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INTEGRATING GENERATIVE AI IN ENERGY-EFFICIENT SMART HOMES FOR EARLY STEM AND TECH LITERACY

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ABSTRACT
The advancement of generative artificial intelligence (AI) has opened new possibilities for learning environments beyond traditional classrooms, including within energy-efficient smart homes. This paper explores how generative AI integration in smart home automation can serve as a medium to foster Science, Technology, Engineering, and Mathematics (STEM) learning and technology literacy in early childhood education. Utilizing qualitative literature-based analysis, the study highlights AI features such as intelligent assistants, interactive feedback, and automated environmental controls (lighting, temperature, and energy usage) as tools that offer contextual, experiential learning for children. These interactions are designed to promote curiosity, problem-solving, and basic understanding of sustainability and automation. Findings reveal that smart homes, when integrated with generative AI and supported by parental guidance, can become effective interactive learning spaces for introducing children to STEM concepts and responsible energy behavior in age-appropriate ways. The study contributes to the educational discourse by emphasizing a child-centered, tech-integrated, and environmentally aware learning model suitable for 21st-century education.
Keywords: smart home; generative AI; early childhood; STEM; technology literacy

INTRODUCTION
The rapid emergence of artificial intelligence (AI), especially generative AI, is reshaping educational landscapes by enabling interactive, adaptive, and personalized learning experiences. While much focus has been placed on classroom applications, there is a growing opportunity to leverage these technologies within informal learning environments—such as smart homes. Early childhood education, especially in STEM (Science, Technology, Engineering, Mathematics) fields, benefits significantly from experiential and contextual learning. Smart homes embedded with generative AI present a unique opportunity for children to interact with intelligent systems that not only automate daily tasks but also explain them in child-friendly terms.

Recent studies emphasize the importance of introducing energy literacy and digital responsibility at a young age to prepare future generations for sustainable living and critical thinking in a technology-driven society. In this context, smart homes can serve as both physical and cognitive environments where children learn through direct interaction with automated systems—like adjusting lights, monitoring energy use, or conversing with AI assistants. These interactions promote inquiry-based learning, reinforce cause-and-effect understanding, and stimulate curiosity.

This paper explores how generative AI integrated into energy-efficient smart homes can foster STEM learning and enhance technology literacy among young children. Through literature-based qualitative analysis, this study investigates how such systems

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can offer age-appropriate educational experiences that support early cognitive development, align with sustainability goals, and reflect the principles of human-centered education in the digital age.

METHOD

This study employs a qualitative literature review approach to investigate the intersection of generative AI, smart home technology, and early childhood STEM education. The method focuses on analyzing peer-reviewed articles, conference papers, and official reports published within the last five years (2019–2024) to ensure relevance and timeliness.

Data were collected through structured searches in digital academic databases such as Google Scholar, IEEE Xplore, ERIC, and ScienceDirect using keywords such as "generative AI," "smart home education," "early childhood technology literacy," and "STEM learning environments." Articles were selected based on criteria including relevance to early childhood education, implementation of AI or smart technologies, and evidence of pedagogical value.

The collected data were synthesized through thematic analysis to identify key patterns, frameworks, and educational opportunities provided by integrating generative AI into smart home systems. The method allowed for extracting both theoretical insights and empirical findings to support the conceptual model of AI-powered smart homes as interactive, energy-efficient, and educational spaces for young children.

RESULTS AND DISCUSSION

The literature underscores strong support for AI-enabled smart homes as promising platforms for early STEM and technology literacy. Badshah et al. (2023) describe how integrating IoT and AI into educational ecosystems—termed "smart education"—boosts engagement, motivation, and deeper learning through interactive and adaptive environments. Applied to smart homes, this means children benefit from real-time, context-aware experiences such as exploring how turning off lights saves energy or observing changes in temperature—supporting experiential STEM learning and environmental awareness.

Design considerations are critical. Ehteshami et al. (2024) highlight the specific needs of child-friendly smart homes, including safety mechanisms, intuitive interfaces, and parental control systems. These elements are essential when young children interact with devices, ensuring the home environment remains supportive and secure while offering educational opportunities.

Generative AI assistants that provide conversational feedback have also been shown to foster curiosity and cognitive growth. For example, when a child asks, "Why did the lights turn off?", a well-designed AI can deliver a simplified explanation ("The light turns off to save energy!"), potentially paired with suggestions for hands-on mini-experiments. These adaptive, narrative-rich responses echo dialogic learning in classrooms and align with 21st-century educational ideals of nurturing inquiry and critical thinking.

Moreover, the flexibility of generative AI allows for cognitive differentiation. A preschooler might receive playful, story-like answers, while a kindergartener could hear more detailed, logic-based explanations. This supports developmental appropriateness and gradually builds digital literacy.

However, multiple scholars emphasize the need for structured mediation. Children benefit most when adults—parents or teachers—guide interactions, guarding against over-reliance or misunderstanding of AI-driven information. Data privacy, age-appropriate content, and parental involvement are therefore non-negotiable design principles. Taken together, these insights suggest that generative AI–driven smart homes can effectively act as a "third teacher," reinforcing STEM concepts, environmental consciousness, and self-guided learning in a nurturing, child-centered home environment. The literature analysis revealed a range of findings supporting the potential of smart homes powered by generative AI as interactive learning environments for early childhood STEM education. The integration of AI in domestic settings introduces a new modality for experiential learning, where intelligent systems not only automate tasks but also interactively explain processes to children in developmentally appropriate language.

One significant insight from the reviewed studies is the promotion of inquiry-based learning. Generative AI assistants can respond to children's questions with simplified yet informative answers, creating a responsive feedback loop. For instance, when a child asks, "Why did the lights turn off?", the AI could respond with, "Because we want to save energy when no one is in the room." This promotes both curiosity and an early understanding of environmental responsibility. Research by Sun et al. (2024) supports this interactional approach, noting that AI-powered storytelling and conversational agents can effectively nurture engagement and early literacy.

In terms of cognitive development, smart homes allow children to engage in trial-and-error learning through everyday activities. For example, adjusting the room temperature or switching devices on and off provides hands-on experiences that relate to cause-effect logic, systems thinking, and basic engineering principles. Studies like Rahman & Khan (2024) suggest that these interactions increase children's comfort with technology and support safe, autonomous learning in supervised environments.

Another important aspect is differentiated learning. AI systems can personalize their communication style and content based on the child's developmental stage. Yıldırım (2025) emphasized that early exposure to AI, when scaffolded appropriately, can enhance problem-solving abilities and digital fluency. Younger children might receive visual, auditory, or story-based inputs, while older children might engage with more analytical and guided explorations.

Furthermore, the findings show that integrating energy-efficient features with educational feedback strengthens the real-world relevance of STEM learning. As children participate in tasks like monitoring electricity usage or scheduling lights, they develop both numeracy and ecological awareness. This bridges the gap between abstract STEM concepts and tangible daily experiences. Badshah et al. (2023) highlight the Internet of Things (IoT) and AI as central to creating such meaningful and context-rich educational spaces.

However, several challenges also emerged. Without appropriate design, AI interactions risk becoming either too complex or overly simplistic, leading to cognitive disengagement or confusion. Moreover, concerns around data privacy, screen time, and overdependence on AI systems remain prominent. Thus, consistent with Yan et al. (2023), the importance of adult mediation and ethical AI design is emphasized. Parental guidance is vital in interpreting AI responses and ensuring emotional and social development is not compromised.

In synthesis, smart homes equipped with generative AI offer promising avenues for creating alternative learning environments that are immersive, responsive, and

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tailored to young children. They support the goals of 21st-century education by aligning digital competencies with environmental responsibility. Nevertheless, successful implementation depends on thoughtful system design, user-friendly interfaces, and active involvement from caregivers or educators. This balance ensures that technology acts not as a replacement but as a complement to human-centered, developmentally appropriate pedagogy.

CONCLUSION

This study concludes that integrating generative AI into energy-efficient smart homes presents a promising educational innovation for early childhood STEM learning and technology literacy. Through adaptive responses, automated systems, and context-rich feedback, children can explore scientific and technological concepts in a natural, inquiry-based manner. These environments provide age-appropriate, experiential learning opportunities that foster curiosity, responsibility, and foundational cognitive skills.

With appropriate parental involvement and ethical safeguards, smart homes can function as complementary learning spaces alongside schools, aligning educational content with sustainability goals. This research contributes to the practice of education by offering a model that supports interactive, technology-enhanced learning beyond the classroom. Furthermore, it provides valuable insights for the future development of child-friendly smart home technologies that balance innovation with pedagogical and developmental considerations. It also encourages education stakeholders to consider informal learning environments as vital components in shaping digitally literate, environmentally conscious, and STEM-prepared generations.

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