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An Outcry from the Classroom: Advancing Virtual Reality and Augumented Reality Integration in Grade 12 Mathematics through Deliverology and Implementation Science Frameworks in Gauteng North

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ABSTRACT

This article investigates the systemic, pedagogical, and contextual barriers to integrating Virtual Reality (VR) and Augmented Reality (AR) in the teaching of Grade 12 Mathematics within Community Learning Centres (CLCs) in Gauteng North, South Africa. Despite the Department of Higher Education and Training (DHET's) ongoing emphasis on the integration of digital technologies in education, CLCs remain marginalised due to historical inequalities, infrastructural deficits, and a lack of institutional support. Adopting a qualitative case study design grounded in the constructivist paradigm, the study utilised focus group discussions with mathematics teachers across selected CLCs to examine their lived perceptions regarding technology integration. Using thematic analysis, five key themes emerged: the absence of digital tools, strong aspirational support for technology, teacher-led workarounds, resource inequities, and the personal burden borne by teachers. Findings reveal that while immersive technologies are not currently in use, teachers value their potential for improving student engagement and conceptual understanding. However, integration efforts are hindered by a lack of digital infrastructure, formal training, and institutional support. To address these constraints, the study recommends a dual-framework approach that applies Deliverology for strategic goal-setting and accountability, alongside Implementation Science to ensure responsive, context-driven innovation. The research concludes that successful VR and AR integration in CLCs requires coordinated investment, policy alignment, and sustained professional development. By foregrounding teacher voices and local contexts, the study contributes to ongoing efforts to advance digital equity in South Africa's post-school education system and offers a practical roadmap for implementing immersive technologies in under-resourced learning environments.

Keywords: *Augmented Reality, Virtual Reality, Integration Of Technology, Mathematics, Community Learning Centres*

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INTRODUCTION

In an increasingly digitised and interconnected world, the imperative for education systems to evolve is more urgent than ever. The global education community has recognised the transformative potential of immersive technologies, namely: Virtual Reality (VR) and Augmented Reality (AR), in fostering conceptual understanding, improving student engagement, and providing equitable learning experiences in complex subjects like mathematics.[1] These technologies enable students to visualise and manipulate abstract mathematical concepts in real-time, thereby enhancing comprehension and retention. AR tools, for example, facilitate spatial reasoning by overlaying visual representations of mathematical ideas onto the physical world, while VR creates immersive environments in which students interact with mathematical models dynamically.

While these innovations have shown promise in global studies, their integration into South African Community Learning Centres (CLCs), particularly within the Gauteng North Region, remains limited and under-researched. CLCs are crucial institutions tasked with redressing historical educational inequalities and extending learning opportunities to underserved populations, including adult students and out-of-school youth.[2] However, the implementation of the Grade 12 Mathematics curriculum within CLCs is persistently hindered by infrastructural deficits, inadequate funding, a shortage of qualified mathematics teachers, and limited access to instructional resources such as textbooks, libraries, and laboratories.[3]

Although digital learning platforms such as the South African Mathematics Olympiad (SAMO) and Mindset Learn have begun to bridge some gaps in content delivery, the incorporation of immersive technologies like VR and AR in CLCs remains sparse and unstructured. Furthermore, studies indicate that teacher discomfort, lack of professional development, and insufficient systemic support continue to obstruct the adoption of these tools.[4] What compounds this challenge is the absence of implementation models that can systematically and contextually guide the integration of emerging technologies into such complex and resource-constrained learning environments.

To address this gap, this study turns to two synergistic frameworks: Deliverology and Implementation Science. Deliverology, developed by Barber et al., is a goal-driven approach that focuses on measurable targets, progress tracking, and accountability mechanisms, often used to improve public service outcomes.[5] In contrast, Implementation Science delves into the ‘how’ of enacting reforms, emphasising adaptation to local context, stakeholder engagement, and data-driven decision-making.[6] When combined, these frameworks provide a powerful means of managing complexity while ensuring structured, scalable change that is responsive to local conditions in CLCs.

Despite evidence of the pedagogical benefits of VR and AR, and the theoretical soundness of Deliverology and Implementation Science, no known studies have explored how these frameworks can jointly support immersive technology integration within Grade 12 Mathematics instruction in CLCs. Existing literature predominantly focuses on either technology deployment in well-resourced settings or on general curriculum delivery in under-resourced environments, rarely addressing both in tandem. Moreover, there is minimal empirical data on how structured implementation processes can mitigate the practical and systemic barriers to VR/AR adoption in South African CLCs. This study seeks to:

1. Diagnose the specific contextual barriers and enablers affecting VR and AR integration in Grade 12 Mathematics instruction within Gauteng North CLCs.
2. Deploy a dual-framework implementation approach, using Deliverology to guide strategic planning and accountability, and Implementation Science to enable contextual adaptation and stakeholder responsiveness.

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[1] Gilles Aldon and Corinne Raffin, “Mathematics Learning and Augmented Reality In,” *Augmented Reality in Educational Settings*, 2019, 123; Nor Farhah Saidin, Noor Dayana Abd Halim, and Noraffandy Yahaya, “A Review of Research on Augmented Reality in Education: Advantages and Applications,” *International Education Studies* 8, no. 13 (2015): 1–8.

[2] Shadrack T Mzangwa, “The Effects of Higher Education Policy on Transformation in Post-Apartheid South Africa,” *Cogent Education* 6, no. 1 (2019): 1592737; L. M. Tawana, “ Curriculum Delivery Challenges in Community Learning Centres: A Gauteng North Perspective,” *South African Journal of Adult Education* 11, no. 2 (2019): 56–68.

[3] F. Roen, N. M. Noor, and A. Al-Shreifeen, “ Teachers’ Experiences of Teaching in Under-Resourced Community Centres,” *International Journal of Educational Development in Africa* 9, no. 1 (2024): 45–59; M. M., Rakoma and S. Schulze, “Challenges of Curriculum Implementation in Adult Learning Centres,” *Journal for New Generation Sciences* 13, no. 2 (2015): 23–40.

[4] S. Matlala, “ Factors Influencing the Implementation of Mathematics Curriculum in Adult Learning Centres,” *Journal of Education and Practice* 6, no. 8 (2015): 130–36; T. Ngwenya, “Teacher Competence and Technology Integration in Under-Resourced Schools,” *South African Journal of Education* 40, no. 3 (2020): 1–11.

[5] M. Barber, P. Kihn, and A. Moffit, *Deliverology 101: A Field Guide for Educational Leaders* (California: Corwin Press, 2015).

[6] Deborah Ghate, “From Programs to Systems: Deploying Implementation Science and Practice for Sustained Real World Effectiveness in Services for Children and Families,” *Journal of Clinical Child & Adolescent Psychology* 45, no. 6 (2016): 812–26; Kim Schildkamp, “Data-Based Decision-Making for School Improvement: Research Insights and Gaps,” *Educational Research* 61, no. 3 (2019): 257–73.

By transitioning from the well-documented promise of immersive technologies to a practical, framework-guided implementation in disadvantaged educational settings, this study aims to offer actionable insights and policy recommendations. Therefore, this study contributes to the broader discourse on equitable digital transformation in education and lays the groundwork for future research on scalable innovations in mathematics pedagogy.

LITERATURE REVIEW

Curriculum implementation in Grade 12 Mathematics is not merely the act of delivering content, but a process involving lesson planning, teaching strategies, student engagement, and assessment aligned with curriculum goals.[7] Effective implementation hinges on the teacher's ability to contextualize learning while adhering to prescribed policies such as CAPS. However, studies reveal that within CLCs, implementation is fraught with systemic and structural challenges that diminish the potential of the curriculum to foster meaningful learning outcomes.[8] These include misalignment between pedagogical approaches and student needs, poor instructional quality, and an absence of sustained professional support for teachers. The apartheid legacy continues to cast a long shadow on education, particularly in mathematics education. Disparities in access to quality resources and teacher development are still entrenched in historically disadvantaged areas, including many CLCs.[9] Despite policy reforms such as Curriculum 2005 (C2005), the Revised National Curriculum Statement (RNCS), and CAPS, many teachers remain ill-equipped to effectively translate these reforms into practice.[10] These findings confirm that mathematics education reform in South Africa is structurally sound, yet often flawed in execution, particularly in non-traditional learning environments like CLCs.

Multiple studies highlight how systemic and institutional factors constrain curriculum delivery in CLCs. Resource scarcity, including a lack of textbooks, manipulatives, digital tools, and infrastructure, emerges as a persistent barrier.[11] According to Tawana, CLCs often operate in underfunded environments with minimal technological capacity, which limits the incorporation of innovative pedagogical methods.[12] Infrastructural limitations, such as overcrowded classrooms and the absence of mathematics laboratories, restrict opportunities for experiential and inquiry-based learning.[13] Additionally, socio-economic disparities severely affect student engagement and academic performance in mathematics. Students in CLCs often come from marginalized backgrounds and may lack foundational academic support structures. Graven and Spaull underscore how poverty and educational inequality act as poverty traps, making it difficult for students to access quality mathematics education.[14]

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7 Sharon L Senk and Denisse R Thompson, *Standards-Based School Mathematics Curricula: What Are They? What Do Students Learn?* (Taylor & Francis, 2020); Jean-Claude, Beacco et al., "Guide for the Development and Implementation of Curricula for Plurilingual and Intercultural Education," *Council of Europe*, 2016.

8 Birgit Pepin et al., "Digital Curriculum Resources in Mathematics Education: Foundations for Change," *ZDM* 49, no. 5 (2017): 645–61; Amanda Thomas and Alden J Edson, "A Framework for Teachers' Evaluation of Digital Instructional Materials: Integrating Mathematics Teaching Practices with Technology Use in K-8 Classrooms," *Contemporary Issues in Technology and Teacher Education* 19, no. 3 (2019): 351–72.

9 Ashwani Kumar, *Curriculum in International Contexts: Understanding Colonial, Ideological, and Neoliberal Influences* (Springer, 2018); M. B. Mhlauli, E. Salani, and R. Mokotedi, " Understanding Apartheid in South Africa through the Racial Contract," *International Journal of Asian Social Science* 5, no. 4 (2015): 203–19.

10 DBE (Department of Basic Education)., *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12* (Pretoria: Government Printers, 2011).N. L. Clark and W. H. Worger, *South Africa: The Rise and Fall of Apartheid* (London: Routledge, 2016).

11 W. Green, "The Ghost of the Past: Historical Disadvantages Still Haunt Rural Schools," *Mail & Guardian*, October 23, 2015; M. Rashid, " Teachers' Technological Pedagogical Content Knowledge (TPACK) and the Integration of ICT in Teaching," *South African Journal of Education* 40, no. 2 (2020): 1–10.

12 Tawana, " Curriculum Delivery Challenges in Community Learning Centres: A Gauteng North Perspective."

13 Ulrike Hanemann, *Narrowing the Gender Gap: Empowering Women through Literacy Programmes: Case Studies from the UNESCO Effective Literacy and Numeracy Practices Database (LitBase) Http://Www. Unesco. Org/Uil/Litbase* (ERIC, 2015); UNESCO, " SDG4-Education 2030, Incheon Declaration (ID) and Framework for Action. For the Implementation of Sustainable Development Goal 4, Ensure Inclusive and Equitable Quality Education and Promote Lifelong Learning Opportunities for All, ED-2016/WS/28.," 2015.

14 Mellony Holm Graven, "Poverty, Inequality and Mathematics Performance: The Case of South Africa's Post-Apartheid Context," *Zdm* 46, no. 7 (2014): 1039–49; Nic Spaull, "Schooling in South Africa: How Low-Quality Education Becomes a Poverty Trap," *South African Child Gauge* 12, no. 1 (2015): 34–41.

These inequalities are compounded when students must study in environments lacking essential facilities, exacerbating performance gaps between students in mainstream schools and those in CLCs.

Teacher capacity is a key determinant of effective curriculum implementation. Studies show that many teachers in CLCs are underqualified or insufficiently trained to teach Grade 12 Mathematics, particularly in integrating new content knowledge and technological tools.[15] Handrianto et al. found that while teachers may be passionate, they often lack proficiency in advanced mathematical concepts or confidence in their instructional abilities.[16] This deficit is linked to poor professional development pathways and a lack of mentoring, both of which are essential to improving teaching quality. Moreover, teacher attitudes are critical to implementation success. Positive attitudes foster openness to innovation and adaptive teaching, while negative or apathetic attitudes hinder student engagement and teaching effectiveness. Certain scholars assert that supportive professional environments and well-resourced classrooms enhance teacher motivation, whereas environments characterised by material deprivation and high workload foster disengagement.[17]

The use of technology in education, particularly VR and AR, is increasingly seen as a means to deepen conceptual understanding and make abstract content tangible. CAPS recognizes the role of technology in enhancing mathematics instruction and encourages its integration through calculators, computers, and digital simulations.[18] However, as Saxena and Onyema point out, many CLCs lack the basic digital infrastructure to support such integration.[19] This includes inadequate access to computers, poor internet connectivity, and a lack of teacher training in digital pedagogy. Despite these limitations, VR and AR have shown potential in increasing student engagement, enabling interactive visualisation of complex mathematical concepts, and fostering problem-solving skills.[20] In contexts where these tools are available, students exhibit higher levels of motivation and academic interest, particularly in topics like geometry and data modelling. However, without systemic support for digital inclusion, such innovation risks remaining aspirational rather than transformational.

THEORETICAL FRAMEWORK

The implementation of immersive technologies in the selected CLCs was informed by a hybrid approach that integrated Deliverology and Implementation Science. Deliverology, as conceptualized by Barber et al., is a performance-driven management framework that emphasizes clarity of goals, monitoring systems, and accountability structures to enhance service delivery.[21] In this study, the Deliverology framework was adapted to establish measurable targets for the integration of VR/AR in mathematics instruction, identify delivery agents (teachers, subject advisors, and centre managers), and monitor progress through school visits and planning sessions. Complementing this, Implementation Science provided tools for contextual adaptation and iterative learning. As explained by Ghate, Implementation Science emphasizes the importance of aligning interventions with local contexts to improve sustainability and effectiveness.[22] Schildkamp further argues that data-driven implementation approaches enable schools to systematically respond to changing needs.[23] Together, these frameworks ensured that the intervention was both strategic and flexible, responding to the diverse realities across different CLCs.

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[15] Rashid, " Teachers' Technological Pedagogical Content Knowledge (TPACK) and the Integration of ICT in Teaching."

[16] Ciptro Handrianto et al., "Teachersself-Efficacy and Classroom Management in Community Learning Centre (CLC) Sarawak," *Spektrum: Jurnal Pendidikan Luar Sekolah (PLS)* 9, no. 2 (2021): 154–63.

[17] D. Blazar and M. A. Kraft, "Teacher and Teaching Effects on Students' Attitudes and Behaviors," *Educational Evaluation and Policy Analysis* 39, no. 1 (2017): 146–70; Umesh Ramnarain and Manzini Hlatswayo, "Teacher Beliefs and Attitudes about Inquiry-Based Learning in a Rural School District in South Africa," *South African Journal of Education* 38, no. 1 (2018).

[18] DBE (Department of Basic Education)., *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12*.

[19] S. Saxena, " Modern Teaching Methods and Techniques," *International Journal of Advance Research and Innovative Ideas in Education* 3, no. 1 (2017): 349–54; E. M. Onyema, " Integration of Emerging Technologies in Teaching and Learning Process in Nigeria: The Way Forward," *International Journal of Education and Development Using ICT* 16, no. 3 (2020): 34–50.

[20] Valentina Dagiene and Gabriele Stupuriene, "Informatics Concepts and Computational Thinking in K-12 Education: A Lithuanian Perspective," *Journal of Information Processing* 24, no. 4 (2016): 732–39.

[21] Barber, Kihn, and Moffit, *Deliverology 101: A Field Guide for Educational Leaders*.

[22] Ghate, "From Programs to Systems: Deploying Implementation Science and Practice for Sustained Real World Effectiveness in Services for Children and Families."

[23] Schildkamp, "Data-Based Decision-Making for School Improvement: Research Insights and Gaps."

METHODOLOGY

Research Paradigm and Design

This study adopted a qualitative ethnographic case study design situated within a constructivist paradigm, which was appropriate for exploring how Grade 12 Mathematics teachers in CLCs experience and interpret the integration of VR and AR in their teaching practices. According to Eyisi, qualitative research enables the exploration of participants' views, meanings, and interactions in a natural setting.[24] Subramani supports this view, noting that a constructivist orientation allows researchers to understand the world through the multiple realities constructed by individuals.[25] The ethnographic approach allowed the researcher to observe and interact with participants over time in their actual instructional contexts, which provided a deeper understanding of the everyday realities and systemic barriers that shape curriculum implementation in under-resourced centres.

Research Participants

The study was conducted across six CLCs in Gauteng North that offered Grade 12 Mathematics. These sites were purposefully selected based on their curriculum offerings and the presence of qualified mathematics teachers. Participants were selected using a purposive and stratified random sampling approach. Teachers were first identified based on specific criteria, including at least two years of teaching Grade 12 Mathematics and experience with CAPS implementation, as suggested by Adeoye, who highlights the value of selecting information-rich cases.[26] Following the initial identification, stratified random sampling ensured that various factors such as geographic location, years of service, and school infrastructure were proportionally represented. The sample comprised 24 teachers, of whom 6 were selected for in-depth focus group discussions. This approach was consistent with the recommendations by Dhivyadeepa, who advocates for stratified techniques to ensure diversity in qualitative studies.[27]

Data Collection Procedures

The study employed focus group discussions (FGDs) as the primary qualitative data collection instrument to generate in-depth and trustworthy data. FGDs were used to explore participants' collective experiences, perceptions, and challenges related to the implementation of the Grade 12 Mathematics curriculum and the potential integration of virtual and augmented reality (VR/AR) technologies in CLCs. The discussion schedule was carefully developed and piloted prior to data collection to ensure clarity, relevance, and alignment with the study's objectives. As noted by Nduna, piloting enhances the effectiveness of data collection tools by refining question structure and improving participant engagement.[28] Each focus group comprised a small number of participants to encourage open dialogue and interaction, enabling the researcher to probe into the social dynamics and shared realities of curriculum delivery in under-resourced contexts. The FGDs provided a valuable platform for participants to express their views collaboratively, revealing patterns and perspectives that might not emerge in individual interviews. Thematic data from these sessions were subsequently analysed to identify recurring themes and contextual insights that informed the study's findings.

Data Analysis

Data collected from the focus group discussions were analysed using thematic analysis, guided by the framework developed by Braun and Clarke. This method was selected for its flexibility and suitability in identifying, analysing, and reporting patterns within qualitative data. Thematic analysis enabled the researcher to extract meaningful themes from the shared experiences and interactions of participants,

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[24] Daniel Eyisi, "The Usefulness of Qualitative and Quantitative Approaches and Methods in Researching Problem-Solving Ability in Science Education Curriculum.," *Journal of Education and Practice* 7, no. 15 (2016): 91–100.

[25] A. Subramani, " A Constructivist Approach to Qualitative Research," . . *International Journal of Research and Analytical Reviews* 6, no. 2 (2019): 780–88.

[26] A. A. Adeoye, *Teacher Development and Curriculum Implementation: Challenges Facing Teachers in South Africa* (Pretoria: UNISA Press, 2023).

[27] E. Dhivyadeepa, *Sampling Techniques in Educational Research* (Mysore Prasaranga: University of Mysore, 2015).

[28] N. J. Nduna, "Teachers' Experiences of Implementing Curriculum Changes in Selected Primary Schools in Limpopo Province, South Africa," *South African Journal of Education* 40, no. 2 (2020): 1–10.

specifically related to curriculum delivery, student engagement, and the potential integration of VR and AR in under-resourced CLCs. The analysis process began with a thorough familiarisation with the audio-recorded and transcribed FGD data, followed by the generation of initial codes. These codes were developed both deductively, drawing from the study's guiding frameworks, Deliverology and Implementation Science, and inductively, emerging from participants' language and interactions. The procedure mirrors the approach used by Tawana, who conducted qualitative coding and thematic categorisation to explore curriculum challenges in CLCs.[29] Key themes included student motivation, collaborative learning, access to technology, and perceptions of teaching quality. To ensure the trustworthiness of the analysis, the researcher applied strategies such as peer debriefing, member checking, and maintaining a detailed audit trail, consistent with the recommendations of Fusch et.al.,[30] These strategies helped validate the findings and ensure that interpretations accurately reflected participants' shared experiences.

Ethical Considerations

Ethical standards were rigorously upheld throughout the study. Approval to conduct the research was obtained from the Tshwane University of Technology Research Ethics Committee, and official permission was granted by the Gauteng Department of Education to access the selected CLCs. Participants were informed about the purpose of the study, the voluntary nature of participation, and their right to withdraw at any time. Written informed consent was secured from all participants, and additional assent was obtained for students under 18 years of age. Anonymity was ensured by using pseudonyms in transcripts and reports, and all data were stored in secure, password-protected files. These ethical procedures adhered to the standards described by Arifin, who emphasized informed consent and data confidentiality in educational research.[31]

PRESENTATION OF FINDINGS

This study employed thematic analysis, as formulated by Naeem et, al., to interpret the qualitative data collected from focus group discussions conducted with Grade 12 Mathematics teachers in CLCs across Gauteng North.[32] Thematic analysis provided a structured yet flexible framework for identifying, analysing, and reporting patterns within the data, particularly as they relate to the integration of VR and AR technologies. Following the six stages of the method: familiarisation, coding, theme generation, theme review, definition and naming, and final analysis, the process enabled the distillation of recurring issues, beliefs, and aspirations relevant to the study's dual-framework approach (Deliverology and Implementation Science). Five key themes emerged from the data and are presented in Table 1, below;

Table 1: Thematic Analysis and findings from Focus Group Discussion

Theme	Findings
Absence of Interactive Digital Learning Tools	Participants consistently reported that their centres did not possess any digital learning platforms or interactive technologies. The responses suggest that VR and AR technologies have yet to reach these educational environments, not due to resistance or rejection, but due to structural absence. As one participant noted, *"I personally never used it and even here at school… I've never seen anyone using it."* This absence was attributed to longstanding resource inequalities, which leave CLCs technologically deprived, compared to mainstream schools. The lack of basic digital infrastructure, such as internet-enabled devices, projectors, and computer labs, limits the implementation of interactive mathematics instruction.

[29] Tawana, " Curriculum Delivery Challenges in Community Learning Centres: A Gauteng North Perspective."
[30] Patricia Fusch, Gene E Fusch, and Lawrence R Ness, "Denzin's Paradigm Shift: Revisiting Triangulation in Qualitative Research," *Journal of Sustainable Social Change* 10, no. 1 (2018): 2.
[31] Siti Roshaidai Mohd Arifin, "Ethical Considerations in Qualitative Study," *International Journal of Care Scholars* 1, no. 2 (2018): 30–33.
[32] Muhammad Naeem et al., "A Step-by-Step Process of Thematic Analysis to Develop a Conceptual Model in Qualitative Research," *International Journal of Qualitative Methods* 22 (2023): 16094069231205789.

	Despite the clear policy emphasis on integrating technology into education, CLCs remain excluded from such advancements. Within the context of Deliverology, this theme points to the need for clear, measurable targets and delivery planning that prioritises infrastructure deployment to disadvantaged educational sites.
Perceived Value of Technology for Future Readiness	Although VR and AR were not in use, the data revealed a strong aspirational discourse among teachers regarding the potential benefits of immersive technologies. Teachers recognised the increasing importance of technological literacy for students, particularly in preparing them for higher education and employment. As **Participant B** expressed, *"It is very imperative for us to have it here… so that when they go out there they are aware of such equipment."* This aspirational outlook highlights teachers' awareness of the demands of a rapidly evolving digital society. Teachers see technology not only as a tool to enhance mathematics understanding, but also as a broader educational necessity. This theme affirms that readiness for innovation exists at the level of professional belief, even if not yet realised in practice. From an Implementation Science perspective, this perceived value suggests fertile ground for change, provided that interventions are appropriately scaffolded to account for local constraints.
Technological Workarounds and Informal Innovations	In response to the absence of formal infrastructure, teachers reported engaging in improvised forms of digital instruction, leveraging personal mobile phones, WhatsApp groups, and data bundles to support students. Participant F illustrated this by stating, *"I mostly use cell phones… WhatsApp groups… all the students can get the information."* Similarly, **Participant E** described using tablets and grouping students with access to data to enable broader content sharing. These strategies reflect a form of adaptive professionalism in which teachers act resourcefully to meet student needs, despite systemic neglect. However, these workarounds also highlight the unsustainability of relying on personal resources in a public education setting. Teachers expressed concern about the limited reach of such efforts and the burden placed on them. This theme signals that innovation is already taking place in limited and informal ways, validating the relevance of both Deliverology and Implementation Science to build on these foundations through structured, equitable implementation.
Inequity in Resource Distribution and Its Impact on Student Performance	Teachers strongly linked student performance to the availability and quality of educational resources, particularly textbooks, lesson hours, and exposure to technology. **Participant A** articulated this clearly: *"A student who uses 3-in-1 [textbook] performs better than one who uses Mind the Gap."* In many cases, students lacked even the most basic materials, and performance discrepancies were attributed to differences in the availability of resources across schools. These disparities were further evident in teaching hours, where students with more contact time in mathematics tended to achieve higher academic outcomes. The theme illustrates how deep-rooted systemic inequities manifest in everyday instructional practices and student achievement. For both Deliverology and Implementation Science, this theme reinforces the importance of context-aware planning and differentiated support systems that acknowledge the material conditions shaping curriculum implementation.
Professional and Personal Burden on Teachers	A recurrent thread in the discussions was the strain placed on teachers, who routinely supplement state-provided resources with personal data, devices, and time. **Participant B** stated, *"I do share my data with students even though it is self-funded... all the gadgets are mine."* This theme speaks to a broader issue of professional sustainability and ethical responsibility.

	Teachers are often forced to take on roles that exceed their formal duties in order to compensate for institutional gaps. While this underscores a strong commitment to student support, it also exposes teachers to burnout, stress, and inequity. From a Deliverology lens, it reflects a failure in the delivery chain where teachers are expected to act as the final point of implementation without being adequately supported. From an Implementation Science perspective, it suggests the necessity of building institutional capacity, not just introducing technological tools, if long-term innovation is to be successful and ethical.

The themes in Table 1 derived from the focus group discussions present a compelling portrait of life in Gauteng North's CLCs: one marked by resource scarcity, pedagogical ingenuity, aspirational outlooks, and systemic neglect. While the actual use of VR and AR is currently nonexistent, teachers are not opposed to their integration; on the contrary, they are actively seeking solutions to modernise instruction. Their narratives suggest that any initiative aimed at integrating immersive technologies must begin with context-sensitive planning, infrastructure development, and structured professional support. Deliverology can help align institutional efforts by defining clear roles, responsibilities, and monitoring systems, while Implementation Science ensures that local realities, teacher capacity, and sustainability are central to any intervention. Together, these frameworks offer a pathway to advance technology integration in ways that are not only innovative but also equitable, feasible, and responsive to the lived experiences of teachers on the front lines.

DISCUSSION

The thematic analysis revealed that a major impediment to effective mathematics instruction in CLCs is the chronic absence of digital infrastructure and technological teaching tools. Focus group participants described their environments as under-resourced and technologically barren, lacking even the most basic equipment like projectors, internet access, or interactive whiteboards, let alone advanced technologies like VR and AR. This absence is consistent with the findings of Umuhoza and Uworwabayeho, who observed that the limited availability of resources severely affects educational quality in CLCs.[33] Similarly, Green and Rashid emphasized that inadequate infrastructure leads to poor instructional quality and obstructs curriculum delivery.[34] This aligns with the Deliverology framework, which underlines the importance of clearly defined delivery chains and measurable targets. Where technology is absent, delivery goals related to digital transformation remain unmet, reinforcing systemic inequality in education access and implementation.

Despite the lack of tools, teachers demonstrated a strong aspirational belief in the potential of immersive technologies to revolutionise mathematics teaching and learning. Teachers expressed that VR and AR would not only improve student engagement and comprehension but also help bridge the gap between abstract mathematical theory and real-world application. These sentiments mirror findings from Onyema, who noted that digital tools enhance motivation and understanding.[35] Teachers further identified technology as a mechanism for preparing students for tertiary education and the evolving digital economy, echoing DBE and the World Economic Forum on the value of digital literacy.[36] This positive orientation towards innovation indicates a readiness for transformation and is congruent with the principles of Implementation Science, which recognises the importance of context and stakeholder perceptions in facilitating change.[37] The potential exists, but requires strategic, contextualised, and well-supported interventions to unlock it.

[33] G., Umuhoza and A. Uworwabayeho, " Teachers' Competencies and Attitudes towards the Implementation of Competency-Based Curriculum in Rwanda," *African Journal of Educational Studies in Mathematics and Sciences* 17, no. 2 (2021): 81–93.

[34] Green, "The Ghost of the Past: Historical Disadvantages Still Haunt Rural Schools"; Rashid, " Teachers' Technological Pedagogical Content Knowledge (TPACK) and the Integration of ICT in Teaching."

[35] Onyema, " Integration of Emerging Technologies in Teaching and Learning Process in Nigeria: The Way Forward."

[36] DBE (Department of Basic Education)., *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12*.WEF (World Economic Forum), *The Future of Jobs Report* (Geneva: WEF, 2018).

[37] P. Nilsen and S. Bernhardsson, "Context Matters in Implementation Science," *Implementation Science* 14, no. 32 (2019): 1–12.

Another emerging theme is the reliance on informal, unsustainable innovations by teachers in response to institutional neglect. Participants reported using personal mobile devices, WhatsApp groups, and self-funded internet data to distribute learning materials and engage with students' practices, which, while creative, underscore the absence of institutional support. Similar practices were recorded in the literature by Saxena, Dagiene and Stupuriene, where teachers in low-resource settings used personal devices as substitutes for digital infrastructure.[38] While these workarounds are commendable, they reflect structural failure in curriculum support and violate the equity principles underpinning both educational justice and the Deliverology approach. According to Barber et al., such gaps signal a breakdown in delivery mechanisms, where the burden of implementation is shifted unfairly onto under-supported teachers.[39] In line with Implementation Science, such informal strategies need to be institutionalized through systemic support and scaled up through structured training and investment in digital infrastructure.

Moreover, the analysis exposed inequitable resource distribution and the compounding effects of socio-economic disparities, which directly affect student performance in mathematics. Teachers reported stark differences in outcomes between students with access to textbooks, digital materials, and additional teaching time, and those without. This theme was reflected in Spaull, who argued that poor students are trapped in cycles of low-quality education due to insufficient access to academic resources.[40] Similarly, Graven highlighted that poverty influences students' educational trajectories, especially in subjects requiring abstract reasoning like mathematics.[41] The implication is that curriculum implementation in CLCs cannot be improved without addressing broader issues of economic inequality and institutional resourcing. From a Deliverology perspective, targeted and differentiated delivery planning is needed to prioritise CLCs for resource allocation. Concurrently, Implementation Science calls for the co-design of interventions that are responsive to community realities, scalable, and inclusive of teachers' and students' needs.[42] Thus, the analysis confirms the necessity of a dual-framework approach for advancing VR and AR in Grade 12 Mathematics education within under-resourced environments.

RECOMMENDATIONS

Based on the study's findings, it is recommended that the Department of Higher Education and Training (DHET), in collaboration with the Gauteng Community Education and Training (GCET), initiate a dedicated infrastructure development programme for CLCs. The study found that the absence of technology, ranging from projectors to digital content platforms, hinders the VR and AR in mathematics instruction.[43] As has been explained, teachers' ability to integrate technology meaningfully is highly dependent on the availability of resources. Therefore, prioritising historically disadvantaged CLCs in infrastructure roll-out aligns with equity goals and addresses spatial and systemic disparities.

Secondly, there is an urgent need for ongoing, context-responsive professional development for mathematics teachers. Although teachers demonstrated enthusiasm toward integrating VR and AR, the study found that they lacked formal training in immersive technology use. The study suggests that professional development should focus on equipping teachers with digital skills aligned to current technological demands in education. Additionally, it has been argued that teacher development efforts must account for the socio-economic and pedagogical realities faced by teachers in marginalized communities. These programmes should be continuous and participatory, involving active modeling, mentorship, and feedback.

A third recommendation is the institutional adoption of a hybrid implementation model that draws on both Deliverology and Implementation Science. The Deliverology model, as outlined by

[38] Saxena, " Modern Teaching Methods and Techniques"; Dagiene and Stupuriene, "Informatics Concepts and Computational Thinking in K-12 Education: A Lithuanian Perspective."
[39] Barber, Kihn, and Moffit, *Deliverology 101: A Field Guide for Educational Leaders*.
[40] Spaull, "Schooling in South Africa: How Low-Quality Education Becomes a Poverty Trap."
[41] Graven, "Poverty, Inequality and Mathematics Performance: The Case of South Africa's Post-Apartheid Context."
[42] C. R. Cook et al., "A Support Framework for Implementation Science in Education," *Educational Psychologist* 54, no. 3 (2019): 174–87.
[43] Umuhoza and Uworwabayeho, " Teachers' Competencies and Attitudes towards the Implementation of Competency-Based Curriculum in Rwanda."

Barber, Kihn, and Moffitt, emphasises structured delivery chains, performance monitoring, and accountability in achieving set educational goals. When combined with Implementation Science, which focuses on adaptability, local relevance, and sustainability, the hybrid model ensures both clarity of purpose and responsiveness to school-specific contexts. District-based training in these frameworks would help CLC leadership coordinate goal-driven, adaptive implementation strategies.

Furthermore, the study recommends the creation of institutional support structures to alleviate the burden teachers currently face in trying to close the digital divide. Teachers reported using personal phones, airtime, and data to share content and engage students, practices that are financially and emotionally unsustainable. Government and educational authorities should respond with policy-backed interventions such as data subsidies, digital resource hubs, and deployment of school-based digital learning facilitators. When systemic inequities are left unaddressed, they compound over time and perpetuate poverty traps within education.

CONCLUSION

This study investigated the challenges and prospects for integrating VR and AR technologies in the teaching of Grade 12 Mathematics in CLCs in Gauteng North. The findings confirm that while immersive technologies are absent in practice, teachers are intellectually and pedagogically prepared for such innovation. Teachers are not resistant to technological change; rather, they are restricted by structural limitations such as a lack of devices, connectivity, and curriculum-aligned training. Their positive disposition toward digital learning tools despite resource constraints presents a valuable opportunity for intervention.

However, the study shows that aspirations alone are insufficient. Effective technology integration in under-resourced CLCs demands comprehensive systemic reform that spans infrastructure provision, professional training, resource equity, and stakeholder engagement. The national curriculum already supports the integration of technology in subject delivery. Yet, implementation remains uneven due to contextual disparities and a lack of supportive planning at the grassroots level.

The dual frameworks of Deliverology and Implementation Science are critical to this process. Deliverology ensures clarity in setting measurable educational outcomes and defines mechanisms for holding implementing agents accountable. Implementation Science, as Cook et al., suggest, focuses on fidelity, sustainability, and adaptability, ensuring that innovations work in diverse settings. The use of these complementary frameworks offers a pathway for bridging the policy-practice gap, particularly in disadvantaged educational contexts.

Thus, the VR and AR integration has significant potential to enhance mathematical learning and digital inclusion in CLCs. However, to realize this promise, the education system must prioritize institutional investment and strategic planning. This includes not only addressing material shortages but also investing in human capital, ensuring that teachers are equipped, supported, and empowered to lead innovation from the classroom. The failure to act decisively risks perpetuating historical inequalities and excluding already marginalized students from 21st-century opportunities. Therefore, a shift toward equity-driven innovation, grounded in practical and accountable frameworks, is both necessary and urgent.

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