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Leveraging AI to Enhance Spatial Thinking, Environmental Awareness, and Culturally Responsive Teaching in Early Childhood Education: An Integrated Framework

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Onyung Sandra Effiong[1], Orji Cyrus Ebere, MCPN[2], Agu Mercy Oluchi[3], Ugwu John-Jerry Tochukwu[4]

[1]Aka Obot Idim, Uyo, Akwa Ibom State, Nigeria,

[2]Department of Computer Science Technology, Imo State Polytechnic Omuma, Nigeria,

[3]Post Graduate Student, Education Department, University of Hertfordshire, UK,

[4]Post Graduate Student, International Business Management, Wrexham University, UK

OSE [0009-0001-5853-0501](), **OCEM** [0009-0004-6389-4803]()

Correspondence: Onyung Sandra Effiong, onyungsandra6@gmail.com

Abstract

Although substantial attention has been paid to the integration of artificial intelligence (AI) in early childhood education (ECE), research continues to be fragmented across different domains. The purpose of this paper is to propose a comprehensive framework that uses AI to support spatial thinking, environmental awareness, and culturally responsive teaching in ECE for children aged 3 to 8years. This is accomplished by drawing on a thorough synthesis of recent literature. AI is positioned as a cognitive scaffold rather than a replacement for human interaction in the proposed framework, which is based on the Technological Pedagogical Content Knowledge (TPACK) paradigm and Transformative Learning Theory. The paper addresses ethical considerations relating to fairness, data privacy, and developmental appropriateness, while also contributing a conceptual model and implementation strategies that require empirical validation for ECE practitioners.

Keywords: Artificial Intelligence, Early Childhood Education, Spatial Thinking, Environmental Awareness, Culturally Responsive Teaching

1. INTRODUCTION

Artificial intelligence (AI) is rapidly transforming educational environments including early childhood education [1]. AI technologies offer great prospects to improve children's learning but research so far has mostly focused on applications in isolation, researching AI for spatial reasoning, environmental education or cultural responsiveness in isolation [2], [3]. The piece-meal approach misses the interrelated nature of children's development and leaves a fundamental research gap: no comprehensive framework to harness AI to support spatial thinking, environmental consciousness, and culturally responsive pedagogy in ECE simultaneously. While AI offers significant potential for enhancing early childhood education, debates persist regarding its appropriate role, developmental appropriateness, and potential risks [21], [28].

Yu and Li [4] discovered that preservice early childhood instructors had difficulty fitting information produced by AI to the cultural context of the pupils, suggesting a gap between their technological understanding and their capacity to be culturally responsive in their work. Similarly, Rahmawati and Subhani [5] revealed that AI promotes spatial reasoning in geography instruction. However, early childhood contexts are rarely addressed in the literature. Omokhabi [6] noted the promise of AI in environmental education, but his attention was mostly on adult learners and sustainability applications. Chen and Delaney [1] emphasized the significance of equality and ethics in AI adoption, but did not address spatial or environmental factors. This study seeks to fill this gap by providing a conceptual framework and practical implementation methodologies in a unified way. The core thesis of this article is that standard artificial intelligence can be a strong instrument for developing these three essential competences in young students, especially those from marginalized backgrounds who often lack access to quality educational resources [1], [7], if it is carefully planned and ethically executed.

We build upon the prior scoping evaluations of Chen [2] and Su and Yang [3] in three important ways. First, while these assessments recognized the fragmented character of AI research in ECE, they did not provide a unified framework to remedy this fragmentation. Second, the AI-SEC Framework bridges three areas that have been investigated in isolation, namely spatial thinking, environmental awareness, and culturally sensitive instruction. Third, this study offers practical application methodologies and ethical frameworks to move theoretical concepts into practical classroom practices.

RESEARCH QUESTIONS

This study addresses the following research questions:

- **RQ1:** How can TPACK and Transformative Learning Theory be integrated to support AI-enhanced learning in early childhood education?
- **RQ2:** What specific pedagogical strategies and AI tools constitute an integrated framework that simultaneously develops spatial thinking, environmental awareness, and culturally responsive teaching?
- **RQ3:** What ethical considerations must be addressed when implementing AI in ECE settings?

2. LITERATURE REVIEW

2.1 Spatial Thinking and AI

Spatial thinking, the ability to understand and reason about spatial relationships, is crucial to STEM learning and cognitive development [5]. Studies have shown that young children's spatial reasoning capabilities can be greatly enhanced by the utilization of AI-based solutions, including intelligent tutoring systems and robotic platforms [8]. GeoAI and AI-powered geospatial analytics help learners to recognize spatial patterns, simulate geographic processes and analyze complex data sets [5], [9].

However, Li and Hsu [8] have noticed that most of the adaptive learning tools for spatial thinking have been designed for older learners and there is very little study in ECE environments. Rahmawati and Subhani [5] argued that the educational benefit of AI is not about automating instruction, but it has the potential to be a cognitive scaffold to enhance human thinking and inquiry-based learning.

Recent technology advances have opened up new options for the assessment of spatial thinking in young children using AI-enabled smart devices. "Smart blocks" are instrumented children's blocks with sensors and artificial intelligence to detect how children interact with blocks by monitoring acceleration, rotation and vibration, and how multiple blocks are handled in a group. They are developed by collaborative research between Michigan State University and Northwestern University funded by the National Science Foundation [17]. The technique allows machine learning algorithms to detect the methods of three-dimensional spatial thinking of youngsters, hence promoting STEM learning for children aged 3 to 8 years [17].

Foundational research in developmental psychology has established that spatial reasoning skills emerge early in childhood and are predictive of later STEM achievement [36], [37], underscoring the importance of targeted interventions in ECE settings.

2.2 Environmental Awareness and AI

The goal of environmental education is to create awareness on ecological problems and encourage sustainable behaviours [6]. AI applications such as earth observation, climate modelling, animal conservation technologies and smart waste management systems are playing an important role in monitoring and maintaining ecosystems [6]. Omokhabi [6] used Transformative Learning Theory to show how AI-powered personalized feedback and simulations might promote critical thinking on environmental decisions.

However, standard methods of environmental education have been criticized for their failure to effectively shift the attitudes and behaviours of individuals toward sustainability [6]. Barriers include conceptual uncertainty, time limits, restricted instructional materials, teacher attitudes toward environmental education [10]. AI could be a promising aid in countering these difficulties through personalization of learning, better access to resources and greater efficacy of education.

Recent empirical studies indicate that AI-generated educational material may be useful in fostering pro-environmental attitudes in young children. Chen's research of 120 Chinese toddlers showed that the pleasure of AI-generated tales that integrated art and science had a beneficial effect on pro-environmental behaviour, and environmental sensitivity was a key mediator of this association [19]. Children with a greater level of environmental sensitivity were more likely to internalize the environmental lessons featured in the tales, turning pleasure into meaningful real-world acts such as recycling and resource conservation [19].

While AI has promise as a tool for environmental education, experts have warned against the dangers of techno-solutionism, the idea that technology alone may provide appropriate answers to complex environmental issues without addressing the underlying social, political, and behavioural elements. This criticism implies that AI should be used to enhance, not replace, direct engagement with nature and critical reflection on patterns of consumption.

2.3 Culturally Responsive Teaching and AI

Culturally Responsive Teaching (CRT) affirms the cultural identities of students and promotes equity by drawing on the cultural knowledge and lived experiences of learners [11]. Yu and Li [4] discovered that teacher candidates were interested in AI tools but had difficulty adapting the content generated by AI to students' cultural contexts or identifying bias and distortion. The contents generated by AI often reflect specific epistemological, ethical and cultural assumptions that need to be critically assessed [4], [12].

Jackson et al. [13] suggested ways for embedding CRT in technology-rich learning settings, which include including home languages, making connections to students' communities, and supporting creative expression anchored in cultural heritage. However, Su and Yang [14] observed that these activities need explicit scaffolding and instructor preparation. Recent frameworks have stressed that improving AI literacy in young children requires purposeful pedagogical approaches in addition to technical education [24], and teacher preparedness and professional development are seen as essential for success [31]. Similarly, critical digital pedagogy academics suggest that educators must teach children to challenge the values and assumptions implicit in electronic systems [25].

2.4 The Research Gap

While existing research has investigated the potential of artificial intelligence in early childhood education (ECE) for spatial reasoning [5], environmental awareness [6], and culturally responsive teaching [4] in isolation. However, no study has yet investigated how an integrated, AI-enhanced pedagogical framework can intentionally and simultaneously foster all three domains in authentic ECE settings. A summary of the fragmented nature of the present research may be seen in Table 1.

Table 1: Summary of Current Research Fragmentation

Domain	Key Studies	ECE Focus	Integration with Other Domains
Spatial Thinking + AI	[5], [8], [9]	Limited	None
Environmental Awareness + AI	[6], [10]	Limited	None
Culturally Responsive + AI	[4], [12], [13]	Moderate	None
All Three Integrated	None	N/A	N/A

Figure 1: Current Research Distribution by Domain (2018-2025)

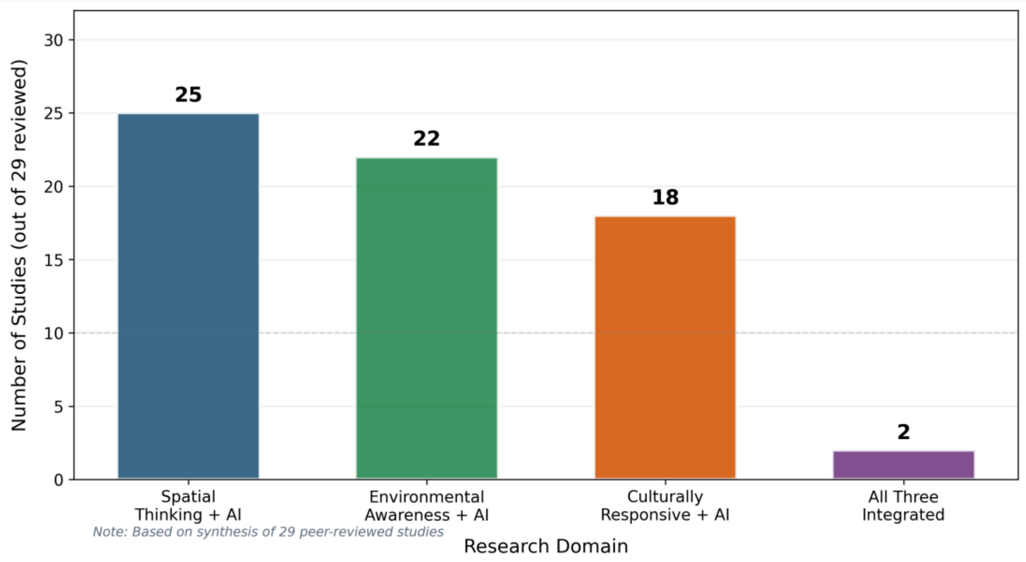

Figure 1 illustrates the fragmented research landscape on AI in early childhood education, based on a review of 29 studies from 2018 to 2025. The data shows a predominance of studies focusing on individual domains: 25 on spatial thinking, 22 on environmental awareness, and 18 on culturally responsive teaching. In contrast, only 2 studies explored connections between these domains, and none integrated all three. This highlights a critical gap addressed by the AI-SEC Framework, emphasizing the need for a unified pedagogical approach that recognizes the interrelated aspects of children's development and learning.

While the research presented gives useful perspectives on AI in the three fields, there are several limits that need to be considered. Chen's [19] research on AI-generated tales showed favourable impacts on pro-environmental views, but it was only performed on Chinese toddlers and may not be generalizable to other cultural settings. Similarly, the study on “smart blocks” [17] does not explore cultural adaptation of these tools for various classroom settings, but rather focuses on spatial reasoning results. The research also demonstrates a contradiction between prospective advantages of AI and existing issues about screen time, data privacy, and algorithmic bias [21], [28]. These constraints highlight the need for a robust structure that handles opportunities and dangers, yet is flexible enough to adapt to varied educational environments. Figure 1 was constructed through thematic categorization of the 29 reviewed studies. Each study was assigned to one or more domains based on its primary focus. Studies addressing multiple domains were counted in each applicable category for the purpose of demonstrating the fragmented nature of the literature. "Connections between domains" refers to studies that explicitly examine relationships between two or more domains.

3. THEORETICAL FRAMEWORK

This study integrated two complementary theoretical lenses, Technological Pedagogical Content Knowledge (TPACK) [15] and Transformative Learning Theory (TLT) [16].

Table 2: Theoretical-to-Practical Mapping

Theory	Key Concept	Practical Implication
TPACK	Technological Knowledge	Teachers select developmentally appropriate AI tools
TPACK	Pedagogical Knowledge	Teachers design age-appropriate learning experiences
TPACK	Content Knowledge	Teachers integrate spatial, environmental, and cultural content
TLT	Critical Reflection	Teachers guide children to question assumptions
TLT	Perspective Transformation	Teachers design experiences that challenge existing understandings
TLT	Action	Teachers support children in applying new understandings

3.1 TPACK Framework

TPACK was conceptualized by Mishra and Koehler [15] as the junction of three types of knowledge: pedagogical knowledge (PK), content knowledge (CK), and technological knowledge (TK). To investigate how preservice teachers engaged with generative AI while generating culturally responsive lesson plans, Yu and Li [4] employed TPACK. They discovered that teacher candidates frequently displayed TK without clear alignment with PK or CK. This was one of the findings of their investigation. Through the explicit incorporation of geographical and environmental content information alongside cultural content knowledge, this study expands the scope of TPACK.

The AI-SEC Framework synergistically utilizes the merging of TPACK and Transformative Learning Theory. TPACK provides a framework for instructional design that identifies what teachers need to know to be able to successfully integrate AI tools (technological knowledge), design age-appropriate learning experiences (pedagogical knowledge), and select culturally and environmentally relevant content (content knowledge). The learning result orientation, i.e., how children’s ideas about spatial connections, environmental responsibility and cultural variety may be critically investigated and altered via AI-enhanced experiences, is informed by the Transformative Learning Theory (Mezirow, 2000). Together these two approaches guarantee AI is not just added to current teaching but is deliberately intended to support deep, meaningful learning across the three domains.

This research expands the TPACK paradigm by explicitly including geographical, environmental and cultural content knowledge as independent aspects of content knowledge. The fragmentation of AI research in ECE among three distinct sectors, unlike TPACK's assumption of content knowledge as a single domain, requires explicit consideration of the interplay of these particular content areas with technical and pedagogical expertise. The expansion recognizes that for AI to be effectively integrated, instructors must concurrently address the distinctive needs of spatial thinking, ecological awareness, and cultural responsiveness as interdependent rather than discrete learning goals.

3.2 Transformative Learning Theory

Mezirow [16] described transformative learning as occurring when individuals critically question their assumptions, encounter alternative perspectives, and take action. Omokhabi [6] applied TLT to environmental education, arguing that AI-based technologies foster critical thinking and support sustainable behaviors through personalized insights and real-time data.

Although Mezirow’s Transformative Learning Theory was first designed to serve adult learners, there are several reasons why it may be used in early childhood education. For instance, transformational learning in young children takes place when they experience something new that challenges their current thinking, such as learning that their actions have an effect on the environment or that various cultural viewpoints exist from their own [6]. Although children between 3 and 8 years of age may not exhibit the same degree of abstract critical thought as adults, perspective alteration may be shown in behavioural change, vocal expression of new knowledge, and development of empathy [16]. That’s where AI technologies come in, offering real, interactive experiences that help make abstract concepts-like geographical interconnections, ecological links, and cultural diversity-tangible and accessible to young students.

Figure 2: Integrated AI-SEC Theoretical Framework

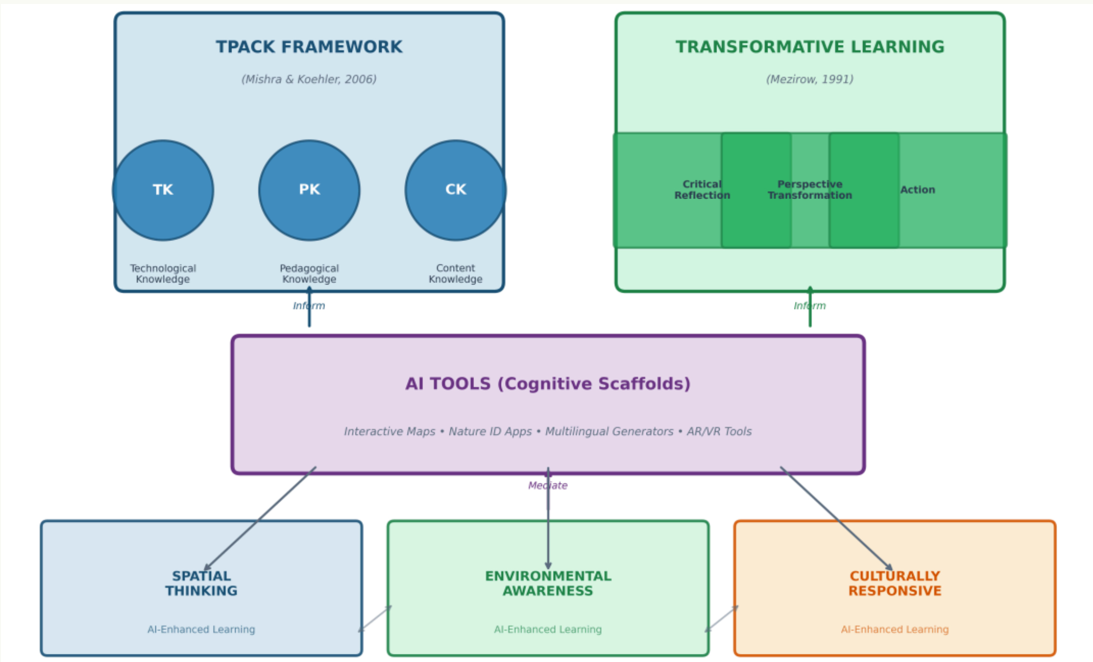

Figure 2 illustrates the conceptual model of the Integrated AI-SEC Framework, merging Technological Pedagogical Content Knowledge (TPACK) and Transformative Learning Theory (TLT) for AI integration in early childhood education. TPACK emphasizes the need for instructors to understand AI technology, pedagogical approaches, and culturally relevant content. TLT highlights critical reflection and perspective transformation as essential for meaningful learning. The framework positions AI tools as cognitive scaffolds, enhancing human interaction and instructor guidance.

The three pillars of learning-Spatial Thinking, Environmental Awareness, and Culturally Responsive Teaching-illustrate how AI supports interconnected learning objectives. This integrated approach suggests that intentional and ethical AI can democratize education, providing equitable opportunities for all children, particularly those from marginalized backgrounds. The arrows from TPACK and TLT to AI Tools suggest that these theories guide the selection and usage of AI tools. The arrows from AI Tools to the three pillars illustrate that AI is a mediating resource that supports each area. The bidirectional arrows connecting the pillars indicate that the realms are interrelated and reinforce each other.

4. METHODOLOGY

This study employed a systematic literature review and conceptual synthesis following established protocols [18]. The search was conducted in Scopus, Web of Science, ERIC, and Google Scholar using the following keyword combinations: 'artificial intelligence' OR 'AI' AND 'early childhood education' OR 'early years'; 'spatial thinking' OR 'spatial reasoning' AND 'AI'; 'environmental awareness' OR 'environmental education' AND 'AI'; and 'culturally responsive teaching' OR 'culturally relevant pedagogy' AND 'AI'.

The search was limited to peer-reviewed journal articles published between 2018 and 2025, as this period reflects the most significant growth in AI research in educational contexts. The initial database search yielded 187 records. After removing duplicates (n=42), screening titles and abstracts (n=145), and full-text assessment (n=89), a final corpus of 29 relevant studies was identified for in-depth analysis [5].

Data extraction focused on key analytical dimensions: research context, educational level, AI approaches applied, learning objectives, and reported pedagogical outcomes. Thematic content analysis was employed to identify recurrent patterns and dominant ideas, which were clustered into higher-order conceptual themes [18].

Figure 3: PRISMA-Style Literature Selection Flowchart

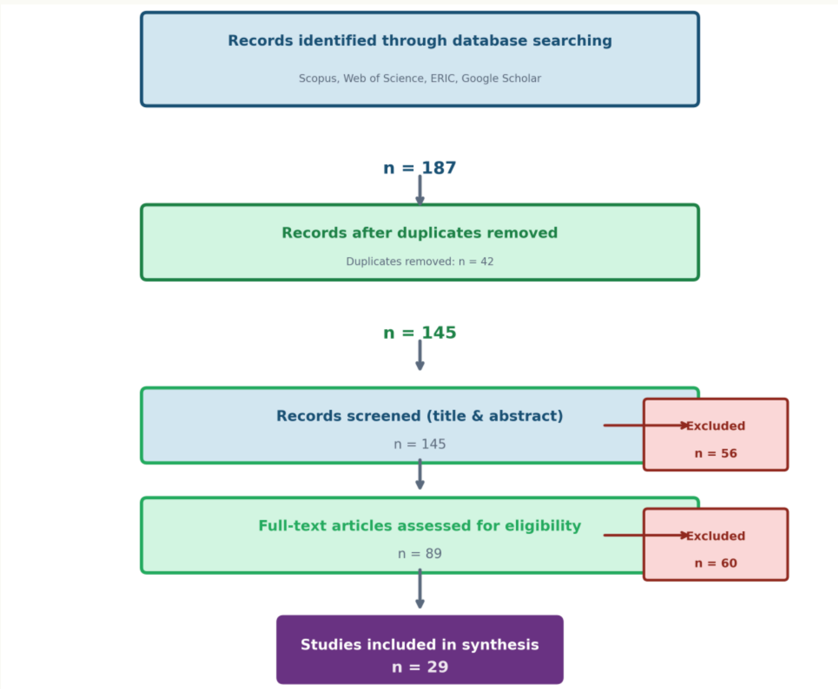

Figure 3 illustrates a flowchart of the systematic literature selection approach of this research in the PRISMA style. In line with the established protocols [18], the search was performed on four major databases; Scopus, Web of Science, ERIC, and Google Scholar with targeted keyword combinations related to artificial intelligence, early childhood education, spatial thinking, environmental awareness, and culturally responsive teaching. The first database search generated 187 entries, which were checked for duplicates and 145 unique records remained for title and abstract screening. In this phase, 56 recordings were eliminated because they did not fit the inclusion requirements (e.g. they did not address ECE situations or were not instructional). The remaining 89 full text articles were screened for eligibility. 60 papers were eliminated for the following particular reasons: 32 did not have a clear emphasis on ECE, 18 were entirely technical or engineering orientated without any educational significance, and 10 did not have accessible complete text. This rigorous, multi-stage screening approach yielded a final corpus of 29 peer-reviewed journal papers published between 2018 and 2025 that were included in the conceptual synthesis [5]. The flowchart offers a clear record of the searching and selecting procedures, assuring methodological rigour and repeatability, in line with best practice for systematic reviews [18].

The flowchart follows PRISMA-style guidelines but is adapted to reflect the specific search and selection process of this study. Exclusion reasons at the full-text stage are shown in the accompanying text rather than on the flowchart to maintain readability.

5. PROPOSED FRAMEWORK

5.1 Integrated AI Framework for ECE

Based on the synthesis of literature, this paper proposes the AI-SEC Framework (AI for Spatial, Environmental, and Culturally Responsive Learning) that integrates three pedagogical pillars supported by AI tools.

Table 2: AI-SEC Framework Components and Implementation Strategies

Pillar	**AI Application**	**Learning Activity**	**Teacher Role**	**Recommended Age**
Spatial Thinking	Interactive mapping apps, AR geometry tools, coding toys	Children use AI-powered maps to navigate schoolyard, identify spatial relationships, create 3D structures	Ask open-ended questions about spatial relationships (e.g., "How far apart are the trees?" "Which is taller?"), introduce spatial vocabulary (e.g., "above," "below," "beside"), provide feedback on children's spatial reasoning	**4-8 years**
Environmental Awareness	Nature identification apps, AI weather models, real-time ecological data	Children identify local plants/trees using AI, track weather patterns, explore ecosystem simulations	Facilitate discussion using prompts like "What happens if we cut down this tree?" "What do plants need to grow?," encourage children to consider consequences of environmental actions	**4-8 years**

Culturally Responsive Teaching	AI multilingual story generators, culturally diverse image creation, translation tools	Children generate stories in home languages, create culturally affirming narratives, share family traditions	Model critical questioning of AI outputs (e.g., "Why does the AI show only one type of family?" "Who is missing from this story?"), invite children's cultural perspectives, adapt content to reflect lived experiences	**4-8 years**

Figure 4: AI-SEC Implementation Flowchart

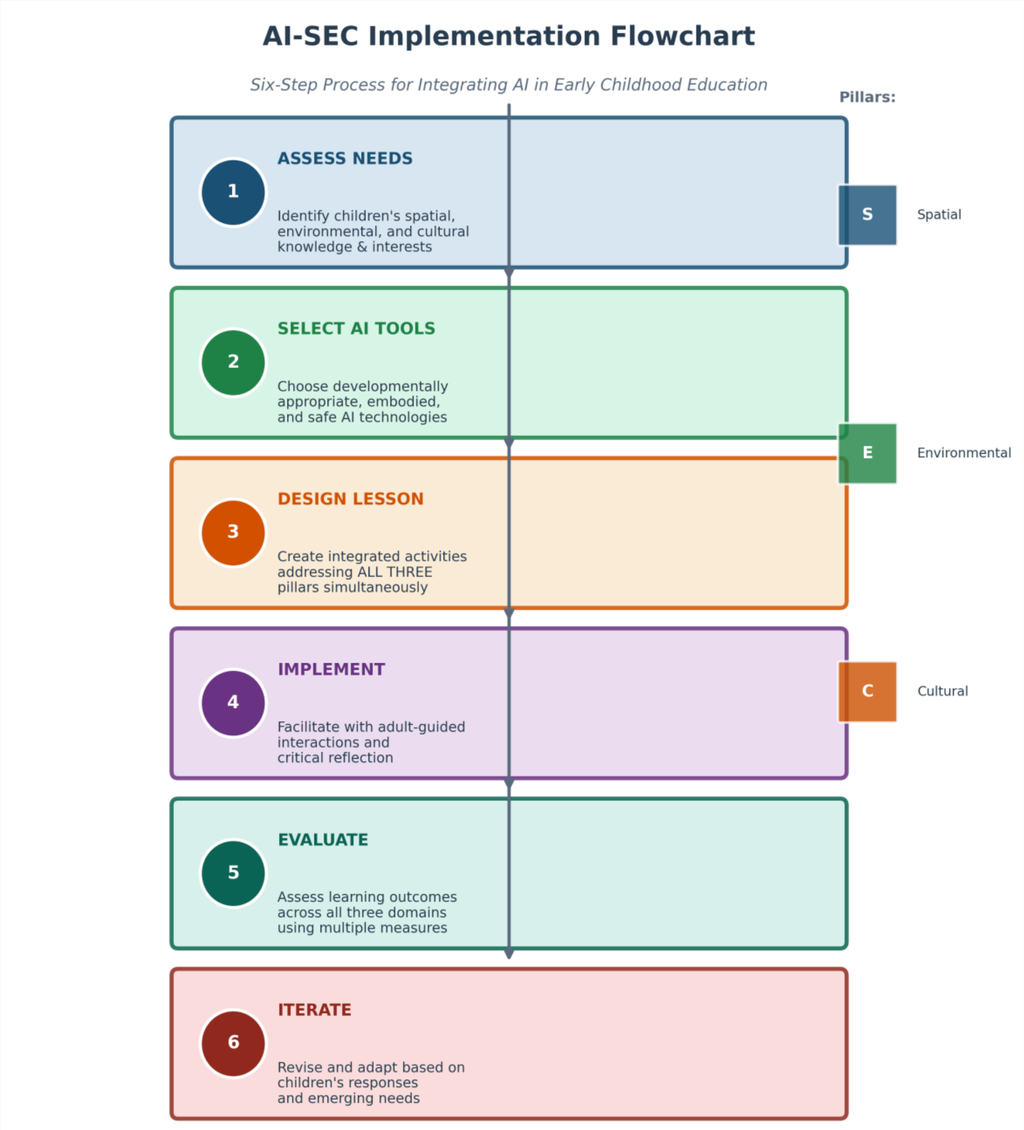

Figure 4 outlines a six-step flowchart for implementing the AI-SEC Framework in early childhood classrooms: 1) Assess Children's Needs through observation; 2) Select AI Tools that are developmentally appropriate; 3) Design Integrated Lessons that incorporate spatial thinking, environmental awareness, and culturally responsive teaching; 4) Implement with Guidance, where teachers facilitate inquiry; 5) Evaluate & Reflect on learning outcomes using various assessments; and 6) Iterate & Improve based on children's feedback, fostering a continuous improvement cycle.

The AI-SEC Framework has been created in a three-stage synthesis process. Stage 1: Domain Identification Recurring themes linked to AI applications in ECE were identified via thematic analysis of the material studied. Three overarching domains emerged based on how frequently they appeared across studies and their interconnectedness in children's development: spatial thinking, environmental awareness, and culturally responsive teaching. Stage 2: Theoretical Integration. The domains were mapped onto the TPACK framework and Transformative Learning Theory to see how AI might help each area and to ensure developmental appropriateness. Stage 3: Strategy Development entailed mapping implementation methods from the literature to the POWER principles for ethical usage of AI. The framework was continuously developed by comparison with current frameworks and validation using the evaluated literature.

5.2 Practical Implementation Example

A single integrated activity might involve children using an AI-powered plant identification app to explore trees in their schoolyard. This activity simultaneously develops:

- **Spatial Thinking:** Children map tree locations, measure distances, create spatial representations
- **Environmental Awareness:** Children learn about native species, discuss ecological roles, understand human-environment interaction
- **Cultural Responsiveness:** Children generate multilingual stories about the trees in their family's home language, share cultural perspectives on nature

This approach aligns with Delaney and Chen's [1] recommendations for developmentally appropriate AI use: selecting tangible and embodied AI tools, engaging through adult-guided interactions, and integrating AI within relationship-centered communities.

Example 2 (Ages 3-5): Weather & Culture Diary Children check the weather everyday using an AI-powered weather app. Then they utilize AI translation tools to write basic weather reports in a range of languages. Weather mapping exercises enhance spatial thinking; discussions of seasonal variations create environmental awareness; sharing weather traditions from other countries develops cultural responsiveness.

Example 3 (Ages 6-8): Neighbourhood Exploration Kids explore their neighbourhood using AI-powered mapping tools to find parks, buildings, and community services. Map making and route planning are used to build spatial thinking; discussions about green spaces and pollution are used to create environmental awareness; studying how various cultural groups utilize places in the community is used to develop cultural responsiveness.

Note: For schools lacking outside area, the plant identification exercise may be modified to include indoor plants or virtual nature exploration tools. Families may be requested to contribute weather customs from their heritage cultures, employing AI translation techniques to assist communication for weather and culture journals in monolingual classroom environments. If it is not safe or logistically possible to explore the neighbourhood in person, activities may be done digitally with the use of online mapping programs such as Google Earth. These adjustments assist in making the framework accessible in a range of educational environments.

5.3 Operationalizing the Framework

The AI-SEC Framework is operationalized through three interrelated pedagogical methodologies that transfer theoretical principles into actual classroom practice.

a. **Inquiry-based exploration:** Children ask questions about their world and use AI tools to examine spatial and ecological phenomena. "Why are there more trees on one side of our playground?"

children could question, using AI-powered mapping tools to investigate spatial patterns and environmental elements [5]. This method corresponds with transformative learning theory as it encourages critical reflection on observations of the environment [6].

b. **Co-creation of narratives:** Children and teachers co-create stories in multiple languages to celebrate their cultures, using AI generators. This technique uses culturally responsive education by bringing home languages and cultural perspectives into learning activities [4]. Teachers ask youngsters to localize the AI-generated stories to their own communities and life experiences [20].
c. **Reflective practice:** Teachers support students to critically appraise the bias and cultural representation of content produced by AI. This includes interrogating the assumptions that are built into AI outputs, detecting the views that may be lacking, and exploring the ways that AI tools represent specific cultural values [4], [12]. This promotes crucial AI literacy from an early age [1].

These strategies work together: inquiry-based exploration provides realistic contexts for learning, narrative co-construction gives cultural meaning to learning, and reflective practice cultivates critical awareness. They collaborate to operationalize the AI-SEC Framework in developmentally relevant ways [1].

6. DISCUSSION

6.1 Contributions to Knowledge

This study makes several significant contributions:

1. It identifies and addresses a critical research gap by proposing the AI-SEC Framework, the first integrated approach connecting spatial thinking, environmental awareness, and culturally responsive teaching in ECE.
2. It extends TPACK theory [15] by demonstrating how AI integration requires simultaneous attention to technological, pedagogical, spatial, environmental, and cultural content knowledge.
3. It operationalizes Transformative Learning Theory [16] in AI-enhanced ECE contexts, showing how AI can facilitate critical reflection and perspective transformation when intentionally designed.
4. It provides practical implementation strategies that address the "AI divide"-the gap between socioeconomically advantaged and disadvantaged children [1]-by emphasizing equitable access and teacher capacity building.

6.1.1 Summary of Contributions

Table 3: Summary of Contributions to Knowledge

Contribution Type	Specific Contribution	Significance
Conceptual	First integrated framework connecting spatial thinking, environmental awareness, and culturally responsive teaching in ECE	Fills critical research gap in AI-ECE literature
Theoretical	Extends TPACK with spatial, environmental, and cultural content knowledge	Provides new theoretical synthesis for AI integration
Practical	Implementation strategies, sample integrated activities, and operational guidelines	Offers actionable guidance for classroom practitioners
Ethical	POWER principles applied to ECE AI use with equity considerations	Guides responsible and developmentally appropriate AI adoption

6.2 Ethical Considerations

The findings highlight several ethical challenges consistent with Chen and Lin's [20] POWER principles (Purposeful, Optimal, Wise, Ethical, Responsible AI use):

- **Data privacy:** AI tools collect substantial data about children, often without informed consent [1], [7]
- **Algorithmic bias:** AI outputs reflect biases in training data, potentially reinforcing stereotypes [4], [12]
- **Developmental appropriateness:** Most AI tools are designed for adult users, lacking empathy for young children [1], [21]
- **Equity:** Unequal access to AI infrastructure and AI literacy education persists [1], [22]. The World Economic Forum [22] reports that in many countries, less than half of all schools are equipped with learning devices and, in schools with learning devices, the equipment are generally shared among large groups of students. This digital divide affects children from marginalized groups disproportionately, limiting their access to AI-enhanced learning opportunities and perpetuating cycles of educational disadvantage [1], [7]. Filling this gap requires focused investment in disadvantaged schools, community AI literacy programs and fair distribution of AI resources [29].

6.2.1 Critical Perspectives on AI in ECE

While the AI-SEC Framework presents a potential path to include AI across three learning domains, a number of counter-arguments and hazards need to be considered. First, the “AI divide” between socioeconomically advantaged and disadvantaged children is a substantial hurdle to fair implementation [1], [22]. Schools serving marginalized populations sometimes lack the infrastructure, gadgets and internet access essential to integrate AI [29]. Second, the worries concerning screen usage and young children’s development still exist. Some research shows that too much screen exposure can affect attention spans and social development [21]. Third, AI technologies are not neutral, and they contain the biases and values in their training data, which may reproduce stereotypes and marginalize existing under-represented voices [12] . Fourth, the environmental cost of artificial intelligence systems, including energy consumption and technological waste, raises doubts about the sustainability of AI in education [34]. These problems do not diminish the possible advantages of the AI-SEC Framework, but rather highlight the need for a deliberate, critical application that centers fairness, developmental appropriateness, and environmental responsibility.

6.3 Limitations and Future Research

It is important to point out that this research has several limitations. First of all, the framework is conceptual and has to be validated empirically by action research in the classroom. Secondly, the literature synthesis is confined to peer-reviewed English-language articles, which may exclude significant research published in other languages. Third, the search was restricted to journal papers published between 2018 and 2025 which may have omitted previous fundamental work on spatial thinking, environmental education, and culturally responsive teaching. Fourth, the AI-SEC Framework represents the researchers’ interpretation and synthesis of the literature and that other researchers may have other priorities or linkages. Fifth, many of the AI technologies reviewed in the framework are not yet accessible in most early childhood settings owing to cost, infrastructure limitations, and inadequate teacher training. Finally, the approach does not address the substantial problems of applying AI in under-resourced settings, where lack of equipment, internet access and technical assistance may make AI integration unfeasible [29]. In addition, this study did not expressly address publication bias - the propensity for studies with good outcomes to be published more often than those with negative or null findings - and this may have impacted the synthesis.

Future research should: (a) conduct longitudinal studies (minimum 2-3 years) on AI integration in diverse ECE settings across multiple countries; (b) study teacher professional development models that develop AI literacy competency over time; (c) develop and validate AI tools specific to each age group (3-5 and 6-8) aligned with the AI-SEC Framework; and (d) explore culturally diverse contexts through comparative studies in at least three different national contexts to ensure global applicability.

6.4 Practical Implications for Policy and Practice

The AI-SEC Framework offers actionable implications for multiple stakeholders in early childhood education.

A. For Education Leaders and Policymakers

Education leaders should prioritize five key areas when implementing AI in ECE settings [1]:

Table 4: Key Areas of AI in ECE

Priority Area	Action Required	Prerequisite	Expected Outcome
AI Infrastructure	Invest in hardware, software, and internet connectivity	-	Foundation for all other priorities
Teacher Capacity	Provide ongoing professional development in AI literacy	Infrastructure	Confident, skilled teachers
Teaching Sensitivity	Develop culturally and linguistically responsive AI guidelines	Teacher Capacity	Inclusive learning environments
AI Safety Guardrails	Establish data privacy and security policies	Infrastructure + Policy	Protected children's rights
Teacher-Parent Partnerships	Create family engagement programs for AI literacy	Teaching Sensitivity	Consistent home-school AI learning

B. For Teacher Educators

Teacher preparation programs must embed AI literacy as a core competency, not an elective [4]. This includes developing four competency areas:

- **AI Literacy Competencies:** Understanding AI capabilities and limitations, recognizing algorithmic bias, critically evaluating AI-generated content
- **Pedagogical Competencies:** Designing AI-enhanced learning activities, facilitating inquiry-based exploration, integrating spatial, environmental, and cultural content
- **Ethical Competencies:** Protecting children's data privacy, ensuring developmental appropriateness, addressing equity and access concerns
- **Reflective Competencies:** Critically evaluating AI tools for cultural bias, adapting AI-generated content to reflect children's lived experiences, modeling appropriate AI use

C. For Classroom Teachers

Practitioners can begin with simple, low-tech AI integrations:

- Use AI-powered plant identification apps during nature walks
- Leverage AI translation tools for multilingual family communication

- Implement coding toys that develop spatial reasoning

D. For Researchers

Future empirical studies should:

- Validate the AI-SEC Framework through classroom-based action research
- Develop and test specific AI tool prototypes aligned with the three pillars
- Examine long-term outcomes of AI-enhanced ECE interventions

7. CONCLUSION

Generative AI does not reimagine pedagogy on its own; rather, its educational significance depends on how thoughtfully and critically it is engaged by teachers within specific pedagogical, cultural, and institutional contexts [4]. This study demonstrates that developing AI literacy among preservice and in-service early childhood teachers is a multifaceted endeavor encompassing pedagogical, ethical, and cultural considerations.

The AI-SEC Framework proposed in this paper offers a pathway for integrating spatial thinking, environmental awareness, and culturally responsive teaching through intentional AI implementation. By anchoring policy and practice in equity, AI literacy, and ethics [1], education leaders and teachers can leverage AI as a democratic tool that empowers all children-especially those from marginalized backgrounds-to participate equitably in an increasingly AI-driven world.

The future of AI in ECE will be shaped not by the technology itself, but by how teachers are prepared to question, adapt, and at times refuse its use in service of their students, communities, and professional commitments [4].

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