative tools for algebra instruction. These internal barriers often persist even when external conditions (such as devices and connectivity) improve. In the present study, such insights underline the importance of addressing attitudes and self-efficacy in professional training programs.

A further constraint is the scarcity of manipulatives and concrete teaching materials, especially in resource-constrained classrooms. In a study of Ugandan primary schools, the availability of basic instructional resources like counters, tiles, and geometric sets was shown to correlate with student engagement in algebraic patterning tasks (Scribd Data, 2020). Without such tools, students rarely progress through the concrete-pictorial-abstract (CPA) continuum, which is essential in supporting early algebraic reasoning (Agustina et al., 2020).

Another factor, often overlooked, is the lack of institutional support and leadership in promoting algebraic reasoning and technology integration. In a study across South African provinces, Timotheou et al. (2023) noted that the absence of coordinated ICT policies and weak leadership at the school level significantly limited innovation in mathematics instruction. These findings suggest that systemic support structures—including leadership vision, clear policies, and follow-up are essential for sustaining instructional reforms.

The digital divide and equity issues further complicate the implementation of algebraic reasoning strategies. As highlighted in the Atlanta Strategic Data Project (2025), inequitable access to devices, software, and internet connectivity limits the ability of disadvantaged students to participate fully in digitally supported mathematical learning. These disparities have profound implications for the current study, particularly in contexts aiming to close achievement gaps in mathematics through technology-enhanced instruction.

Moreover, inexperience with metacognitive and reflective teaching strategies continues to limit algebraic reasoning development. Baumgartner (2021) and Cengiz et al. (2023) found that many teachers lack training in promoting self-explanation, think-alouds, or reflective journaling—practices known to enhance metacognition and critical thinking. Such pedagogies are central to helping students articulate their reasoning processes, a key component of algebraic thinking.

Lastly, emerging literature points to gender-based disparities in technology usage, where female teachers, in some contexts, report lower confidence and engagement with digital tools for math instruction. A study by Teo, Fan, and Du (2015) found that these perceptions, if unaddressed, could inadvertently limit students' access to technology-supported learning experiences, particularly in gender-imbalanced teaching environments. While not always explicitly acknowledged, such factors warrant further exploration in future studies.

The Importance of Algebraic Skills in Teaching and Learning

Algebra plays a central role in shaping both academic success and everyday reasoning. Several studies confirm that algebra is not merely a mathematical strand but a foundational gateway to higher-level thinking and future learning. Peters and Carter (2023) emphasize its bridging function across mathematical domains linking arithmetic, geometry, and statistics and its foundational role in later topics such as calculus and discrete mathematics. Similarly, Schoenfeld et al. (2025) argue that when learners see these interconnections, mathematics becomes more cohesive and meaningful.

Beyond academics, algebra cultivates quantitative literacy crucial for real-world decision-making. EdResearch for Action (2025) and Adamuz Povedano et al. (2021) show that tasks such as comparing phone data plans or budgeting empower students to apply structured reasoning and build independence. These studies, largely based in U.S. classroom and policy contexts, revealed that students exposed to real-life algebra scenarios gained both confidence and competence in problem-solving. The current study, conducted in Ugandan primary and teacher education settings, found that while teachers recognize the value of such applications, actual integration into lessons remains minimal often due to lack of contextual resources or practical training.

Equity also features prominently in algebra discourse. The Atlanta Strategic Data Project (2025) found that early access to algebra reduces STEM opportunity gaps for underrepresented groups. Blanton et al. (2018) support this view, linking algebra proficiency to career readiness in STEM fields like engineering and computer science. In Ugandan contexts, however, the current study noted that trainee teachers often lack exposure to inclusive, differentiated algebra instruction. This highlights a need for equity-focused pedagogical approaches during teacher preparation.

Moreover, algebra supports transferable skills like logical reasoning and structured thinking. Peters and Carter (2023) found that solving algebraic problems builds the kind of disciplined thought processes useful in interpreting graphs, analyzing surveys, and even everyday planning. Students who master algebra develop stronger mathematical identities and greater self-efficacy (EdResearch for Action, 2025), reducing math anxiety and boosting classroom engagement.

The Role of the Teacher in Developing Algebraic Skills

The teacher plays a central role in shaping learners' algebraic understanding. Research consistently emphasizes that effective algebra instruction depends not only on content knowledge but also on pedagogical practices that align with how students develop algebraic reasoning.

Glassmeyer and Edwards (2016), along with Blanton et al. (2018), underscore the importance of Pedagogical Content Knowledge (PCK) in algebra teaching. Their findings show that when teachers possess both a deep understanding of algebraic structures and strategies for making those concepts accessible, they can move students from procedural memorization to conceptual understanding. In contrast, as de Garcia (2008) observed, teachers with limited algebraic content knowledge often default to rote teaching methods, restricting students' ability to apply algebra flexibly across contexts. This finding revealed a gap that is particularly relevant in the current Ugandan study, where pre-service teachers displayed strong procedural focus but struggled with conceptual scaffolding of algebraic ideas.

Professional development emerged as a transformative factor in shifting instructional quality. Tagle et al. (2016) studied learning environments that allowed teachers to engage with algebra at a deeper level and analyze common student misconceptions. They found that such settings help teachers evolve from seeing algebra as symbol manipulation to recognizing it as a tool for reasoning and generalization. The current study addressed the absence of such reflective, algebra-focused training in Uganda’s teacher education programs and proposed targeted interventions during practicum sessions.

In terms of instructional strategies, Kullberg et al. (2017) demonstrated the effectiveness of modeling multiple solution paths to foster flexibility in thinking. Blanton and Kaput (2003) emphasized the value of mathematical discourse, showing that when students are encouraged to explain and critique ideas, they develop relational thinking which is a core aspect of algebra. Steele and Johanning (2004) also found that rich mathematical tasks promote pattern recognition and generalization, pushing learners beyond surface-level recall. These studies, largely situated in U.S. and European classrooms, revealed the power of student-centered practices in deepening algebraic understanding. The current study noted a lack of such strategies in Ugandan training classrooms and responded by integrating them into microteaching exercises.

Furthermore, responsive teaching which values student thinking was shown by Adamuz-Povedano et al. (2021) to support learners in bridging informal strategies with formal algebraic reasoning. Their findings support a learner-centered model that resonates with constructivist pedagogy. In Uganda, the current study identified a gap where trainee teachers often overlooked students' intuitive understandings, highlighting the need for greater emphasis on diagnostic and adaptive teaching approaches.

Lastly, collaborative learning was found to strengthen algebraic reasoning. When learners worked in groups to justify solutions and co-construct meaning, they developed transferable reasoning habits (Adamuz-Povedano et al., 2021). However, the Ugandan study found limited use of collaborative practices in observed lessons, with instruction still largely teacher-directed. This gap informed the study’s recommendation to integrate structured group tasks into teacher training.

Methods Used by Teachers in Assessing Algebraic Skills

Assessing algebraic skills is not just about marking right or wrong answers—it plays a critical role in diagnosing students’ misconceptions, monitoring progress, and guiding instruction. Research across different educational contexts highlights a range of assessment strategies, from traditional testing to innovative diagnostic tools, each with its own implications for effective teaching and learning.

In Ghana, Oppong et al. (2024) analyzed the algebraic errors made by 250 pre-service mathematics teachers across four colleges using Newman’s Error Analysis. Their study revealed that transformation and encoding errors were most frequent, pointing to learners' difficulty in manipulating algebraic structures. These findings emphasize the need for teachers to use error analysis as a formative assessment tool, which allows for targeted remediation. For the present study, this stresses the importance of equipping pre-service teachers with diagnostic strategies to better interpret and respond to student errors in algebra.

From the U.S., Namakshi et al. (2022) assessed the noticing skills of 99 pre-service teachers through interviews

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and classroom tasks. The study found that when Mathematical Knowledge for Teaching (MKT) was explicitly addressed, participants were more adept at identifying and interpreting student thinking. This highlights the potential of noticing-based assessments in enhancing teacher responsiveness and reinforces the current study's focus on developing pre-service teachers' capacity to assess student understanding beyond surface-level correctness.

A qualitative study by Jojo and Salani (2023) in South Africa found that junior secondary teachers relied heavily on teacher-centered methods, rarely using conceptual tasks or manipulatives for assessment. This lack of learner-centered assessment methods limited their ability to identify conceptual misunderstandings. The current study responds by exploring how shifting towards more student-engaged and conceptual assessment strategies can improve algebra instruction, especially in under-resourced settings.

In Turkey, Arabacı et al. (2024) demonstrated through an experimental study with Grade 7 students that pattern-based, open-ended tasks significantly enhanced algebraic thinking and generalization skills. These task-assisted assessments enabled deeper cognitive engagement, supporting the notion that rich, non-routine tasks can serve both as teaching and assessment tools. This informs the present study's recommendation to integrate such tasks into Ugandan teacher training programs.

An innovative approach was explored in an MDPI (2023) intervention study, which paired worked examples with metacognitive prompts. Students showed improved problem-solving by reflecting on their reasoning, suggesting that assessments which include structured reflection not only evaluate skills but also support learning. This supports the incorporation of metacognitive elements in assessment design in the current study's context.

A more technologically advanced approach was piloted by Otero, Druga, and Lan (2024), who developed an AI-driven diagnostic tool capable of identifying 55 types of algebraic misconceptions with 83.9% accuracy. While this tool is not yet widely accessible, its diagnostic precision reinforces the importance of technology-enhanced assessment methods. The present study considers how simpler tech tools like digital quizzes or analytics from learning platforms could serve similar functions in low-resource contexts.

In the Netherlands, Veldhuis and Van den Heuvel-Panhuizen (2016) explored the use of Classroom Assessment Techniques (CATs) such as exit slips, red/green cards, and mini-whiteboards in Grade 3 mathematics. These low-stakes, formative methods led to improved student outcomes and teacher satisfaction. The findings highlight that informal, responsive assessments can be just as effective as formal tests. This supports the present study's goal of encouraging Ugandan teacher trainees to adopt a broader repertoire of assessment strategies.

From Ghana again, Amoah, Atingane, and Amoako (2019) used a mixed-methods approach to examine the classroom assessment practices of junior high teachers. While classwork, homework, and tests were common, challenges such as large class sizes and limited training hampered effective assessment. This illustrates the gap between policy and practice, pointing to the need for ongoing teacher development an area the current study directly addresses by embedding assessment literacy into training modules.

A broader review by MDPI (2021) consolidated findings on Mathematical Knowledge for Teaching (MKT) and showed that strong content and pedagogical knowledge enhances teachers' ability to select appropriate assessment strategies. This aligns with the present study's interest in assessing how well Ugandan pre-service teachers integrate MKT into their assessment practices.

Finally, in Germany, Pohl, Forgasz, and Leder (2018) investigated how pre-service teachers' understanding of equity and differentiation influenced their assessment practices. Teachers with stronger MKT were more likely to use varied assessment methods and identify subtle misconceptions, promoting inclusive instruction. This aligns with the present study's exploration of how assessments can serve diverse learners equitably within Ugandan classrooms.

Barriers to Developing Algebraic Skills among Primary Pupils

The development of algebraic skills in the early grades is increasingly recognized as critical for enhancing analytical reasoning, problem-solving ability, and long-term mathematical achievement (Peters & Carter, 2023; EdResearch for Action, 2025). However, multiple studies between 2015 and 2025 have identified a range of barriers spanning instructional, infrastructural, and pedagogical dimensions that hinder the effective integration of algebra in primary school settings. These barriers hold particular relevance for the current study, which seeks to understand how such constraints affect classroom practice and learner outcomes.

A key barrier identified in several studies is the limited instructional time dedicated to deep mathematical thinking. Education Week (2024) reported that over a third of U.S. mathematics educators cited time constraints as a major impediment to engaging students in sustained algebraic reasoning. Similarly, Bland (2024), examining curriculum structures in Canadian elementary schools, found that teachers often prioritize standardized test preparation over inquiry-based tasks, limiting opportunities for pattern recognition and generalization. Schoenfeld et al. (2025) confirmed that strict pacing guides restrict exploratory activities essential for conceptual understanding. These findings suggest that unless instructional time is restructured to accommodate algebraic inquiry, primary educators may remain confined to procedural teaching methods.

Another major obstacle is the inadequacy of professional development (PD) in equipping teachers with the necessary pedagogical content knowledge for early algebra. Ball and Bass (2024), in a study conducted in urban U.S. schools, found that many PD programs emphasize general strategies rather than algebra-specific reasoning and instructional methods. Complementary findings by Darling-Hammond et al. (2024) emphasized that one-off workshops are insufficient; rather, effective PD should be ongoing, collaborative, and connected to real classroom challenges. For the current study, these insights reinforce the importance of teacher preparation programs that focus not only on content knowledge but also on strategies to promote algebraic thinking in young learners.

Weak foundational knowledge in number sense among students also emerged as a critical constraint. Carraher and Schliemann (2024), in a longitudinal study in Brazil, established a strong link between early algebraic reasoning and learners' understanding of number relationships, equivalence, and inverse operations. Kieran (2025), through a meta-analysis, similarly noted that the inability to transition from arithmetic to algebraic abstraction is often rooted in fragile numeracy skills. These findings imply that reinforcing foundational number concepts in the lower grades is vital for preparing pupils for algebraic learning in upper primary, a point of consideration for the current research.

Technological and infrastructural limitations pose additional challenges, particularly in low-resource environments. Neumann et al. (2025), in a South African study, highlighted limited access to devices, poor internet connectivity, and inadequate teacher training as key impediments to integrating digital tools such as Desmos or GeoGebra into algebra instruction. These conclusions align with Sacristán (2017), who found that the digital divide significantly undermines equitable access to technology-enhanced mathematics learning. Within the context of the current study, these findings emphasize the need to assess not only the availability of digital tools but also the training and support structures that determine their effective use.

Teacher attitudes and resistance to technology constitute further barriers. Ertmer's framework (1999), supported by more recent studies in sub-Saharan Africa (Teo et al., 2020), indicates that technophobia, low confidence, and attachment to traditional methods often prevent educators from adopting innovative approaches to algebra instruction. These internal, second-order barriers can persist even when external resources are available. For the present study, this underscores the importance of addressing teacher beliefs and self-efficacy as part of any effort to reform algebra teaching practices.

Lack of concrete teaching resources such as manipulatives also limits algebraic engagement. A study conducted in Ugandan primary schools (Scribd Data, 2020) revealed that students rarely progressed through the concrete–pictorial–abstract (CPA) model due to the unavailability of basic instructional materials like counters and geometric tiles. Agustina et al. (2020) supported this finding, emphasizing that such resources are crucial for supporting conceptual development in algebra. This suggests that without appropriate materials, many learners remain confined to rote procedures rather than understanding algebraic structures.

Institutional and policy-related limitations further restrict algebra instruction. Timotheou et al. (2023), studying

South African provinces, observed that weak school leadership, unclear ICT policies, and lack of structured support limited the implementation of innovative practices in mathematics classrooms. These findings stress the role of systemic support, leadership vision, and follow-up mechanisms in sustaining algebraic reform—an area of concern that this study aims to explore.

Digital inequities and gender disparities in technology use are also notable. The Atlanta Strategic Data Project (2025) reported that unequal access to digital resources exacerbates learning gaps in mathematics, particularly among disadvantaged learners. Additionally, Teo, Fan, and Du (2015) identified that female teachers in some contexts reported lower confidence in using technology for mathematics instruction, potentially affecting how students experience tech-enhanced learning. These insights raise important equity considerations relevant to the current research.

Finally, teacher unfamiliarity with metacognitive teaching strategies presents an overlooked yet critical barrier. Baumgartner (2021) and Cengiz et al. (2023) found that many educators lacked exposure to reflective practices such as self-explanation, journaling, and think-alouds, which are known to support algebraic reasoning and critical thinking. The current study could thus benefit from examining how such pedagogical gaps influence classroom assessment and student learning outcomes in algebra.

In sum, the literature reveals a complex landscape of barriers to developing algebraic skills in primary education ranging from time and curriculum constraints to teacher capacity, resource availability, and systemic inequities. These challenges underscore the need for multi-dimensional interventions that address both structural and pedagogical aspects of early algebra instruction, forming a critical foundation for the current study.

Conceptual and theoretical Framework

This study established a conceptual framework grounded in two complementary theoretical perspectives: Sociocultural Theory (Vygotsky, 1978) and Constructivist Learning Theory (Piaget, 1952; von Glasersfeld, 1995). These theories provide a robust lens to understand how teachers define, develop, and support algebraic reasoning among primary school learners. Together, they illuminate the interplay between teaching practices, teacher beliefs, and contextual factors in shaping students' algebraic thinking.

Guided by Constructivist Learning Theory, the study emphasizes that teachers' beliefs about algebraic skills significantly influence their instructional decisions. Teachers who view learning as an active, constructive process tend to promote exploration, discovery, and student agency in mathematics teaching (Fosnot & Dolk, 2001; Blanton & Kaput, 2005). This perspective frames algebraic learning as a process where learners build understanding through engagement with meaningful tasks rather than rote memorization.

Drawing on Sociocultural Theory**,** the study foregrounds the role of social interaction and scaffolding within the Zone of Proximal Development (ZPD) **(**Vygotsky, 1978). It highlights the importance of teachers and peers as mediators who support learners' development by providing appropriate guidance. This sociocultural lens underscores the value of collaborative reasoning, feedback, and discourse as key elements in nurturing algebraic thinking.

The study also conceptualizes instructional strategies such as scaffolding, open-ended problem solving, guided discovery, and collaborative dialogue as rooted in these theoretical frameworks (Kazemi & Stipek, 2001; Piaget, 1952). Such strategies are believed to foster student engagement with algebraic structures, encouraging them to recognize patterns, generalize relationships, and develop flexible problem-solving skills central to early algebra (Carraher, Schliemann, & Schwartz, 2008).

Additionally, this framework acknowledges that teachers operate within systemic and contextual constraints, including curriculum demands, resource availability, and time limitations. These external factors can either facilitate or impede the translation of constructivist and sociocultural principles into classroom practice (Daniels, 2001; John-Steiner & Mahn, 1996). Understanding these conditions is crucial to developing effective instructional approaches that support algebraic reasonin

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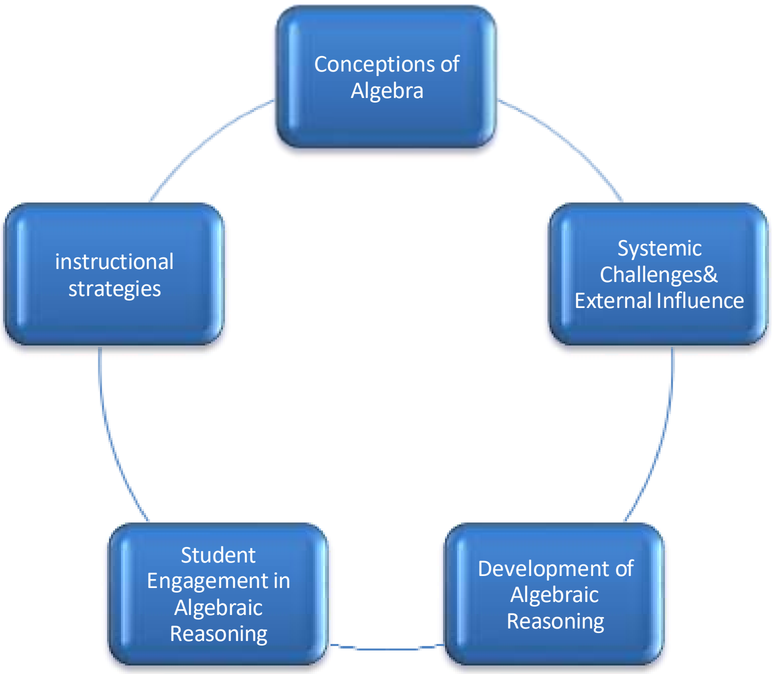

Figure 1: Conceptual and theoretical framework

METHODOLOGY

This qualitative case study explores how algebraic thinking can be effectively supported in mathematics education, using an interpretive framework. Conducted in three primary schools with six middle primary mathematics teachers, the study combines literature review, classroom observations, and reflective inquiry.

Data was collected through a review of scholarly works published between 2016 and 2025, focusing on algebraic thinking, pedagogy, and teacher education. Classroom observations and semi-structured interviews with teachers provided practical insights. Key themes identified included relational understanding, conceptual progression, culturally responsive teaching, and symbolic reasoning. The author, acting as a mathematics educator and mentor, used a Reflective Inquiry Protocol to analyze teaching practices, lesson planning, and feedback sessions. These reflections were compared with literature-based themes to deepen the findings. Ethical standards were strictly followed, with participant anonymity maintained and informed consent obtained. This methodology bridges theory and classroom practice, offering guidance on effective strategies for developing algebraic thinking in teacher education.

Data presentation and Discussion of Findings

Biographical Data of Respondents

This section presents summarized demographic and professional characteristics of the six mathematics teachers who participated in the study. All respondents taught in government-aided primary schools at the middle primary level (P3–P4) and took part in both classroom observations and interviews, resulting in a 100% response rate.

Table 1: Summary of Respondents' Biographical Data (N = 6)

Respondent	Age (Years)	Sex	Teaching Experience (Years)	Education Level	Response Rate
R1	35	Female	12	Certificate in Education	100%
R2	42	Female	18	Diploma in Education	100%
R3	30	Male	6	Certificate in Education	100%

R4	33	Female	9	Certificate in Education	100%
R5	40	Female	15	Diploma in Education	100%
R6	28	Male	5	Certificate in Education	100%

Source: Primary Data

Among the six respondents, four (66.7%) were female and two (33.3%) male, reflecting gender trends typical in primary education (UNESCO, 2016). Their ages ranged from 28 to 42 years, with most in their 30s signaling a productive age for teaching and professional development.

Teaching experience varied, with three teachers (50%) having over 10 years, and the rest between 5–9 years. This moderate to extensive experience base suggests potential for effective classroom practice, though effectiveness is also shaped by training quality (Hill et al., 2005).

Regarding education level, two respondents (33.3%) held Diplomas, and four (66.7%) had Certificates. Diploma holders generally demonstrated greater confidence and depth in algebra instruction, consistent with findings that link higher qualifications to improved pedagogical content knowledge (Ball et al., 2008).

Despite all teachers receiving initial training in mathematics, only half had attended recent in-service professional development, and none had specialized training in algebra instruction. This lack of ongoing support limits their ability to teach early algebra concepts effectively, which are increasingly emphasized in primary mathematics curricula (Kaput, 2008).

In conclusion, the respondent profile highlights a committed but under-supported teaching force, with qualifications and training levels that may hinder effective delivery of algebra content. Continuous, targeted professional development is essential to bridge this gap and improve mathematics outcomes in middle primary classrooms.

Meaning of Algebraic Skills

Table 1: Teachers' and Learners' Engagement with Algebraic Skills

Indicator	Frequency (N = 6)	Percentage (%)
Algebraic concepts explicitly explained	5	83
Students articulate algebraic thinking	3	50
Defined algebraic skills in terms of patterns/relations	5	83
Differentiated algebraic reasoning from arithmetic	4	67
Believed early algebra should begin in primary school	6	100

Source: Primary Data

This study explored how primary teachers and learners engage with algebraic skills during early mathematics instruction. Data from Table 1 reveals both promising practices and areas needing development. A majority of teachers (83%) explicitly introduced algebraic ideas like patterns, variables, and generalization practices aligned with Sfard and Linchevski's (2020) recommendation to make algebraic thinking accessible in early education. For example, one teacher emphasized using patterns to build toward understanding variables.

However, only 50% of observed classrooms featured students articulating algebraic thinking beyond basic arithmetic. While there were moments of relational reasoning such as a student identifying a sequence increasing by 3, these were not consistent across classrooms. As Blanton et al. (2018) note, such early pattern recognition

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is essential for developing algebraic reasoning, yet the limited frequency suggests a gap between teacher instruction and learner uptake.

Most teachers (83%) described algebraic skills as involving patterns and relationships rather than procedures, indicating a conceptual shift toward structural understanding. This reflects international research emphasizing the foundational role of generalization in early algebra (Kieran, 2004; Kaput, 2008). One teacher remarked, "Algebraic thinking is about noticing patterns and making rules," demonstrating growing awareness of the distinction between algebraic and arithmetic thinking—a view supported by Windsor (2010) and Blanton et al. (2018).

All teachers (100%) agreed that algebra should begin in primary school, supporting global pedagogical trends. Blanton et al. (2018) argue early exposure enhances abstract reasoning and prepares learners for advanced problem-solving. This belief was evident in teachers' integration of algebraic ideas into pattern and problem-solving tasks.

Despite this alignment, the gap between teacher belief and student reasoning indicates a need for more learner-centered strategies. Adamuz-Povedano et al. (2021) recommend guided pattern generalization tasks to deepen understanding. Additionally, promoting verbalization, representation, and reflection is essential for developing representational and relational fluency (ZDM Mathematics Education, 2022).

Finally, while most teachers showed a solid theoretical grasp of algebraic thinking, many require further training in instructional strategies that help students move from recognition to abstraction. Professional development should focus on creating tasks that prompt explanation, justification, and generalization, aligning with the competence-based curriculum's goals.

In conclusion, teachers demonstrated growing conceptual understanding of early algebra, but learner engagement remains limited. Enhancing lesson design, questioning techniques, and formative assessments will be critical to bridging this gap and aligning Uganda's practices with international standards in mathematics education.

Strategies for Developing Algebraic Skills

Table 2: Teaching Strategies Supporting Algebraic Reasoning.

The Table 2 outlines observed teaching strategies supporting algebraic reasoning.

Strategy/Indicator	**Number of Classes (N=6)**	**Percentage (%)**
Use of manipulatives or symbolic reps	4	67
Problem-based or inquiry-based activities	5	83
Use of technology tools (GeoGebra, etc.)	3	50
Scaffolding and questioning techniques	6	100
Student engagement in reasoning tasks	4	75

Source: Primary Data

Across all six classrooms, teachers consistently utilized scaffolding and thoughtful questioning. Examples such as, "Can you explain why the pattern grows this way?" highlighted an emphasis on metacognitive engagement and conceptual reasoning. These practices align with research by Way (2008) and Blanton & Kaput (2003), who advocate for open-ended questioning as a catalyst for deeper mathematical thinking. As observed, this type of instructional scaffolding offers essential support while gradually increasing complexity a method championed

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by Glassmeyer & Edwards (2016). Yet, to truly embody cognitive apprenticeship, teachers must also model their thought processes and steadily shift responsibility to learners, as noted by Kieran et al. (2016). This implies a need for teacher education programs to integrate guided demonstrations and reflective modeling into their training processes.

Problem-based and inquiry-oriented learning was also evident in five of the six classrooms. By encouraging students to approach mathematics as problem solvers rather than answer-seekers, teachers fostered engagement with algebraic ideas embedded in real-world contexts. These instructional choices echo recommendations by Carraher et al. (2003) and Kieran (2004), who emphasize the importance of grounding algebra in meaningful tasks. However, the absence of such approaches in one classroom suggests that not all teachers have internalized or operationalized this pedagogical model. Incorporating microteaching and real-life task design into pre-service training as advised by Stephens et al. (2017) and Duda et al. (2023) could help bridge this gap.

Additionally, student reasoning was meaningfully supported in 75% of observed lessons. Learners were prompted to recognize patterns, justify their thinking, and begin generalizing rules—skills essential for building algebraic fluency. These findings affirm the importance of reasoning in early algebra, a point widely supported in the work of Kaput & Blanton (2005) and Blanton et al. (2018). In contrast, a minority of classrooms fell back on answer-focused instruction, limiting opportunities for mathematical discourse. Leatham et al. (2015) underscore the value of noticing and leveraging students' spontaneous mathematical insights to enrich classroom dialogue an area requiring further attention in teacher preparation.

When it came to instructional tools, manipulatives and symbolic representations were employed in four of the six classrooms (67%). These tools support learners in making the leap from concrete experiences to abstract understanding, a principle at the heart of the CPA (Concrete–Pictorial–Abstract) model. Scholars such as Montessori (2021) and Apsari et al. (2020) emphasize the importance of this progression, particularly for young or emerging learners. Still, one-third of the teachers did not use such tools, raising concerns about access or confidence in implementing tactile strategies. The use of algebra tiles and balance scales, for instance, has been shown to support concepts like equality and relational thinking (Tagle et al., 2016; Sibgatullin et al., 2022). Thus, it's vital for teacher training institutions to include hands-on workshops that model how to integrate these resources, especially in multilingual or resource-limited classrooms (Ndamenenu et al., 2022).

The integration of digital tools was noted in only half of the classrooms. Those who used platforms like GeoGebra provided students with dynamic ways to explore algebraic relationships across visual, symbolic, and graphical forms an approach supported by Mason et al. (2021). Unfortunately, the remaining 50% of classes missed this opportunity, possibly due to infrastructural limitations or gaps in digital pedagogical training. Research by Levin & Walkoe (2022) illustrates how digital tools can foster conceptual connections and promote algebraic reasoning. In response, training programs in contexts like Uganda must explore alternative solutions, such as low-tech simulations or offline digital resources (Sibgatullin et al., 2022), ensuring all educators are equipped to integrate technology effectively.

In summary, while teachers showed strong use of scaffolding and inquiry, inconsistency in applying manipulatives, technology, and reasoning tasks reveals areas for growth. Fostering algebraic thinking requires a systematic application of varied instructional tools, reflective questioning, and student-centered dialogue. Building on the work of Walkoe & Levin (2022), Molina & Castro (2022), and Blanton et al. (2018), it is clear that teacher education programs should embed strategies like variation theory (Chen & Lee, 2024), cognitive apprenticeship (Kieran et al., 2016), and error analysis frameworks (Leatham et al., 2015) to prepare teachers for deep, relational mathematics teaching. Empowering educators with such adaptive expertise will ensure that algebra instruction goes beyond procedures to foster lasting understanding.

Table 3: Teachers' Views on Strategies for Developing Algebraic Skills

Strategy/Tool Used	Frequency (N=6)	Percentage (%)
Use of manipulatives and concrete tools	4	67

Use of inquiry/problem-based lessons	5	83
Integration of technology (e.g., smartboards, apps)	3	50
Scaffolding and structured questioning	6	100

Source: Primary Data

The integration of teacher interviews with classroom observations offered a holistic picture of how algebraic reasoning is cultivated in Ugandan primary schools. While classroom visits revealed instructional realities, interviews provided context and intent behind those practices. This twofold lens helped clarify areas of strength and highlight opportunities for growth in early algebra teaching.

A strong point of alignment was the consistent use of structured questioning and scaffolding. Teachers frequently used prompts such as "What stays the same?" and "Why does the pattern grow this way?", which were echoed in both the interview responses and actual classroom dialogue. These questions fostered deeper reasoning and metacognition among learners, reinforcing findings by Mason et al. (2021) and Blanton and Kaput (2003) on the value of purposeful questioning in building mathematical understanding. Observations confirmed that this questioning strategy was not just theoretical it was actively applied in teaching practice. As Glassmeyer and Edwards (2016) note, encouraging students to articulate and justify their thinking is a key indicator of developing algebraic reasoning, and this was visible across all observed classrooms. Additionally, the approach mirrors the principles of cognitive apprenticeship, where knowledge is gradually transferred from teacher modeling to student independence (Kieran et al., 2016).

The inquiry-based nature of many lessons further illustrated the teachers' commitment to meaningful, exploratory learning. In five out of six classrooms, students tackled real-world tasks like modeling growing patterns or exploring cost changes activities that encouraged functional reasoning rather than rote procedures. This practice is in line with the constructivist emphasis advocated by Vargas Hernández and Vargas González (2022), and earlier by Carraher et al. (2003), who highlighted the importance of embedding algebra in authentic contexts. One teacher reflected that such problem-solving "allows students to explore and reason rather than just calculate," a perspective that underscores the shift from procedural to relational thinking as emphasized in the work of Blanton et al. (2018) and Stephens et al. (2017).

While the use of manipulatives and symbolic tools was present in two-thirds of classrooms, the inconsistency among the remaining third suggests a developmental gap. Items like pattern blocks, algebra tiles, and diagrams observed in several lessons were recognized by teachers as essential in helping students bridge the gap between concrete and abstract thinking. This resonates with the CPA (Concrete-Pictorial-Abstract) model outlined by Apsari et al. (2020), and is further affirmed by Montessori's (2021) emphasis on hands-on learning. One teacher noted that manipulatives "make abstract ideas come alive," illustrating an awareness of their pedagogical power. Still, as Ndamenenu et al. (2022) point out, consistent and well-sequenced use of these tools is particularly important in multilingual and under-resourced classrooms, where visual and tactile supports can anchor conceptual learning more effectively.

Technology use revealed a more mixed picture. Half of the teachers reported using tools like GeoGebra or interactive whiteboards resources observed in the same number of classrooms. These tools, as highlighted by Levin and Walkoe (2022), enhance students' ability to visualize and manipulate algebraic structures. One teacher shared how digital platforms helped learners "see how the pattern grows over time," underscoring the dynamic nature of tech-based learning. However, the absence of such tools in the other half of classrooms reflects either limited infrastructure or a lack of teacher confidence in integrating technology. In agreement with Sibgatullin et al. (2022), training programs must ensure that teachers are prepared to use both high- and low-tech tools to ensure inclusive and equitable access.

Beyond these core practices, the data suggest a generally strong alignment between what teachers claimed and what they implemented. Structured questioning, problem-centered learning, and the use of concrete tools all reflect a student-centered orientation that Way (2008) identifies as essential for developing early algebraic fluency. However, areas for improvement remain. Metacognitive practices such as journaling or think-alouds were notably absent, despite their value in helping students internalize and reflect on patterns and relationships a strategy Walkoe and Levin (2022) emphasize in building deeper reasoning.

Another area requiring attention is formative assessment. While teachers often relied on oral questioning to gauge understanding, this approach may not always reveal hidden misconceptions. Molina and Castro (2022) recommend integrating more deliberate assessment tools such as exit tickets or short conceptual checks to better diagnose student thinking and tailor instruction accordingly.

In summary, the overlap between teacher intentions and classroom implementation is encouraging. Teachers are clearly moving toward inquiry-based, conceptually grounded practices that emphasize reasoning over routine. Yet to strengthen this foundation, professional development must now focus on deepening technology integration, expanding manipulative use, embedding metacognitive strategies, and enhancing formative assessment practices. These improvements will ensure that early algebra instruction remains dynamic, reflective, and aligned with both international research and the evolving needs of Ugandan learners.

Importance of Algebraic Skills for Thinking and Problem Solving

To better understand the role of algebraic reasoning in promoting problem-solving and higher-order thinking, a comparison was drawn between observed classroom indicators and teacher interview responses. These are synthesized in the table below:

Table 4: Comparison of Observed Indicators and Teacher Perspectives on Algebraic Reasoning

Indicator	Observed (N=6)	Interview Report (N=6)	Percentage Observed	Percentage Reported
Tasks requiring generalization or abstraction	4	4	67%	67%
Student explanations or justifications	3	4	50%	67%
Belief that algebra supports logic and problem-solving	N/A	6	N/A	100%
Reports of improved reasoning from algebra instruction	Observed in 4	4	67%	67%

Source: Primary Data

Teachers’ perceptions and practices around algebraic reasoning generally showed strong alignment, particularly through tasks that emphasized generalization and abstraction. In four of the six classrooms observed, students engaged in identifying patterns or rules, signaling a shift toward conceptual understanding of algebra. This aligns with Kieran’s (2022) assertion that generalization is a foundational skill for symbolic reasoning and anticipatory thinking. Teachers supported this through prompts like “What do you think will happen if we change the rule?”, nudging learners toward abstract reasoning. These practices reflect algebra’s role not only in bridging mathematical strands such as arithmetic and geometry but also in nurturing logical and transferable thinking (Schoenfeld et al., 2025). Peters and Carter (2023) similarly affirm that algebra acts as a springboard into advanced topics like functions and modeling in secondary education.

Despite these strengths, metacognitive practices were inconsistently applied. Although four teachers reported encouraging student explanations, only half the classrooms showed observable evidence of students justifying their reasoning. This highlights a need to embed deeper metacognitive strategies such as reflective journaling or think-alouds that help students internalize and refine their thinking processes (Baumgartner, 2021; Cengiz et

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al., 2023). As students verbalize their strategies, they deepen both understanding and self-regulation.

All six teachers emphasized the value of algebra in enhancing logical thinking and problem-solving skills. One teacher remarked, "Algebra helps kids think ahead and justify their answers as it's more than just calculations," a sentiment supported by Edmentum (2024), which links algebra to structured, logical, and flexible problem-solving. Moreover, four teachers reported noticeable growth in reasoning abilities after introducing algebraic tasks like solving for unknowns or modeling relationships. These observations were corroborated by classroom behaviors, such as increased use of mathematical vocabulary and structured argumentation. This supports the findings of EdResearch for Action (2025), which associate algebra instruction with cognitive development and decision-making skills through tasks like budgeting or comparative data analysis.

The strategic reasoning fostered through algebra also resonates with Adamuz Povedano et al.'s (2021) findings that highlight the subject's capacity to build learner confidence, independence, and real-world problem-solving skills. Although not uniformly present, the growing use of abstraction and justification in observed classrooms signals progress toward developing quantitative literacy. Teachers unanimously viewed algebra as a fundamental part of students' learning journeys, not only for academic success but also as a critical tool for career readiness and social equity. The Atlanta Strategic Data Project (2025) underscores that early algebra exposure can narrow STEM achievement gaps, especially for underrepresented groups.

Furthermore, classroom tasks based on Problem-Based Learning (PBL), such as cost modeling or designing constrained gardens, promoted autonomy, persistence, and collaborative reasoning. These real-life scenarios encouraged students to optimize, adjust, and justify their solutions, reflecting authentic mathematical practice (Problem-Based Learning, 2025). However, the limited use of metacognitive tools like reflection or error analysis remains a missed opportunity. Collins et al. (2023) argue that cognitive apprenticeship models emphasizing scaffolding, modeling, and gradual responsibility release are essential for nurturing independent thinking and a strong mathematical identity.

In conclusion, while teachers demonstrate a clear understanding of algebra's role in fostering higher-order reasoning and problem-solving, enhancing metacognitive engagement remains critical. Greater emphasis on reflective practices alongside algebraic tasks could deepen students' reasoning and solidify their conceptual understanding.

Role of the Teacher in Fostering Algebraic Reasoning

Table 5: Teachers' Perceptions of Their Role in Developing Algebraic Reasoning

Teacher Role in Developing Algebraic Reasoning	Frequency	Percentage
Guide/scaffold student reasoning	5/6	83%
Promote conceptual understanding	4/6	67%
Encourage student problem-solving skills	3/6	50%
Support diverse learners	2/6	33%

Source: Primary Data

Interview responses revealed that the majority of teachers saw themselves primarily as facilitators of reasoning rather than deliverers of content. About 83% described their role as centered on scaffolding student thinking and creating opportunities for learners to uncover mathematical relationships on their own. As one teacher put it, "I see myself more as a guide, my job is to create situations where students discover the rules and relationships themselves." This view reflects a broader shift in algebra instruction from procedural teaching toward fostering relational and structural understanding, as highlighted by Blanton and Kaput (2003).

In addition, two-thirds of the participants prioritized conceptual understanding over procedural fluency. This

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preference connects closely with the framework of Pedagogical Content Knowledge (PCK), which emphasizes the importance of not just knowing the curriculum but also understanding how students learn it. According to Glassmeyer and Edwards (2016), effective teachers tailor their methods to match cognitive development, while Blanton et al. (2018) argue that deep PCK is necessary to move beyond rote teaching and instead cultivate skills like generalization and transfer. De Garcia (2008) warns that without such a dual lens, instruction can easily default to surface-level procedures that do little to build lasting mathematical reasoning.

Despite these strengths, only a third of the teachers brought up the importance of differentiation for diverse learners. This limited attention is concerning, especially given the wide range of algebra readiness levels found in typical classrooms. Tagle et al. (2016) point out that addressing diverse learning trajectories is essential to equitable mathematics instruction. The omission in teacher responses suggests an area ripe for professional development specifically in strategies for supporting varied pathways to understanding algebraic concepts.

Table 6: Cross-Analysis of Teachers' Beliefs and Practices on Algebraic skills

Practice/Role	Mentioned in Interviews	Observed in Practice	Alignment (%)
Scaffolding and feedback	5/6 (83%)	5/6 (83%)	100%
Encouraging peer discussion	4/6 (67%)	4/6 (67%)	100%
Formative assessment	2/6 (33%)	3/6 (50%)	67%
Differentiation	2/6 (33%)	2/6 (33%)	100%

Source: Primary Data

This study found strong alignment between what teachers expressed during interviews and what was actually observed in the classroom particularly in areas such as scaffolding, encouraging student discourse, and establishing environments where learners feel safe to take intellectual risks. Such alignment is a positive indication that many educators are translating their pedagogical intentions into effective classroom practices. According to Glassmeyer and Edwards (2016), this ability to put knowledge into action is a defining feature of well-developed Pedagogical Content Knowledge (PCK).

While these core practices were evident, other areas especially differentiation and formative assessment—showed only partial implementation. Teachers often spoke of their commitment to meeting students' needs, yet observable practices didn't always reflect this. As Adamuz-Povedano et al. (2021) note, honoring student thinking requires deliberate attention to flexible instructional approaches. Similarly, Kullberg et al. (2017) emphasize that modeling adaptive strategies is essential for promoting deep algebraic understanding. The disconnect seen here points to an opportunity for targeted professional development aimed at strengthening these areas.

The broader literature has long asserted that students' growth in algebraic reasoning is closely linked to their teachers' pedagogical decisions and depth of content knowledge. In this study, the observed use of multiple representations, rich mathematical discussions, and scaffolded opportunities to generalize ideas reflects the best practices outlined by researchers such as Blanton et al. (2018) and Steele & Johanning (2004). Teachers were not simply delivering procedures but guiding learners to recognize patterns and make sense of relationships—key habits of algebraic thinkers.

Yet, the absence of consistent differentiation strategies and limited use of formative assessment reveal that there is still work to be done in making instruction fully responsive. Tagle et al. (2016) have highlighted that adapting teaching to different learning profiles is not a luxury but a necessity, particularly in algebra where students often begin at varying levels of readiness.

Overall, the findings affirm that strong algebra instruction is much more than procedural training. It involves

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creating learning spaces where students are actively engaged in reasoning, where their ideas are valued, and where mathematical meaning is co-constructed through social and cognitive interaction. In the classrooms studied, teachers generally fulfilled their roles as both facilitators and content experts, signaling a move toward more student-centered approaches.

Nonetheless, the gaps in formative assessment and differentiation suggest the need for continued growth. Investing in sustained professional learning opportunities will be essential for helping teachers refine their practices and fully embrace the vision of algebra as a subject rooted in reasoning and generalization, not just symbolic manipulation. With such support, teachers can more effectively navigate the complexities of instruction and meet the diverse needs of their learners an outcome that benefits both students and the discipline itself.

Methods Used in the Assessment of Algebraic Skills

Table 7: Methods Used by Teachers in Assessing Algebraic Skills

Assessment Method	Evidence from Interviews	Evidence from Observations	Frequency (out of 6)	Percentage (%)
Oral Questioning	"I often ask questions during lessons to check understanding."	Teachers were observed asking probing questions during group work and whole-class discussions.	6/6	100%
Written Exercises	"Pupils complete practice tasks after new concepts."	Exercises and worksheets were used in all observed lessons.	5/6	83%
Group Work and Peer Assessment	"Sometimes they discuss in groups and assess each other."	Peer feedback observed during group problem-solving tasks.	4/6	67%
Use of Manipulatives	"We use blocks or counters to see if they grasp the pattern."	Learners manipulated physical objects to demonstrate understanding.	3/6	50%
Homework Assignments	"I assign problems for them to try at home."	Not directly observed in class sessions.	4/6	67%
Class Presentations	"Students explain their thinking on the board."	Observed in some lessons where pupils presented solutions.	2/6	33%
Quizzes/Tests	"I give short quizzes to assess progress."	Evidence of quiz materials seen but not actively administered.	3/6	50%

Source: Primary Data

Data from Table 4 highlight a range of assessment strategies employed by teachers to evaluate algebraic reasoning. These include oral questioning, written exercises, peer assessment, manipulatives, homework, quizzes/tests, and class presentations. Triangulated data from interviews and observations confirmed the actual application of these strategies in practice. Oral questioning, used by all six teachers (100%), emerged as the most prevalent tool. It aligns with Black and Wiliam’s (1998) emphasis on formative assessment as a means to elicit student thinking. This mirrors findings from Oppong et al. (2024), who observed that real-time questioning reveals misconceptions in Ghanaian classrooms. Namakshi et al. (2022) further noted that teachers trained to interpret students’ verbal responses enhanced their diagnostic capacity, particularly in algebra.

Written exercises were reported by 83% of teachers, mainly used for procedural fluency. Kilpatrick, Swafford, and Findell (2001) emphasized that consistent algebraic practice supports both conceptual and procedural growth. However, Jojo and Salani (2023) and Arabacı et al. (2024) warned that over-reliance on written tasks may overlook deeper conceptual understanding if not varied. Group work and peer assessment, cited by 67% of teachers, support collaborative reasoning. According to Vygotskian theory and MDPI (2023), peer dialogue enhances metacognitive awareness. Namakshi et al. (2022) found that such interactions aid in identifying students' mathematical thinking. Observations showed that group tasks created rich informal assessment opportunities.

Homework, also used by 67%, was primarily for reinforcement. Amoah et al. (2019) found it to be inconsistently monitored, which reflects this study's observation that it was rarely integrated into feedback cycles, limiting its diagnostic impact.

Manipulatives were used by half the teachers to provide tangible representations of abstract ideas. Carpenter et al. (2003) emphasized their role in bridging concrete and symbolic understanding. Arabacı et al. (2024) showed how manipulatives improve algebraic reasoning in middle school students. Despite this, use was limited and inconsistent. Quizzes and tests, also used by 50%, served as summative check-ins but lacked regular feedback, weakening their value. Pohl et al. (2018) called for more differentiated and equitable assessment strategies, and Veldhuis and Van den Heuvel-Panhuizen (2016) advocated for frequent low-stakes assessments to monitor understanding effectively. Class presentations, reported by only 33% of teachers, were the least used strategy. Yet, they offer strong opportunities for students to verbalize reasoning, as supported by MDPI (2021) and Namakshi et al. (2022). Jojo and Salani (2023) noted that such practices are often sidelined due to time and curriculum constraints.

In summary, assessment in these classrooms heavily favors informal and formative techniques like oral questioning and written work, in line with Black and Wiliam (1998). While efforts toward collaborative and conceptual assessment exist (Oppong et al., 2024; Otero et al., 2024), limited use of reflective strategies signals areas for growth in assessment literacy and practice. Professional development is needed to support consistent use of varied, student-centered diagnostic tools.

Barriers to Effective Development of Algebraic Skills

Table 8: Barriers to Effective Development of Algebraic Reasoning Skills Among Mathematics Teachers

Barrier Identified	Frequency (N=6)	Percentage (%)
Limited instructional time	5	83%
Insufficient professional development (PD)	4	67%
Weak foundational knowledge in learners	4	67%
Technological challenges	3	50%
Curriculum rigidity	5	83%

Source: Primary Data

A majority of teachers (83%) highlighted time constraints and rigid curricula as major obstacles to fostering algebraic reasoning in their classrooms. Many expressed frustration that the demands of covering extensive syllabi often leave little room for deep, exploratory learning. This aligns with Bland (2024), who argues that overcrowded curriculum structures inhibit conceptual engagement. Teachers reported that time limitations restrict opportunities for pattern-based inquiry and generalization which is a core processes in algebraic reasoning. Education Week (2024) similarly found that over one-third of math educators feel pressured by time, limiting their ability to cultivate rich mathematical discussions.

Curriculum rigidity was another recurring theme. Several teachers noted that a heavy emphasis on procedural fluency and preparation for standardized tests limits their ability to use open-ended or collaborative tasks. Schoenfeld (2025) warns that such environments deprive students of the iterative exploration necessary for building algebraic insight, particularly in primary classrooms.

Professional development (PD) emerged as another significant gap. Four of the six teachers indicated that although materials such as textbooks are often available, meaningful PD that supports conceptual teaching or technology integration is rare. This concern echoes a 2025 Frontiers in Education study, which found that most teachers receive generic training that fails to reflect classroom realities. Teachers called for training that is more practice-oriented and focused on the development of mathematical reasoning, not just content delivery. Ball and Bass (2024) emphasize that enhancing mathematics-specific pedagogical content knowledge (MPCK) is critical for supporting student reasoning. Similarly, Darling-Hammond et al. (2024) advocate for PD that is sustained, embedded within collaborative settings like PLCs, and directly tied to classroom practice.

Student readiness also surfaced as a challenge, with 67% of teachers pointing to weak foundational understanding of number and operations. This gap hinders students' ability to engage with algebraic reasoning tasks. As Kieran (2025) notes, fluency in basic arithmetic operations is essential for manipulating variables and recognizing patterns. Teachers described situations where students struggled with equivalence or inverse relationships, even when tasks were designed to encourage pattern recognition. This supports Carraher and Schliemann's (2024) view that strong numerical reasoning in early primary years lays the groundwork for algebraic thinking.

Another barrier cited by half the teachers was limited use of digital tools due to infrastructure challenges and a lack of confidence in using educational technology. Teachers mentioned unreliable internet and insufficient devices as key limitations. More importantly, even where tools like GeoGebra or Desmos were available, teachers felt unprepared to integrate them effectively into instruction. Neumann et al. (2025) point out that while such tools can enhance visualization and manipulation of algebraic concepts, teachers need training grounded in the TPACK framework which integrates technological, pedagogical, and content knowledge. Encouragingly, Petrou and Haspekian (2025) found that when teachers are supported in both access and application, student engagement and conceptual understanding improve significantly.

In summary, the barriers to effective algebra instruction are multifaceted, ranging from systemic issues like time and curricular constraints to gaps in teacher preparation and student readiness. Addressing these challenges will require a more responsive curriculum, focused PD, and sustained efforts to build foundational skills early in students' academic journeys.

CONCLUSION

The study concludes that the development of algebraic skills is foundational to students' mathematical thinking and problem-solving abilities, requiring more than procedural fluency as it demands deep conceptual understanding, pattern recognition, and reasoning. Effective teaching strategies such as scaffolding, mathematical discourse, and the use of rich, open-ended tasks were found to significantly support this development. Teachers play a critical role as facilitators of reasoning, and their Pedagogical Content Knowledge (PCK) is essential in creating learner-centered environments that promote generalization and exploration. However, challenges such as limited differentiation and underuse of formative assessment hinder the effective cultivation of these skills. Addressing these barriers through ongoing professional development and reflective practice is crucial in empowering both teachers and learners in the journey toward meaningful algebraic reasoning.

Implications and Recommendations

Meaning of Algebraic Skills

Understanding algebra as more than symbolic manipulation is crucial. Teachers, curriculum designers, and policymakers must recognize that algebraic skills involve reasoning, generalization, and recognizing patterns

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across contexts

RECOMMENDATIONS

Teachers should continue to embrace student-centered approaches that promote pattern recognition, reasoning, and mathematical discourse, aligning with contemporary views of algebra as a tool for thinking, not just calculating.

Curriculum designers should embed rich, open-ended tasks that foreground the conceptual nature of algebra and its connection to real-world reasoning.

Strategies for Developing Algebraic Skills

Effective teaching of algebra requires deliberate instructional choices, such as the use of collaborative tasks, visual representations, and modeling of multiple strategies.

Recommendations

Curriculum designers must provide adaptable, inclusive resources with scaffolding prompts and opportunities for collaborative reasoning.

Digital tools like GeoGebra and Desmos should be integrated intentionally to support visualization, exploration, and dynamic manipulation of algebraic relationships.

Schools should support the use of digital platforms not only for content delivery but for facilitating collaborative reasoning (e.g., interactive simulations, discussion boards).

Importance of Algebraic Skills for Thinking and Problem Solving

Algebraic reasoning fosters critical thinking and enables students to generalize across contexts. Promoting these skills prepares students for future learning and real-life problem-solving.

Recommendations:

School leaders must prioritize deep exploration of algebraic ideas over superficial curriculum coverage by advocating for flexible scheduling and instructional time.

Policymakers should reduce curriculum overcrowding to allow time for inquiry-based, exploratory learning aligned with 21st-century competencies.

Interdisciplinary teaching should be encouraged to reinforce algebraic reasoning across subjects such as science and technology.

Role of the Teacher in Fostering Algebraic Reasoning

Teachers play a pivotal role in creating classrooms that value reasoning, exploration, and risk-taking. Their pedagogical decisions and use of feedback directly impact student learning.

Recommendations:

Schools should embed algebraic reasoning into whole-school improvement plans and encourage teacher leadership roles focused on peer mentoring and professional learning.

Professional development should include classroom-based inquiry cycles where teachers experiment with and refine instructional strategies for algebraic thinking.

Establish school - university research partnerships to create a feedback loop between theory and practice.

Assessment of Algebraic Skills

Effective assessment practices are essential to support reasoning. However, formative assessments are underused, and diagnostic tools are not always available to address conceptual gaps.

Recommendations:

Teachers must be supported in using formative and diagnostic assessments to identify and address gaps in conceptual understanding early.

Professional learning should emphasize assessment for learning how to use student thinking to guide instructional adjustments.

Learning management systems (LMS) can support asynchronous feedback and offer differentiated pathways for students' progression in algebraic reasoning.

Barriers to Effective Development of Algebraic Skills

Barriers such as time constraints, rigid pacing guides, limited differentiation, and insufficient PD impede the development of algebraic thinking.

Recommendations:

Policymakers and curriculum developers should allow local curriculum flexibility to tailor instruction to students' needs and community contexts.

Long-term, sustained PD models such as Lesson Study, PLCs, and instructional coaching must be adopted to address instructional gaps and support reflection and collaboration.

PD should target culturally responsive teaching, differentiation strategies, and conceptual pedagogy that address diverse learners' needs.

Investment in digital infrastructure must be matched with professional support to ensure meaningful use aligned with TPACK frameworks (Mishra & Koehler, 2024).

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