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A conceptual participatory framework for integrating coding and robotics in early childhood education

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ABSTRACT

Coding and robotics is an essential competency in the twenty-first century. In South Africa, coding and robotics is a mandatory subject in the Foundation Phase. However, successful integration into these early learning environments requires more than curricular inclusion, it also demands responsive support for educators navigating complex contextual realities. This study presents a framework, derived from a literature synthesis and participatory action research; to guide coding and robotics in early childhood education through playful learning using thematic data analysis. Co-constructed with ten Grade R educators and one external participant over a nine-month period in the Tshwane South district, data generation involved semi-structured interviews, observations, focus groups and a systematising expert interview. The framework, synthesised as NELO, comprises four interrelated components: Needs, External factors, the Learning process, and Outcomes. Findings indicate that educators require professional development, resources and collaboration initiatives to implement coding and robotics. The learning process of coding and robotics is progressive and embeds play-based, developmentally appropriate pedagogies while foregrounding localised and context-sensitive strategies. By bridging theoretical knowledge with practical realities, NELO offers a sustainable and scalable approach for the integration of coding and robotics in diverse early childhood education settings.

KEYWORDS

Coding and robotics; early childhood education; educator support; participatory action research; playful learning

SUSTAINABLE DEVELOPMENT GOALS

SDG 4: Quality education

Introduction

As technology continues to permeate nearly every aspect of modern life, coding and robotics (CR) has emerged as an essential literacy for the digital age (Abanoz and Kalelioğlu 2025; Lee 2019; Metin 2020; Papadakis 2021; Yang, Ng, and Gao 2022; Zurnaci and Turan 2024). No longer confined to specialised fields, CR is recognised as a competency necessary for active participation in twenty-first-century society. In response to this imperative, the South African Department of Basic Education (DBE 2024) has introduced CR as a compulsory subject within the national curriculum for the Foundation

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Phase from 2024. The curriculum aims to foster children's twenty-first-century skills from the earliest stages of formal education.

However, the integration of CR into early childhood education (ECE) presents challenges. These are especially pronounced in under-resourced South African contexts, where many early learning environments (ELEs) lack the infrastructure, pedagogy and professional development (PD) needed for delivery (Bers, González-González, and Armas-Torres 2019). Educators, particularly those working in low-income communities, frequently report feeling ill-equipped to meet the curricular and technological demands of CR education. These challenges underscore the urgent need for a research-informed and contextually responsive model to support CR implementation in ECE settings.

In response, this study developed a conceptual participatory framework that addresses the how, what, and why of implementing CR in ECE. The development of such a model necessitates a synthesis of ideas. First, it requires understanding how young children learn, drawing on constructivist, experiential and sociocultural theories (Bruner and Kenney 1965; Kolb, Boyatzis, and Mainemelis 2000; Malaguzzi 1998; Piaget 1951; Vygotsky 1967; Yilmaz 2008). Second, implementation must be understood as a staged process consisting of different implementation phases (Botma et al. 2015; Donovan and Darcy 2011). Third, the model must reflect collaborative and reflective input from a range of stakeholders, aligned with the principles of participatory design (Jimoyiannis 2012; Scher et al. 2023). Lastly, attention must be paid to pedagogical design (Biggs 1996; Koehler and Mishra 2009) and to the specific CR concepts that children are expected to acquire (DBE 2024; Lee 2019; Metin 2020; Papadakis 2021; Yang, Ng, and Gao 2022; Zurnaci and Turan 2024).

Guided by sociocultural learning and implementation perspectives, educator needs, external factors and participatory learning processes are treated as theory-derived determinants whose alignment yields practice-level outcomes. Accordingly, we ask: *Which theory-based components are essential for integrating coding and robotics in early childhood education, and how do these components inform the participatory co-construction of an implementation framework (NELO)?*

Educator needs in implementing coding and robotics

The successful integration of CR in ECE depends on recognising and responding to educator needs. As central agents of curriculum delivery, educators translate policy into practice. However, they often face barriers in under-resourced contexts where CR is still an emerging field. In the South African context, such challenges are frequently compounded by infrastructural disparities and large class sizes, which may hinder the adoption of new, technology-rich pedagogies.

Central to educator preparedness is the provision of initial educator education and PD. Educators need both content and pedagogical knowledge, and an understanding of CR's developmental relevance and alignment with broader educational goals, including twenty-first-century skills and digital literacy (Bers, González-González, and Armas-Torres 2019; Koehler and Mishra 2009). Research suggests that educators who understand the purpose of CR and feel confident in its use are more likely to integrate it meaningfully and consistently into their practice (Vidal-Hall, Flewitt, and Wyse 2020; Yıldırım 2021). As such, PD should prioritise not only the acquisition of skills but also the cultivation of positive educator dispositions toward CR.

This highlights the importance of supporting educators' pedagogical transformation. Traditional models of teaching, where the educator assumes the role of information provider, are poorly suited to CR environments that require exploratory learning and collaborative problem-solving. Instead, educators are encouraged to adopt constructivist, learner-centred approaches that view children as capable, curious and active participants in their own learning (Papadakis et al. 2021). Shifting to inquiry-based teaching requires rethinking the educator's role, supported by PD, mentoring and collaboration.

In addition, specific beliefs predict CR uptake in ECE – most notably educators' CR self-efficacy, perceived age-appropriateness of CR activities and perceived value for early learning (Papadakis et al. 2021; Saxena and Chiu 2022). Educators who report low CR self-efficacy or view CR as developmentally misaligned tend to delay integration; conversely, those who recognise unplugged CR as a vehicle for creativity, language, and problem-solving embed it in daily routines (Ertmer and Ottenbreit-Leftwich 2010; Papadakis et al. 2021). Accordingly, PD should aim to strengthen both competencies and confidence while addressing common misconceptions and encouraging ownership of new pedagogical approaches.

Material and infrastructural support are also essential. Educators need access to functional equipment, suitable learning materials and adaptable lesson plans to implement CR meaningfully. Financial constraints remain a key barrier, particularly where institutions cannot afford programmable toys, tablets, or reliable internet connectivity. Nevertheless, emerging research demonstrates that effective CR learning can occur through low-cost strategies, including the use of recyclable materials and unplugged activities that introduce computational thinking without digital tools (Bers 2020; Sentance and Csizmadia 2017). These approaches not only reduce reliance on expensive technologies but also foster creativity and promote sustainable teaching practices.

CR implementation requires more than skills or resources: it calls for a mindset of inquiry, adaptability, and lifelong learning. This mindset is best nurtured in professional learning communities where educators are encouraged to share experiences, co-construct knowledge, and reflect critically on their practice (Avalos 2011). Such collaborative spaces allow educators to troubleshoot challenges, celebrate progress and iteratively refine their approach to CR integration, thereby establishing a stronger foundation for long-term success. In this paper, educator needs explicitly include PD and guidance, as well as time and resources.

This broader perspective on educator development transitions directly into the next component of the NELO-model: the external conditions that influence whether educators can implement CR effectively within the ELE.

Contextual constraints influencing the successful implementation of coding and robotics

While educator knowledge, skills and beliefs are central to the adoption of CR in ECE, successful implementation is equally shaped by broader contextual and systemic factors. In South Africa, infrastructure, language barriers, and community involvement significantly affect CR feasibility. Understanding these influences is essential for creating equitable and supportive environments in which CR can thrive.

Overcrowding, especially in rural and township settings, is a significant barrier. Classrooms that exceed the recommended learner-to-educator ratio of 40–1 (DBE 2014) pose an obstacle to implementing pedagogies that rely on small-group work, guided exploration and individualised attention. These conditions make it difficult for educators to implement CR in ways that support inquiry-based learning.

Language of learning and teaching (LoLT) is another key factor. Although the CR curriculum is delivered in English, many children speak a different home language. This misalignment can create barriers to understanding, especially when children are introduced to abstract CR concepts such as sequencing or algorithms.

Parental and caregiver engagement also plays a critical role in the success of CR implementation. Recent studies confirm parents shape children's computational thinking through encouragement, co-activity and access to resources (Cai and Wong 2023; Relkin et al. 2020; Zviel-Girshin, Kukliansky, and Rosenberg 2024). McWayne and Melzi (2023) similarly highlight the importance of constructing learning experiences that embrace existing knowledge and cultural communities.

In the South African context, where families are diverse and caregiving often extends beyond the nuclear household, engagement strategies must be flexible and inclusive. Schools and policymakers must take active steps to foster culturally sustaining relationships that support children's CR experiences both in and out of the ELE.

Taken together, these external factors reinforce that CR implementation in ECE is not only dependent on educator preparedness or curriculum design. It is also shaped by broader systemic conditions that either support or inhibit innovation in practice. This understanding leads to the next consideration in the NELO-model: how CR is delivered through the learning process itself.

The playful learning process of early coding and robotics

Understanding how young children learn is central to designing effective CR experiences in ECE. At this developmental stage, children construct knowledge not through passive absorption but through active engagement with their environment. Playful learning, widely acknowledged as a developmentally appropriate pedagogy where child-led exploration is enriched by educator guidance (Zosh et al. 2022), provides a natural foundation for CR integration. Theoretical contributions from educational thinkers such as Froebel, Steiner, Montessori, and Vygotsky converge on the idea that play is a powerful cognitive and social tool for learning (Bruce 2012; Vygotsky 1967). Through play, children explore ideas and make sense of complex concepts. These processes align directly with the aims of CR education (DBE 2024).

In this study, constructivism is specified for CR as children's active construction of procedural knowledge through hands-on, play-based tasks (e.g. sequencing, conditional choices, debugging) enacted with peers and educators. The apprenticeship dimension is realised as guided participation: educators model CR vocabulary and problem-solving moves, scaffold within the ZPD, and progressively release responsibility as children move along a kinaesthetic-to-abstract progression. Framing constructivism this way locates the theory in CR-specific mechanisms rather than as a general pedagogical claim.

Empirical research reinforces this view, demonstrating that playful learning supports deeper learning than traditional direct instruction, particularly when educators balance child-initiated free play with adult-guided learning (Pyle and Danniels 2017). In CR settings, this dual structure is especially effective. Educator-scaffolded tasks may introduce sequencing or pattern recognition, while unstructured play allows children to tinker, iterate and build confidence in their problem-solving abilities. CR activities such as coding, coding puzzles and algorithm games promote curiosity and trial-and-error learning, reflecting playful learning's emphasis on exploration, creativity and agency (Bers 2020). These experiences also foster collaboration, as children often work in pairs or small groups to complete tasks, thereby developing essential social and communication skills.

Effective CR pedagogy must move beyond general play and consider progression. A concrete-to-abstract progression (kinaesthetic-concrete-representational-abstract [KCRA]) provides a pathway that mirrors early cognitive development, beginning with physical engagement and progressing toward symbolic forms (Bruner and Kenney 1965; Sarama and Clements 2016). In CR contexts, kinaesthetic learning might involve children using their bodies to act out sequences or follow directional paths. The concrete stage builds on this kinaesthetic foundation using manipulatives. These physical objects allow children to simulate algorithmic processes through exploration and arrangement. They may include toy figurines, grid tiles or recycled materials configured to represent input and output relationships (Boggan, Harper, and Whitmire 2010). According to Clements and Sarama (2012), manipulatives are most effective when integrated into meaningful learning contexts and accompanied by guided reflection. This becomes especially relevant at the representational stage, where drawings, diagrams and icons begin to replace physical actions as tools for understanding.

At the abstract level, children use symbols like arrows, sequences, or programming blocks to encode logic. Even at this stage, understanding remains grounded in earlier kinaesthetic and concrete experiences. As Wolf (2017) suggests, young children benefit from opportunities to move fluidly between stages, depending on the task and their individual learning preferences. This concrete-to-abstract approach supports differentiated instruction by recognising that cognitive development is not linear or uniform but dynamic and responsive to multiple influences.

What makes both playful learning and concrete-to-abstract progression effective is not solely the materials or the order of activities, but the role of the adult in mediating the learning experience. Vygotsky's sociocultural theory underscores the importance of scaffolding within the zone of proximal development (ZPD), where adults or more capable peers assist children in completing tasks beyond their current independent ability (Vygotsky 1967). In CR education, this may involve prompting children with questions, modelling the debugging process or co-constructing algorithms using familiar language.

These pedagogical approaches suggest that the learning process in CR is most effective when rooted in active, experiential and socially mediated engagement. This highlights the need for flexible strategies that meet young children's developmental needs. With this foundation in place, it is now important to consider the outcomes that such approaches can achieve, not only for children but also for educators and the broader education system.

Outcomes of coding and robotics implementation in early childhood education

When thoughtfully implemented, CR education in the early years offers multifaceted benefits that extend beyond digital literacy to support children's holistic development.

Research shows early exposure to CR fosters competencies like problem-solving, algorithmic thinking, creativity and collaboration (Bers 2020; Papadakis et al. 2021). Such competencies are not developed in isolation but are cultivated through iterative exploration, reflection and social interaction, embedded within play-based pedagogies.

CR activities also present opportunities for children to build confidence and resilience. As children engage in debugging, sequencing or constructing logical solutions, they learn to embrace mistakes as part of the learning process. This disposition is essential for navigating complex and unpredictable challenges in the modern world (Bers 2020; Resnick 2017). Furthermore, CR tasks often require collaboration, where children are expected to listen, negotiate and share control to achieve a common goal. These interactions support cognitive and socio-emotional development, reinforcing CR as a platform for holistic learning.

The outcomes of CR implementation are equally significant for educators. Engaging with CR can catalyse professional growth and pedagogical transformation. Many educators report increased confidence in using technology and a shift in their educational philosophy from directive instruction to facilitative, inquiry-based learning (Kalelioglu, Gülbahar, and Kukul 2016). This evolution supports a reconceptualisation of the educator's role as a guide who scaffolds learning rather than dispensing information. As educators explore CR strategies, reflect on child responses, and adapt activities to diverse needs, they build capacity in both technological and pedagogical domains. In this way, PD becomes both a condition for and a result of sustained CR engagement.

Beyond immediate ELE outcomes, CR education supports broader policy goals, aligning with SDG 4 by promoting inclusive, equitable education and advancing digital inclusion in under-resourced communities (UNESCO 2015). By equipping children with future-ready skills and advancing digital inclusion from the earliest stages, CR implementation can help reduce entrenched educational disparities, particularly in under-resourced communities (UNESCO 2015). Additionally, embedding CR into foundational education helps build a society in which children are not only consumers of technology but also creators and critical thinkers with the potential to shape the digital future.

Sustainability is another important consideration. CR promotes transferable skills beyond the ELE, including metacognition, perseverance and design thinking. These skills support future learning in science, technology, engineering and mathematics, and strengthen adaptability in a rapidly evolving world (Grover and Pea 2013). Moreover, when implemented through accessible and locally appropriate methods, such as unplugged activities and recyclable materials, CR becomes a cost-effective and contextually relevant strategy for innovation in early childhood education.

Taken together, these outcomes demonstrate the transformative potential of CR education when it is aligned with learner needs, educator capacity, and contextual realities. They also affirm the need for supportive frameworks that can guide CR implementation in meaningful, sustainable, and equitable ways.

Methodology

Research design

This study employed a PAR design to co-develop a conceptual participatory framework for integrating CR in ECE. Teaching practices are often structured through top-down dissemination of predetermined content, with limited responsiveness to the realities of specific learning environments. PAR challenges these traditional structures by privileging the voices of educators and enabling democratic participation in iterative cycles of reflection, action, and evaluation (Lawson 2015; Schneider 2012). In this study, educators were immersed as co-researchers, articulating their own ideas, practices and needs within their lived contexts. The resulting model was grounded in relational empowerment and responsive engagement (Lawson 2015). The study took place over a period of nine months, with data gathered during ten non-consecutive weeks. Each research cycle contributed to the gradual development and refinement of NELO and allowed for sustained reflection and collaborative dialogue.

Ethical considerations

Ethical clearance for the study was granted by the Faculty of Education Research Ethics Review Committee at the University of Pretoria (clearance number EDU166/21) and the Gauteng Department of Education. Informed consent was obtained from all participants, and informed assent was obtained from the children who functioned as secondary participants. Children's assent was obtained through age-appropriate verbal explanations. The study adhered to the ethical principles of voluntary participation, confidentiality and anonymity.

Participants and sampling

Purposive sampling was used to recruit ten Grade R educators from five ELEs located in the Tshwane South district of Gauteng. Three of the ELEs were preschools and two were early childhood sites linked to primary schools. None of the participating educators had prior exposure to CR. This sampling strategy was appropriate for qualitative research, as it allowed for the selection of participants with relevant experience and contextual knowledge (Maree and Pietersen 2016). In addition, one expert participant with specialist experience in early years educational technology was included to support interpretation and reflection. The expert participant held no formal authority over the educators and acted in a non-directive, collaborative role. Their contributions were limited to co-facilitated reflections and interpretive discussions, with all findings validated by the educator participants to minimise bias and uphold the participatory integrity of the study.

Research context

The selected ELEs were situated in urban areas but varied in terms of infrastructural quality, class size and available resources. This diversity contributed to a rich dataset and allowed the model to be developed in relation to both structural barriers and site-specific realities. All ten educators developed and implemented CR-related activities in their ELEs, offering first-hand insight into contextualised integration practices.

Data generation methods

The study gathered a multi-voiced corpus of qualitative methods, including semi-structured interviews, ELE observations, focus groups, and a systematising expert interview.

These techniques captured both the processes and outcomes associated with educator-led CR integration. Data generation commenced with introductory briefings to orient participants from each school (five sessions lasting 30–45 min each). This was followed by individual, semi-structured interviews with each educator to surface starting points and contextual constraints (ten interviews lasting approximately 30–45 min each). Furthermore, virtual focus groups were held on Google Meet where educators co-planned, trialled and reflected on activities (three meetings across the project, approximately two hours each). Guided ELE observations also took place twice in each ELE focusing on how unplugged CR tasks were set up, adapted and negotiated with young children (nine educators per round, lasting between 30–45 min per observation). Across these cycles and methods, triangulation was prioritised understanding and analysing what educators said in interviews, what they enacted in classrooms and what was co-constructed in collaborative reflection. An expert interview was then conducted with a specialist in educational technology to validate the preliminary NELO-framework. The interview lasted 90 min and included seven open-ended questions. The expert's responses were evaluated using criteria developed by Tastle, Wierman, and Rex Dumdum (2005) to assess educational frameworks based on clarity, comprehensiveness, adaptability and trustworthiness.

Data analysis

Qualitative thematic analysis was conducted manually, following the six phases of Braun and Clarke (2006, 2019). Data was read closely to gain an understanding of the corpus and analytic notes were kept noting recurrent codes. Codes were then organised into themes which were checked against the full dataset, refined and adjusted. Each theme was subsequently named and described in clear terms and linked back to the aims and framework.

A systematising expert interview was used to appraise clarity, comprehensiveness, adaptability and trustworthiness. Following this, a second manual analysis was undertaken. Credibility and trustworthiness were supported through triangulation across methods and sites, brief member-oriented reflections in online meetings to check interpretations and keeping an audit trail.

Conceptual participatory framework development: process

NELO is embedded in a participatory, context-responsive process. It did not emerge from external theory alone, but rather through collaborative dialogue and action with ten Grade R educators over three iterative research cycles. The educators reflected on their needs, constraints pedagogical approaches, and the observed impact of CR integration. Table 1 below offers a synthesis of how NELO's four components were informed by empirical data using pseudonyms of participants' responses.

Across the PAR cycles, educator feedback not only refined activity design but also reshaped the sequencing of NELO's components, with both consensus and dissenting voices recorded and debated before integration. At the foundation, NELO recognises that educators cannot meaningfully implement CR unless their professional and pedagogical needs are addressed. The data revealed a widespread sense of uncertainty about how

Table 1. Synthesis of participants' insights informing the NELO-model development.

Model component	Empirical focus	Verbatim insights
Educator needs	Professional development and guidance, as well as time and resources	'*I am still very unsure … I would definitely need training in using coding and robotics …* ' (T3)
External factors	ELE realities: overcrowding, limited infrastructure, economic challenges	'*Large classes would also obviously need careful class management … Lack of finances due to the current economic times will also pose a challenge*' (T10)
Learning process	Use of kinaesthetic and concrete strategies; intuitive use of child development theory	'*We always start concrete …* ' (T9)
Outcomes	Learner enthusiasm, deeper thinking, educator reflection on future preparedness	'*I could see how the* [children] *think in different ways.* "(T1)" … *we need to equip them with it* [the skills related to CR].' (T8)

to begin. Educators spoke not just of lacking technical knowledge, but also of a deeper absence such as a lack of orientation, structure and purpose. As T3 shared, '*I am still very unsure because I* [do not] *quite know how to apply it … I would definitely need training in using coding and robotics as well as worked-out lesson plans*. This underscores that educator needs are both technical, such as training in tools and platforms, and pedagogical to understand developmentally appropriate strategies for young children. Additionally, educators expressed a need for rational clarity regarding a deeper understanding of why CR matters in ECE. This reflects a critical insight: that implementation is not merely procedural, but also conceptual. Unless educators feel invested in the logic and values behind CR, uptake is unlikely to be meaningful or sustained.

The second layer reflects the systemic conditions that enable or constrain practice. Participants raised concerns about large class sizes, limited access to learning materials, and financial constraints; all of which directly influenced their ability to apply CR concepts. For example, T10 noted the importance of managing large ELEs and the possible challenge that a lack of funding might pose. Similarly, T3 questioned how CR could realistically be introduced in a typical class of 30 children. These insights reveal that educators were not resistant to innovation but constrained by everyday ELE conditions. Rather than abstracting implementation challenges, participants located them within material and systemic realities. NELO recognises that such conditions must be considered when introducing CR into ELEs.

The third component centres on how learning occurs in CR contexts. Educators overwhelmingly drew on kinaesthetic and concrete strategies, often without labelling them as such. For example, T9 noted, '*We always start concrete, using objects or sensory experiences to introduce what we want to teach them*'. These tactile strategies support progression to abstract reasoning aligned with concrete-to-abstract progression. Furthermore, the data revealed that educators frequently applied developmental learning theories in intuitive, embedded ways. Though they may not have explicitly cited specific theories, educators scaffolded activities, leveraged peer interaction and designed play-based challenges that aligned with these traditions. T5 remarked, '*I do not implement it* [theories or practices] *intentionally, but I am sure that I use many of them without even realising* [it]'. This insight positions NELO as responsive to educator wisdom, recognising that pedagogy is often grounded in practice-led knowledge rather than formal theoretical articulation. By naming and validating these practices, the model strengthens the bridge between informal expertise and structured guidance.

Lastly, the NELO-model incorporates outcomes that extend beyond basic technological competence. Educators consistently reported that children engaged more deeply with CR activities, often displaying elevated levels of focus, collaboration and creativity. T1 commented, '*I could see how the* [children] *think in different ways*', while T8 remarked, '*I now realise that coding and robotics are such a big part of our children's future, and we need to equip them with it*'. These reflections suggest that CR is not simply a content area, but a vehicle for broader developmental goals such as cultivating cognitive flexibility, resilience and future-oriented skills. Moreover, educators themselves experienced moments of professional growth. As they designed and reflected on CR activities, they began to see themselves not only as curriculum implementers, but as co-creators of knowledge.

Interpretation

The integration of CR in ECE requires a nuanced, context-responsive approach that acknowledges the realities of both children and educators. In response to this need, the NELO conceptual participatory framework, seen in Figure 1, has emerged from the literature synthesis and the participatory action research (PAR) cycles. Its originality lies in its participatory design and explicit emphasis on educator agency as the driver of implementation. NELO is thus a framework, rooted in real-world ELEs yet flexible enough to evolve across settings, children, and professional communities.

Rather than offering a fixed model, NELO provides a dynamic and adaptable structure through which educators, researchers and policymakers can conceptualise and support CR integration in varied ELEs. To support a developmental view of implementation, NELO is structured as a three-phase process: before, during and after implementation. The first phase includes educator needs and external factors, which shape the conditions under which implementation becomes possible. The second phase, learning process, focuses on how CR is facilitated within the ELE through pedagogical practice. The third phase, outcomes, captures both learner growth and educator transformation following implementation. This phased structure emphasises that CR integration is not a one-time intervention but a dynamic, ongoing journey responsive to evolving needs, contexts and reflections. The following section outlines the empirically derived

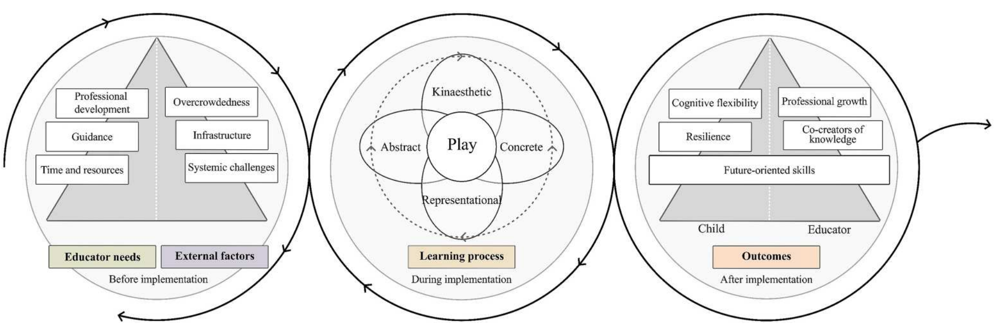

Figure 1. Conceptual participatory framework to integrate coding and robotics in early childhood education.

components of NELO, drawing on both the study's findings and overall implementation process.

Component 1: educator needs

The first component recognises the central role of educators in determining the success of CR initiatives. Participants emphasised PD and clear pedagogical guidance, with one noting a need for '*a manual or textbook with clear aims and objectives … to plan my lessons accordingly*', which highlights a gap in accessible pedagogical resources. These findings align with broader research indicating that educator confidence in CR is closely tied to opportunities for reflective learning, peer collaboration, and guided experimentation (Bers 2020; Falloon 2020). Participants also expressed a desire not only to adopt CR but to adapt it to their own contexts, reinforcing NELO's emphasis on flexible, contextually responsive implementation and positioning educators as co-designers of curriculum rather than passive implementers. For this reason, professional learning should build both subject knowledge and the ability to integrate CR meaningfully across the curriculum using developmentally appropriate methods. In addition to PD, educators require access to resources that are effective and adaptable to low-resource contexts, including guidance on how to use recyclable materials for unplugged CR activities where robotic kits or digital devices are unavailable. Understanding educator needs is therefore foundational, as it sets the conditions for sustainable implementation.

Component 2: external factors

The NELO-model acknowledges that broader systemic and environmental conditions significantly influence the feasibility of CR integration. Educators identified a range of external constraints, including overcrowded ELEs, limited access to materials and funding challenges. As one participant highlighted that '*a lack of finances …* ' ' *… will also pose a challenge*' which echoes wider national concerns regarding under-resourced ECE settings (DBE 2024). Language diversity further shapes implementation: in all sites, the LoLT differed from many children's home languages which may create barriers to understanding abstract CR concepts. These are not peripheral issues but structural realities that directly affect both educational access and pedagogical delivery. At the same time, parental and community engagement emerged as an enabling factor. When families are engaged as partners in learning, CR activities extend into the home, reinforcing concepts beyond the ELE and supporting deeper learner engagement.

Component 3: learning process

Educators' intuitive reliance on playful learning provided supportive ground for the integration of CR. The data revealed the use of concrete-to-abstract progression, even when it was not explicitly labelled as such. One educator explained, '*we start concrete and sensory, then on 2D or paperwork and end with talking about and testing the abstract concept*'. This sequencing supports conceptual development and aligns with established best practices in ECE (Hirsh-Pasek et al. 2020). Participants also drew upon a range of pedagogical theories in organic ways. Constructs from Vygotsky's sociocultural theory, Piaget's developmental stages, and practices associated with Montessori and Reggio Emilia were present across the observed CR activities. These were not always deliberately applied but emerged naturally from educator practice. As one participant noted, '*you use what you know will work … depending on what you are trying to teach*'. This interplay between play, theory, and educator intuition reinforces NELO's emphasis on developmentally appropriate, socially meaningful, and exploratory learning experiences, while offering a structured yet flexible pathway for children to transition from physical manipulation and sensory exploration toward more abstract reasoning.

Component 4: outcomes

While developing computational thinking and coding literacy are core aims of CR education, the findings of this study point to a wider range of learner outcomes. Educators observed increased engagement, collaboration, creativity, and lateral thinking. One participant shared that CR '*speaks to the children on another level … it excites them and helps the information sink in much quicker*'. These affective and cognitive responses are especially important in the early years, where foundational dispositions toward learning are being shaped.

Educators also highlighted the contribution of CR to school readiness and long-term educational goals. One participant remarked, '*it prepares them for their future to learn new things, words, numbers and so on*'. Such outcomes align with Sustainable Development Goal 4 (SDG 4), which advocates for inclusive, equitable and quality education, positioning CR not as a luxury but as a necessary element of future-oriented teaching.

At the same time, the findings highlight that these benefits depend on ongoing support, contextual sensitivity, and meaningful educator involvement. Without such conditions, CR risks becoming a top-down initiative. The NELO-model mitigates this risk by embedding implementation within co-creation, continuous reflection, and local relevance. For children, the intended outcomes extend beyond digital literacy to include collaboration, creativity, logical reasoning, and socio-emotional development, supporting holistic growth and readiness for a technology-driven world. For educators, CR integration fosters professional growth, pedagogical innovation, and greater confidence in using technology meaningfully. By equipping young learners and educators with accessible, future-oriented skills, NELO contributes to both immediate pedagogical goals and long-term educational sustainability.

Limitations and future implications

This study drew on a small, context-specific cohort of Grade R educators from five early learning environments in one district. Findings are offered in terms of analytic transferability rather than statistical generalisation and are most applicable to settings with similar organisational conditions, staffing, language profiles, and curriculum pacing. Potential biases such as reliance on self-reports and reactivity during observations, were mitigated through triangulation.

NELO reflects patterns observed and co-constructed in this setting and rests on several assumptions: educators have time for planning and reflection, sufficient discretion to adapt classroom activities, and opportunities for iterative implementation. Where these conditions are limited, alignment between components may be harder to achieve.

Future research should investigate the applicability of NELO's components in diverse regions, school types, and resource contexts, while also establishing practical thresholds. In addition, further studies should examine the long-term impact of CR integration on children's computational thinking, problem-solving, and socio-emotional development.

In addition to this, future research should also consider specifying low burden, objective indicators for programme evaluation across the NELO components. For needs, teams of educators could pilot short coding artefact analyses with task aligned criteria, brief fidelity checklists as well as simple counts of debugging attempts and successful fixes. For external factors, researchers might adapt a site readiness inventory with a small set of observable items such as space, materials, timetable slots and device access, recorded each term. For the learning process, studies could trial structured classroom observations with ratings of peer interaction, turn taking, problem solving moves and teacher prompts. For outcomes, educators might use short performance tasks that ask learners to plan, execute and explain a sequence or a conditional, and keep portfolio traces such as photos of work with a two line educator note. These indicators are examples that can be developed and adapted to support comparison across settings and time.

Conclusion

This study explored how educators can be supported to implement CR in early childhood ELEs, leading to the development of the NELO-model. The model provides a structure for integrating CR across diverse, often under-resourced contexts and bridges conceptual and practical dimensions of digital integration. By foregrounding educator voice and grounding innovation in lived practice, NELO positions ELEs as spaces where digital fluency and playful learning coexist.

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