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The promise and peril of Coding & Robotics education in South Africa: A scoping review of teacher preparation and generative artificial intelligence's potential for delivering equity

Mashite Tshidi

Division of Science and Technology, Wits School of Education, University of the Witwatersrand, Johannesburg, South Africa
tshidimashite@gmail.com
https://orcid.org/0000-0002-1288-1576

Alton Dewa

Division of Science and Technology, Wits School of Education, University of the Witwatersrand, Johannesburg, South Africa
alton.dewa@wits.ac.za
https://orcid.org/0000-0002-0776-4447

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Abstract

Integrating the Coding & Robotics (C&R) subject in South African schools signifies the nation's commitment to Fourth Industrial Revolution preparedness. However, challenges like inadequate teacher preparation and limited technological infrastructure must be addressed to ensure equity. Although Generative Artificial Intelligence (GenAI) may not address the infrastructural deficiencies directly, in this scoping review we examine its potential to complement existing resources and support teachers in delivering C&R instruction. Following Arksey and O'Malley's framework, we conducted a systematic literature search in numerous databases, followed by a screening procedure: 10 of the 61 eligible papers satisfied the inclusion criteria. Our findings reveal that GenAI can optimise C&R teacher development through personalised learning, content generation, feedback on teaching methods, and fostering collaboration with other teachers. Despite its potential, issues including equity, ethical concerns, technological fluency gaps, and overreliance on GenAI tools, must be navigated to enhance equitable C&R instruction and prepare learners for the digital era.

Keywords: Coding & Robotics, GenAI, scoping review, teacher preparation, equity

Introduction

Despite rapidly advancing technology and a global knowledge-based economy, educational systems continually adapt to meet 21st-century demands. Numerous countries undergo educational reforms driven by economic, social, and cultural objectives to prepare individuals for success in a digitally integrated world (Reimers, 2021). Countries have implemented these reforms to maintain a competitive edge economically, culturally, and socially in a technology-driven global landscape in recognising the importance of cultivating active creators rather than passive consumers of technology, and the role of individuals as agents of cultural change (Storte et al., 2019). The convergence of economic, social, and cultural factors propels educational systems towards mapping a terrain in which individuals can thrive in a technological landscape.

In South Africa, a pivotal initiative of this reform was the introduction of a new subject in 2021 called "Coding & Robotics" (C&R) across Grades R–9 by the Department of Basic Education (DBE). This initiative aligns with the nation's commitment to the Fourth Industrial Revolution (4IR) to prevent learners from being left behind (Ogegbo & Ramnarain, 2022). The 4IR era in South Africa represents a transformative period marked by the convergence of social, digital, and economic realms driven by technological advancements (Arendse, 2023), thereby necessitating a paradigm shift in education, like introducing C&R subjects that aim to equip learners with problem-solving abilities, foster critical thinking, encourage collaborative and creative skills, and prepare them to thrive in a digital information-driven era (Department of Basic Education, 2021).

However, the piloting of C&R across Grades R–9 hinges not only on the infrastructure and curriculum design but also on the training and assistance provided to the teachers. Teachers have a significant impact on how learners perceive programming and their ability to master it (Bano et al., 2023). Still, they frequently face challenges in obtaining the expertise and developing the abilities needed to teach C&R effectively (Hadad et al., 2021). The inadequate technological infrastructure in many South African schools, with nearly 16,000 of them lacking dedicated computer labs, further exacerbates these challenges (Greyling, 2023). This infrastructural deficiency limits the hands-on learning component with digital tools integral to C&R. C&R provides learners with an engaging and dynamic learning environment by allowing them to assemble and programme robots thus creating an enjoyable learning experience (Castro et al., 2018). The ramifications of this deficiency are far-reaching since the practical aspects of the subject may remain unrealised, hindering the development of technical skills necessary for navigating the digitally integrated world (Storte et al., 2019).

Compounding this challenge is the limited access to comprehensive and ongoing professional development programs designed for teaching C&R. Although there is a possibility that many teachers are (un)aware of the advantages of C&R and are not equipped to teach it well, this is primarily down to the dearth of specialised training programs provided by educational institutions and an inadequate level of existing professional development initiatives (Schina et al., 2021). This challenge stems from barriers hindering sustainable professional

development in C&R education, including the lack of collaboration between higher education institutions and schools, thereby constraining the impact of professional development programs on transforming teaching practices (Ni et al., 2023). For instance, while South Africa's DBE has long offered Information Technology (IT) as a subject for secondary learners in Grades 10–12 to instil computing fundamentals, including coding and problem-solving skills (Department of Basic Education, 2011), many C&R teachers may lack extensive practical coding experience given their university education or IT teaching backgrounds. Moreover, implementing short programs without sustained support fails to support teachers with the requisite continuous learning and growth essential for proficient coding instruction. This underscores the lack of focus on discipline-specific pedagogical content knowledge (PCK) in professional development endeavours (Ni et al., 2023), often resulting in teachers being insufficiently prepared and lacking the specialised skills and understanding required for effective C&R instruction (Changpetch et al., 2022).

Given these challenges, innovative solutions are needed to bridge the gap between subject requirements and teacher capacity (Gorrah & Papers, 2024; Schina et al., 2021). GenAI's capacity to generate content in the formats of text, photos, music, videos, and 3D models by detecting patterns and information from written requests provides a potential solution to these challenges (Chiu, 2023). This is made possible by GenAI's wide range of applications, including OpenAI (ChatGPT, GPT-4), Amazon (CodeWhisperer), and Google (Alpha-Code, Gemini), among many others that have gained attention recently and are used to personalise learning experiences, automate administrative tasks, and enhance teachers' and learners' abilities in programming classrooms (Becker et al., 2023). While GenAI may not address the physical infrastructural deficiencies, it can complement existing resources and support teachers in delivering C&R instruction (Greyling, 2023).

Against this backdrop, in this scoping review, we investigate how GenAI can address teachers' challenges in implementing C&R instruction in South Africa. The study is predicated on the idea that effective integration of C&R instruction requires well-prepared teachers. Adequate teacher preparation significantly affects the development of learners' digital abilities, especially their coding skills (Chiu, 2023). Thus, in this review, we seek to understand how GenAI can mitigate PCK gaps, minimise the adverse impacts of inadequate technological infrastructure, and promote long-term learning and growth among teachers overseeing C&R instruction. To achieve these objectives, the following research questions guided the review:

1. How can GenAI address teachers' challenges in acquiring the necessary pedagogical skills and programming knowledge for effective C&R instruction?
2. What are GenAI's potential implications for teacher preparation and support in C&R education?

To answer these research questions, in the rest of the review, we build on the introduced need for teacher preparation for C&R in South African schools. We begin the discussion in the next section with a historical overview of programming education in South Africa through the key policies and initiatives that have influenced it. This includes attending to teachers'

challenges in acquiring the necessary knowledge and skills to teach C&R effectively. In the following section, our focus shifts to the methodological approach to the study. Moving forward, we then focus on the results and discussion of potential applications of GenAI in C&R education and navigate the tensions associated with its integration from the reviewed studies. Finally, we offer a summary and a call to action for further research.

Foundations of programming education in South African schools

Formal programming education in South Africa has a complex history that is influenced by the legacy of apartheid. Before 1994, racial segregation resulted in a stark disparity in resources and instructional quality between white and Black schools (Fleisch, 2002). White schools received far more resources and provided a wider range of academic subjects, whereas Black schools had lower academic expectations and emphasised practical skills for blue-collar occupations (Fiske & Ladd, 2004). The unequal distribution of funding and resources resulted in overcrowding in classrooms, poor infrastructure, and insufficiently qualified teachers in schools serving Black learners, thus perpetuating attainment discrepancies (Fleisch, 2002). This disparity hindered the education of Black learners in computer science and impeded the development of a diverse IT workforce (Galpin & Sanders, 2007).

Post-apartheid efforts were made to address these inequalities. A major step in eradicating the legacy of apartheid education was the adoption of Curriculum 2005 (C2005) in 1998. C2005 focused on learner-centred and outcomes-based education (OBE) but faced challenges because of teachers' inadequate training (Fiske & Ladd, 2004). Factored in here, was the butterfly effect of apartheid's legacy that left many schools, particularly those in historically disadvantaged communities, with inadequate resources and (technological) infrastructure to fully implement the C2005 philosophy in their programmes (Fleisch, 2002). In 2002, C2005 was revised and became the Revised National Curriculum Statement (RNCS). With an emphasis on eight learning areas, including Technology, the RNCS stressed principles like social justice, fairness, and development and encouraged the growth of creative, critical, and problem-solving individuals to provide the groundwork for computer science education and also sought to improve teacher training and resources (Department of Education, 2002; Galpin & Sanders, 2007).

The 2004 introduction of RNCS was followed by its 2007 revision of the National Curriculum Statement (NCS). NCS's extension focus on integrating technology into the classroom led to the introduction of new subjects such as Computer Applications Technology (CAT) and Information Technology (IT) in Grades 10–12 under the Curriculum Assessment Policy Statement (CAPS) (Department of Basic Education, 2011). These subjects were endorsed by two ICT-focused white paper policies that were produced by the South African Government Gazette with other plans and strategies, such as the 2016 National Integrated ICT Policy White Paper, 2017 National e-Strategy, and 2020–24 Basic Education Strategic Plan supporting their implementation to create capacity, establish ICT norms and standards,

promote fairness, and provide access to ICT infrastructure (Department of Education, 2002, 2004). The 2004 White Paper on e-Education encourages teachers to use ICT to improve teaching and learning across the board in the education and training system to guarantee ICT competence for all learners in the nation (Department of Education, 2004). While the introduction of CAT and IT represented progress in the attainment of these goals, literature on these fields highlighted challenges that contributed to the digital divide and limited foundational digital skills development since they were targeted at the senior grades in secondary school (Koorsse et al., 2015; Mentz et al., 2012).

Effective computer programming requires integrating critical thinking, problem-solving, and science-based reasoning with program design and development. Teachers unprepared for this multifaceted approach struggle to balance these demands (Ogegbo & Ramnarain, 2022). The focus of IT is often on how teachers can support learners in learning *how* to solve problems by providing procedural information rather than prioritising the development of critical thinking and problem-solving abilities. This is reflected in the objectives of the subject; learners are required to demonstrate proficiency in using appropriate techniques and procedures to plan solutions and devise algorithms for problem-solving using suitable techniques and tools (Department of Basic Education 2011). This approach may limit learners' ability to adapt to new programming challenges and languages by concentrating on predefined methods rather than fostering creative problem-solving skills (Prather et al., 2023).

Unequal resource distribution exacerbates these challenges. The DBE mandates computer labs and internet access for IT classes (Department of Education, 2011). However, many public schools, particularly in rural and historically disadvantaged areas, still lack the necessary infrastructure (Munje & Jita, 2020). This digital divide restricts learners' access to computers and hampers their ability to acquire basic programming skills.

The Department of Basic Education's 2021 initiative to make C&R a compulsory subject for Grades R–9 aims to address these challenges by equipping learners with fundamental ICT skills, including problem-solving, critical thinking, collaboration, and innovation (Moraiti et al., 2022). C&R is intended to be taught alongside core subjects such as reading, writing, and mathematics. However, many South African learners lack basic skills in these foundational subjects. This has ignited ongoing debate on whether addressing the lack of these basic skills should precede the immediate challenges associated with the C&R subject (Geldenhuys & Fataar, 2021). An examination of learners' proficiencies in areas such as writing, reading, and mathematics indicates the need to integrate computational thinking that encompasses problem-solving capabilities, system design acumen, and a nuanced understanding of human behaviour (Moraiti et al., 2022). This aspect also bolsters acquiring and retaining STEM knowledge and skills. Therefore, the endorsement of computational thinking in early exposure to C&R can enhance learners' STEM knowledge by piquing their curiosity, helping them apply existing concepts, and inspiring the development of new ones (Bano et al., 2023). This technique can help to add interest and enjoyment to this learning exercise. Research has indicated that learners may learn computer programming, science, maths, and problem-

solving techniques with robots (Prather et al., 2023). Given that C&R is enjoyable, introducing this in primary and secondary schools while fostering learners' creativity and logical and language abilities is a great initiative. However, the efficacy of integrating computational thinking into standard teaching practices of C&R depends on the ability of teaching staff to meet the demands of the subject (Schina et al., 2021).

Integrating computational thinking into C&R teaching requires addressing teachers' misconceptions and limited knowledge. Research indicates that teachers often lack engagement with C&R concepts because of insufficient training (Changpetch et al., 2022). The effectiveness of C&R activities is diminished if prior training is lacking (Castro et al., 2018). Furthermore, research indicates that teachers' attitudes significantly influence how well educational technology is used (Litlhakanyane, 2022; Schina et al., 2021). Teachers tend to be less motivated to conduct tasks if they lack competence in the subject matter. Although brief exposure to educational technology courses and tools has demonstrated the potential to augment teachers' understanding of C&R (Boz & Allexsaht-Snider, 2022), comprehensive training programs covering basic programming concepts are still needed. Addressing these challenges is essential for the success of the C&R initiative. Hence, in this scoping review, we examine the promising solutions that GenAI offers to bridge this gap.

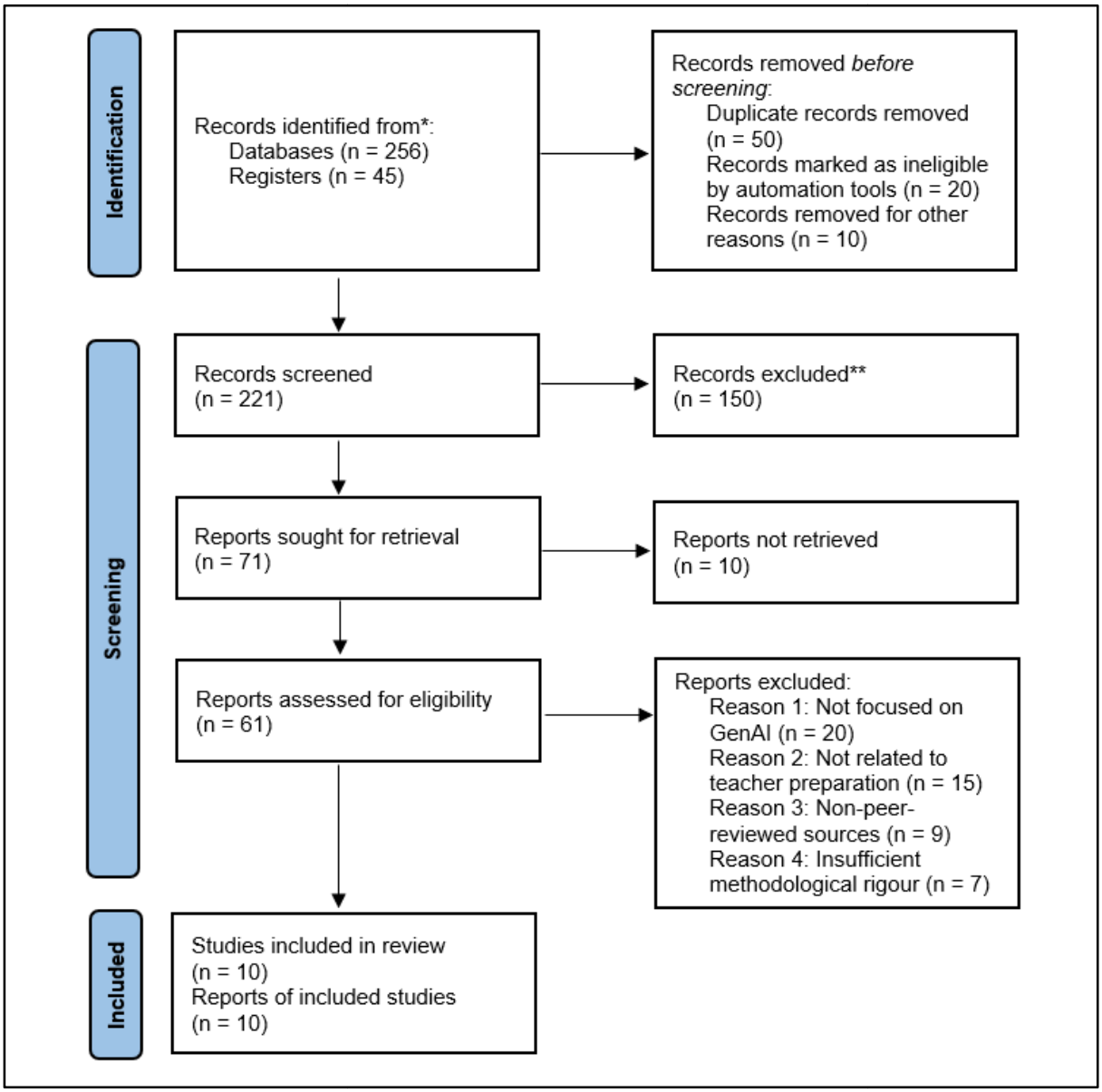
Methodology

Our scoping review aimed to explore the promises and perils related to integrating GenAI in teacher preparation for C&R education. For this review, we used a systematic strategy to search, select, and synthesise existing literature. We adhered to the framework established by Arksey and O'Malley (2005). This review consists of four steps beyond the identified research questions that include (a) identifying relevant studies, (b) study selection, (c) charting the data, and (d) collating, summarising, and reporting results. The adopted rigorous transparency method we adopted allows the search strategy to be replicated and enhances the validity of the research findings (Fan et al., 2022).

Identifying relevant studies

We undertook a comprehensive literature review published from 2022 to May 2024. Figure 1—Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagrams, provided by Moher et al. (2009), detail the procedure used to synthesise the published peer-reviewed literature. We carried out the literature search using many databases, including the Education Resources Information Center (ERIC), Google Scholar, IEEE Xplore, and Scopus. Examples of the used search strings focused on the concept of "GenAI" and its applications in "teacher preparation" and "coding and robotics", including derivative terms like "artificial intelligence," "machine learning," and "educational technology." Outcome-related keywords included "pedagogical content knowledge," "technological infrastructure," "teacher training," and "C&R instruction." These terms and keywords were found in published works on GenAI, C&R education and teacher preparation.

Figure 1
Flow diagram for data searched (Moher et al., 2009).



Study selection

We screened over 221 abstracts using Covidence, a systematic review management system enabling individuals to evaluate abstracts for inclusion. The following criteria were used to determine study inclusion: (a) studies focused on using GenAI in educational contexts, (b) studies on teacher preparation and professional development for C&R education, (c) studies published between 2022 and 2024, and (e) studies examining GenAI applications and computational thinking in teacher training. Dissertation studies were omitted. When we concluded that the abstract satisfied the inclusion requirements, we moved on to the full-text review stage of this article.

We evaluated more than 200 publications in their entirety. Following the analysis, we used specific grounds for exclusion in the following sequence when publications were eliminated

during the full-text review: (a) studies outside the scope of teacher preparation or GenAI, (b) preparation for C&R education, (c) articles not available in full text, (d) non-peer-reviewed sources, and (e) inadequate rigour in the methodology. This priority allows coding exclusions when articles may have been omitted for various reasons (Fan et al., 2022). Subsequently, we searched all included publications manually, searched through reference lists, and identified recent publications by using the Times Cited count feature of the Web of Science database.

Charting the data

Table 1 describes the resulting 10 studies, organised by the data extracted, including author(s) and year of publication, study design and methodology, population and sample size, context and setting, key findings related to GenAI and teacher preparation, and implications for policy and practice.

Table 1
Summary of data from included studies.

Author(s) and year of publication	Study design/methodology	Population/sample size	Context and setting	Findings related to GenAI tools and teacher preparation	Implications for policy and practice
Becker et al. (2023)	Position paper	N/A	Schools	Simplifying problem descriptions can improve teachers' ability to communicate algorithmic challenges accurately, enhancing GenAI tools' success in producing accurate answers. Code-generating tools may expose teachers to various problem-solving techniques, thus aiding their coding efficiency and approaches. Teachers may use GenAI tools, including Codex, to help learners understand programming concepts by creating new programming assignments and explanations. Copilot can assist teachers in overcoming writer's block by generating initial code and encouraging rewriting, refactoring, and debugging.	GenAI-generated code can include biases, demanding human oversight to ensure safe and ethical school use. Policymakers must establish guidelines for the ethical use of GenAI tools in the classroom. Policy should be developed to guarantee that AI technologies facilitate inclusive education. Promote creating a wide range of instructional materials using GenAI tools.
Bringula (2024)	Qualitative	Teachers and learners	University	ChatGPT can create functional programming codes with annotated comments. ChatGPT can generate content for teaching-learning activities and act as a virtual tutor. Excessive use of ChatGPT may hinder teachers' use of varied instructional materials and critical thinking.	Teachers need to verify the accuracy and relevance of generated content. Regulations need to govern ChatGPT's use in educational contexts.

Author(s) and year of publication	Study design/methodology	Population/sample size	Context and setting	Findings related to GenAI tools and teacher preparation	Implications for policy and practice
Changpetch, et al. (2022)	Mixed-methods	151 preservice teachers	University	GenAI tools can create interactive learning environments, like the WARiable game, helping pre-service teachers grasp abstract programming concepts through real-world simulations and immediate feedback.	Policies should support Python inclusion in the teacher education curriculum because of its efficacy in reducing programming misconceptions. Professional development programs should equip pre-service and in-service teachers with tools, including GenAI, for teaching programming languages. Teachers should assess learners' understanding regularly to identify and correct misconceptions early. Teachers should use GenAI tools that offer early feedback to assist learners in understanding and correcting their misconceptions.

Author(s) and year of publication	Study design/methodology	Population/sample size	Context and setting	Findings related to GenAI tools and teacher preparation	Implications for policy and practice
Chiu et al. (2023)	Qualitative	88 teachers	School	GenAI tools, notably ChatGPT and Midjourney, help teachers view learning objectives differently. These tools emphasise the need for digital, media, and information literacy, critical thinking, AI literacy, and the development of learners' basic abilities. Incorporating ChatGPT and Midjourney into classrooms requires teacher development in a GenAI-driven environment to improve curriculum leadership, AI literacy, facilitating abilities, and interdisciplinary teaching. GenAI tools necessitate rethinking assessment methods in focusing on formative and summative approaches that assess digital literacy and critical thinking.	Professional development programs should foster a learn-it-all mentality to improve facilitation skills and interdisciplinary teaching. Schools should implement interdisciplinary teaching strategies to prepare students for the workforce and future education in the AI era. Schools must create new assessment techniques, such as evaluating AI literacy, inquiry-based learning, and critical thinking.
Denny et al. (2024)	Mixed-methods	Teachers	School	GenAI presents challenges and opportunities in C&R education, requiring refining pedagogical strategies to focus on new skill sets. GenAI tools can solve typical programming challenges. Therefore, teachers need to rethink assessment strategies. Pedagogical strategies could emphasise teaching strategic problem decomposition and accurate prompt specification for GenAI tools to students. Teachers must guide students in using these tools responsibly.	Integrating GenAI tools for teaching and learning requires teachers to understand their advantages and disadvantages. Developing assessment procedures that consider the existence of GenAI tools is essential.

Author(s) and year of publication	Study design/methodology	Population/sample size	Context and setting	Findings related to GenAI tools and teacher preparation	Implications for policy and practice
Ni et al. (2023)	Systematic review			Professional Learning Communities (PLCs) encourage teamwork and reduce isolation among teachers. PLCs assist teachers inside and outside professional development initiatives through collaboration and resource sharing.	Implementing online, hybrid and in-person PLCs can meet diverse teacher needs. Policies should involve administrators and stakeholders to support C&R education.
Prather et al. (2023)	Mixed methods	22 teachers	Schools	Existing computer programs could include unstated covert learning objectives, such as problem decomposition, code reading and tracing. Teachers must identify and incorporate these covert objectives into lesson design and assessments to better match intended results. Reducing the focus on programming syntax with GenAI tools may improve retention rates.	Teachers should acknowledge the presence and potential use of GenAI tools, whether they allow or restrict them. They must also ensure that learning objectives, activities, and assessments have been matched constructively and consider how GenAI tools can influence these components. GenAI tools can assist in creating instructional materials, but teachers should be aware of potential biases in the outputs. Teachers can use GenAI to help learners understand GenAI-generated code and provide additional practice opportunities.

Author(s) and year of publication	Study design/methodology	Population/sample size	Context and setting	Findings related to GenAI tools and teacher preparation	Implications for policy and practice
Sun et al. (2024)	Quasi-experimental design	82 learners	College	The results indicated that ChatGPT-enabled learning delivered personalised feedback that aided programming learning. Following the intervention, learners had better attitudes towards and intentions about using ChatGPT because they thought it was helpful and straightforward.	Teachers must understand the pros and cons of integrating ChatGPT into lessons. While it offers personalised feedback, it can also produce errors. Maximising its pros and reducing any possible problems requires strategy and execution. Teachers should create pedagogical strategies that use GenAI tools. This involves explaining how to apply ChatGPT in programming tasks. Teacher preparation programs should include training on using GenAI tools, covering pedagogical and technical aspects.
Wieser et al. (2023)	Mixed-methods	120 learners	University	Teachers must modify assessment procedures to account for ChatGPT and other GenAI tools, possibly including assessments to better evaluate learners' comprehension and abilities. While ChatGPT can detect errors and suggest alternatives, teachers should remain the primary assessors for consistency and precision in grading. To optimise ChatGPT's role in personalised instruction, teachers must plan carefully and define learning objectives before using it as a supplementary tutor.	Schools may need to adjust academic integrity policies to address the challenges GenAI poses. Policies should guide using ChatGPT in assignments, ensuring learners' work reflects their understanding and abilities.

Author(s) and year of publication	Study design/methodology	Population/sample size	Context and setting	Findings related to GenAI tools and teacher preparation	Implications for policy and practice
Yilmaz and Yilmaz (2023)	Mixed-methods	41 learners	University	ChatGPT allows individuals to practice coding and debug code. It can generate solutions to problems but may offer inaccurate responses if questions are misinterpreted. Overreliance on ChatGPT could impede the development of algorithmic thinking in teachers and learners.	Teachers should incorporate GenAI tools into their teaching practices to supplement learning. Assignments should require algorithmic thinking and integrate GenAI responses into broader projects. Exploring the versatility of GenAI tools can help tailor teaching strategies for different programming classes and age groups. Teachers should discuss the ethical considerations of using GenAI with learners, underscoring the need to verify the information produced by the tools and recognise any potential biases in its outputs.

Reporting results and discussion

This scoping review maps out the body of research on the potential of integrating GenAI to address challenges with teacher preparation in C&R instruction. We performed thematic analysis to organise and categorise the included studies based on key themes linked to the research questions, including teacher preparation, the potential application of GenAI tools, and navigating the potential perils are discussed in the subsequent sections.

The potential application of GenAI tools

Research question 1

- How can GenAI address teachers' challenges in acquiring the necessary pedagogical skills and programming knowledge for effective C&R instruction?

The introduction of C&R as a compulsory subject in South African schools presents an opportunity, but as noted earlier, its implementation hinges on a well-equipped teaching force. Recent AI developments, especially GenAI, have emerged as a potential solution to this challenge. Many GenAI tools can comprehend and produce source codes and instructions written in plain language, primarily because of large language models (LLMs) (Wieser et al., 2023). The reviewed studies indicate the potential of GenAI to address the challenges teachers encounter in the programming paradigms used in C&R—text-based and block-based programming. The C&R subject uses pre-existing programming environments and tools, like Scratch, Microsoft Micro: bit, Arduino, Code Combat, and MakeCode, to make learning programming efficient and fun (Yilmaz & Yilmaz, 2023). LLMs leverage natural language processing and machine learning technologies to support these programming tools through user-friendly interfaces, integration with many programming languages, comprehensive search capabilities, concise explanations with useful examples, and personalised learning experiences (Sun et al., 2024; Yilmaz & Yilmaz, 2023).

Drawing on teachers' existing proficiencies across diverse programming paradigms, emerging findings from reviewed studies indicate that GenAI tools can evaluate a teacher's proficiency, understanding of computer science principles, and desired objectives relevant to each program's learning paradigm. This enables GenAI to assess teachers' basic understanding of computational concepts and recommend materials that focus on areas in which the teacher requires the most support and allow them to work at their own pace (Sun et al., 2024; Wieser et al., 2023). This personalised learning path could be curated in a block-based learning platform like Scratch. Similar to a study by Govender and Govender (2021) that focused on pre-service teachers from a South African university and their experiences with physical computer programming using Scratch for Arduino, Scratch was found to be an ideal platform to introduce programming concepts because it provides an informal and beginner-friendly approach. This learning route could be augmented by tutorials and practice tasks, resulting in proficiency in basic programming concepts before advancing to the text-based paradigm (Yilmaz & Yilmaz, 2023). In this thread, an LLM such as ChatGPT could

serve as a personal tutor, modifying examples to help teachers practise a particular coding concept and offering step-by-step solutions to learn at their own pace (Wieser et al., 2023).

This personalised method enables teachers to avoid reiterating sections of instructional material that they have previously mastered. Govender and Govender (2021) indicated that a rapid and efficient transfer to text-based coding should occur once the basic coding concepts have been covered in block-based programming. When it comes to block-based settings, a novice teacher may get too accustomed to them and be reluctant to transition to text-based coding. The text-based programming paradigm requires technical expertise, and an understanding of the basic concepts required to resolve programming-related challenges (Wieser et al., 2023). Becoming proficient in various text-based programming languages with numerous features is the goal of learning to code. To achieve this goal, GenAI can create learning pathways that concentrate on text-based languages, such as Arduino, frequently utilised in the subject's C&R senior phase strand. These paths could include interactive lessons covering syntax, coding conventions, and debugging techniques (Yilmaz & Yilmaz, 2023). The findings highlight that GenAI-powered learning platforms provide tasks focused on problem-solving and accurate code writing, helping users improve their coding abilities (Becker et al., 2023). With the aid of these resources, teachers may enhance their programming abilities and advance at their own speed while receiving personalised instruction and immediate feedback (Sun et al., 2024).

GenAI's capacity to offer timely and personalised feedback on lesson plans, teaching methods, and coding exercises across various programming paradigms was also found to address the deficiencies in these areas. Research demonstrates that LLMs like ChatGPT and Codex offer interactive features that can benefit teachers. These can function as conversational agents responding to inquiries, explaining programming terminology, providing relevant content, and even assisting with debugging code (Bringula, 2024). This interactive process nurtures teachers to accept suggestions and feedback on their lesson plans and teaching methods thus helping them to improve their programming practice and identify potential areas for refinement (Sun et al., 2024; Yilmaz & Yilmaz, 2023).

Denny et al. (2024) conducted a study focusing on the potential of LLMs to assist teachers in creating programming exercises and code explanations. Using Codex, exercises based on input prompts with contextual themes and programming principles were generated for coding. The results indicated that most created exercises featured executable example answers and test cases. Although not all sample solutions passed the tests, the test suites provided complete statement coverage when they did. In terms of code explanations, Codex produced detailed explanations of the given code because of the input. An analysis showed that around 70% of the explanations for individual lines were accurate, and 90% of the explanations covered every section of the code. The results are similar to other studies, i.e. Prather et al. (2023), that suggest that LLMs can reduce the workload of C&R teachers by creating vast repositories of diverse learning resources and support materials.

In a further review of a study by Prather et al. (2023) on using LLMs in C&R classrooms, the findings suggest that 60% of teachers use ChatGPT in these settings. One key application involves generating code examples for learners as starting points for modification and analysis. These examples have a dual purpose: they help teachers understand the applicability of topics and common coding patterns and streamline the process of creating engaging programming activities for learners to practice their coding skills. This technique allowed teachers to analyse efficiently the relevance of topics to their C&R curriculum, identify common coding patterns, and provide opportunities for learners to improve their coding abilities. To optimise the benefits of GenAI for C&R teachers, it is essential to promote collaboration through PLCs.

Teacher preparation

Research question 2

- What are GenAI's potential implications for teacher preparation and support in C&R education?

The findings revealed that teacher training programs for C&R often face challenges because of geographically dispersed locations. The lack of training options in the areas where C&R teachers teach contributed to their sense of isolation (Ni et al., 2023). The isolation of C&R teachers highlights the necessity of providing training that encourages teacher network-building and collaboration. The concept of a PLC emphasises a potential intervention during which teachers could collaborate to improve each other's learning. With the prevalence of digital technologies, such as smartphones, C&R teachers could transcend their geographical limitations by participating in opportunities to join digital PLCs with individuals with similar educational interests (Department of Basic Education, 2018). Participants in these PLCs examine lessons, data, outcomes, and strategies to improve their teaching as part of a continuous improvement cycle. This method of inquiry not only improves learner achievement but also improves teacher satisfaction (Ogegbo & Ramnarain, 2022). Effective PLCs promote enhanced teacher self-efficacy and teamwork, minimising teacher isolation (Ni et al., 2023). To address the issues faced by C&R teachers, building PLCs with GenAI could represent an essential step in advancing C&R education in grades R–9.

The PLCs may operate at various levels and can vary significantly in the domain of teaching C&R with each programming paradigm. Examples include digital PLCs such as social media, blogs, and social website groups that can facilitate discussions dedicated to sharing practices and resources and building peer support networks among C&R teachers from different schools (Department of Basic Education, 2018). While the current digital platforms provide a foundation for discussions, GenAI may enhance these digital PLCs. Through real-time analysis of discussion data (Chiu, 2023), GenAI tools draw attention to areas in which teachers require support and provide suggestions and feedback on their teaching (Bringula, 2024). Given the significance of offering teacher development opportunities tailored to curriculum requirements (Hadad et al., 2021), GenAI, for instance, can analyse C&R lesson

plans and materials that are shared in the PLC and provide input on how well they meet curriculum requirements for block-based and text-based programming paradigms and how effective they are. These GenAI features can transform digital PLCs into dynamic, supportive environments for professional development and collaboration among C&R teachers. While this section highlighted the immense potential of introducing technologies like GenAI for C&R, its potential challenges and tensions must be considered for its adaptation.

Navigating potential perils of GenAI integration

Although GenAI presents an avenue for C&R teacher preparation, concerns about its potential impede several challenges. The primary challenge is equity. The implications drawn from the reviewed studies are that the efficiency of GenAI tools depends on the availability of technology and reliable internet connections (Becker et al., 2023; Prather et al., 2023). This has the potential to exacerbate existing inequities between well-resourced and under-resourced schools. Elsewhere, it has been found that teachers in under-resourced schools could find it difficult to use GenAI tools, hindering their capacity to benefit from tailored learning experiences and immediate feedback (Yan et al., 2024).

The uptake of GenAI tools is contingent upon the willingness of teachers to include them in their C&R teaching and learning process. Although South Africa's Department of Basic Education endorses policies such as the Professional Development Framework Digital Learning that necessitates teachers to integrate digital tools and resources in their teaching and learning practices (Department of Basic Education, 2018), some teachers may view GenAI as a challenge to their pedagogical expertise or as a replacement for their role in the classroom. Findings suggest that teachers concerned about the effects of GenAI may change their teaching methods in ways that reduce the efficacy of their lessons (Prather et al., 2023). For instance, they could emphasise assigning students to replicate predefined code that restricts their ability to think critically and learn, rather than on tasks like programming exercises that call for these skills (Hadad et al., 2021). Alternatively, they might change the subject material to exclude topics that call for coding knowledge, making learners less ready for subsequent grades that require such coding expertise (Prather et al., 2023). Mitigating these potential tensions necessitates transparent communication regarding the use of GenAI tools to modify methods of instruction to improve the learning experience while adhering to the C&R subject requirements (Sun et al., 2024).

GenAI is considered a technological tool so, to use it for C&R education, most teachers who are unfamiliar with it require assistance (Chiu, 2023). Without assistance, teachers may inadvertently create underspecified exercises, inaccurate reference answers, or insufficient or erroneous test cases when they employ GenAI to help create C&R learning resources (Prather et al., 2023). Thus, it is recommended from the reviewed studies that training in using GenAI becomes a necessary component of professional development programs so that teachers can use the tool's potential to improve their teaching (Chiu, 2023; Ni et al., 2023). An instance deduced from this is research conducted by Wieser et al. (2023), who assessed ChatGPT's programming tutoring capabilities and discovered that its general recommendations were

frequently generic without a clear learning objective. This is where the quality assurance of GenAI recommendations comes into play.

Findings revealed that rigorous quality assurance processes must be implemented to ensure the accuracy and effectiveness of material generated by GenAI. Although GPT-4 and other advanced LLMs have much to offer, they still have some limitations similar to previous iterations (Sun et al., 2024). Specifically, they can produce inaccurate information, potentially biased content, and induce logical errors (Chiu, 2023). Thus, caution must be exercised, and ethical considerations must be at the forefront while one is using LLM outputs, particularly in high-stakes settings (United Nations Educational, Scientific and Cultural Organization 2023, 2023), including classrooms where C&R learning occurs. Depending on the particular use case, precautions like peer review or additional information may be required to ensure the accuracy and dependability of the data generated by the language model (Chiu, 2023; United Nations Educational, Scientific and Cultural Organization, 2023). These exercises must be created using a performance metric suitable for the type of tasks that teachers ask GenAI to perform (United Nations Educational, Scientific and Cultural Organization 2023). The portion of the generated code that is directly executable (i.e., if the generated code can be run in a programming language and pass the unit tests) could be used as the code generation data (Denny et al., 2024; United Nations Educational, Scientific and Cultural Organization, 2023). Doing this may take numerous prompt recurrences until the intended result is obtained.

From these findings, it is important to note that some errors in the error detection system of GenAI tools could affect teachers' interest and capacity to use the feedback offered. Submitting a learning objective leads to better recommendations for teacher practice, including step-by-step responses and solution approaches (Wieser et al., 2023). The use of GenAI in conjunction with skills endorsed for C&R should be prioritised in teacher development programmes to reduce this risk (Chiu, 2023). Encouraging C&R teachers to analyse GenAI recommendations, adjust them based on the unique needs of learners, and reflect on their methods of instruction to ensure GenAI is used to complement teacher creativity and critical thinking.

Another concern with incorporating GenAI into C&R teaching methods is an over-reliance on automated assistance with tasks, including lesson planning, feedback generation, and learning resource development. C&R education supports the development of problem-solving skills, computational thinking, critical thinking, and creativity (Moraiti et al., 2022). Teachers may become accustomed quickly to auto-suggested solutions, especially when using GenAI-powered tools like LLMs, whose coding design can complement various programming paradigms (Denny et al., 2024). An overreliance on LLMs could lead to a lack of critical reading of problem statements and a reduced awareness of the computational steps necessary for problem-solving (Becker et al., 2023). The process of teaching and learning to code has become challenging and requires cognitive work to be able to retain language syntax (Denny et al., 2024), think computationally (Moraiti et al., 2022), and understand C&R PCK knowledge (Ni et al., 2023). Therefore, overreliance on GenAI tools might prevent these capabilities from being developed.

Limitations of the study

We understand that this scoping review is based on a limited number of papers, that may not represent the scope of available research on GenAI's role in teacher preparation for C&R instruction. The inclusion criteria were based on studies published in the selected timeframe (2022–May 2024) and in English, which may have omitted significant research in other languages given inadequate translation resources. The variation in the calibre and rigour of the included studies further impacts the reliability of the findings. While GenAI's ethical and privacy concerns are acknowledged, they have not been thoroughly investigated and require further research.

Conclusion

In this scoping review, we aimed to provide insight into how GenAI can address teachers' challenges in acquiring the necessary pedagogical skills and programming knowledge for effective C&R instruction and its potential implications for teacher preparation and support in South African schools. The review identified GenAI tools, leveraging LLMs, provide personalised learning routes to enhance teacher proficiency in block-based and text-based programming paradigms through personalised instruction and real-time feedback. These tools can assess teachers' understanding of computational concepts, create learning resources and offer step-by-step solutions. Furthermore, the review highlighted the potential of GenAI tools to assist PLC members. Through digital PLCs, GenAI can facilitate discussions, provide feedback on lesson plans, and suggest improvements, thus promoting continuous professional development. However, managing this potential transformation requires addressing perils and tensions.

In the review, we identified perils regarding equity and a lack of technology fluency among teachers, as well as a demand for communication and professional development support. We also noted ethical concerns such as the accuracy and dependability of GenAI-generated content and the need for rigorous quality assurance processes. To further reduce the risk of an over-reliance on automated solutions, it is essential to help teachers develop their capacity for critical thinking and their pedagogical knowledge in tandem with using GenAI. By blending AI-generated resources with teacher-created content, GenAI can serve as a tool to enhance, not replace, teacher creativity.

Recognising that GenAI implementation and C&R teacher training are still in the earliest phases is essential. Further research must be conducted to assess their long-term effectiveness in improving teacher abilities and learner outcomes. Furthermore, research on developing ethical practices for responsible GenAI integration in the specific context of C&R education, including in special needs contexts (Bano et al., 2023), is needed. This would make it possible to create strategies promoting policies, such as the United Nations Educational, Scientific and Cultural Organization's (2023) advocacy for ethical GenAI integration through teacher training efforts and fair access to technology.

Declaration of interest statement

The authors declare no conflicts of interest.

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