ISSN: P-2455-0515
E- 2394-8450

Educreator Research Journal

OPEN ACCESS

Volume–XIII, Issues–III

May – June 2026

Original Research Article

LIFE SKILL EDUCATION FOR SUSTAINABLE LIVING: A CYBER-PHYSICAL-HUMAN FRAMEWORK

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Abstract:

The escalating severity of climate change and resource depletion necessitates a fundamental shift in daily human habits, making life skill education for sustainable living a critical priority. Traditional educational paradigms often rely on passive dissemination of information, which is frequently insufficient to drive long-term behavioral transformation. In response, this paper proposes a comprehensive educational framework that integrates pedagogical strategies with emerging cyber-physical-human systems, such as smart home technologies, Internet of Things (IoT) monitoring, and artificial intelligence-driven recommendation systems. By bridging the gap between theoretical environmental knowledge and practical, everyday actions, the proposed methodology aims to embed sustainability into core life skills. The framework encompasses cognitive learning, practical application through digital nudging, and social reinforcement within inclusive communities. Furthermore, this study outlines a hypothetical evaluation plan designed to measure both immediate resource conservation and the longitudinal retention of sustainable behaviors, ultimately striving to foster a resilient and environmentally conscious society.

Keywords: *Life Skill, Education, Sustainable, Living, Cyber, Physical, Human, Framework*

Introduction:

The rapid emergence of extreme climate events and the continuous depletion of global resources have significantly raised societal awareness regarding the necessity of sustainable living (Jing et al., 2025). Every day, individuals are faced with numerous lifestyle decisions, spanning from dietary choices to household energy consumption, which collectively exert a profound impact on the global environment (Fontan et al., 2023). Consequently, life skill education must evolve beyond traditional personal finance and basic home economics to include practical competencies in environmental stewardship. Education systems, particularly those intersecting with engineering and technology, are increasingly recognizing the need to transfer sustainability knowledge directly into societal applications (Bilbao et al., 2024). Establishing robust life skill education for sustainable living is therefore essential for mitigating greenhouse gas emissions, a large portion of which stems directly from residential electricity consumption and individual lifestyle choices (Lu et al., 2024).

Despite the growing consensus on its importance, the current scope and definition of life skill education for sustainable living remain somewhat fragmented. In the context of this paper, sustainable life skills are defined as the practical, daily competencies required to minimize personal ecological footprints, including energy management, waste reduction, and sustainable consumption. The problem lies in effectively teaching these skills in a manner that translates theoretical knowledge into consistent, automated habits. While technologies related to the Internet of Things (IoT) and smart homes have seen remarkable growth (Bilbao et al., 2024), their integration into formal and informal educational curricula remains limited. Bridging this gap requires treating the household and the community as active, cyber-physical-human learning environments where behaviors are continuously shaped and reinforced (Fontan et al., 2023).

Existing approaches to life skill education and sustainable behavioral modification are currently insufficient for several critical reasons. First, traditional methods that encourage behavioral shifts are often overly demanding or rely on passive engagement, failing to actively nudge users toward greener choices in real time (Jing et al., 2025). Second, in the realm of domestic energy management, traditional educational models and rule-based systems struggle to adapt to non-stationary residential settings, where shifting contexts and varying renewable generation can invalidate previously learned user policies (Lu et al., 2024). These limitations underscore the need for an adaptive, technologically augmented educational approach that does not rely solely on user willpower but rather integrates seamlessly into their daily digital environments.

To address these systemic shortcomings, this paper introduces a novel approach to life skill education that synthesizes pedagogy with smart technologies. The primary contributions of this paper are as follows:

- We propose a multi-layered educational framework that combines formal sustainability education with active, AI-driven behavioral nudging in domestic environments.
- We outline a comprehensive, hypothetical evaluation methodology leveraging social networks and smart home data to quantify the adoption and retention of sustainable life skills.

Related Work:

Formal Education and Curriculum Integration:

The first major category of related work revolves around the integration of sustainability principles into formal higher education and specialized training programs. Academic institutions are increasingly launching projects that utilize open hardware-based IoT devices to teach students about environmental factors, such as measuring the efficacy of urban gardens and composting processes (Bilbao et al., 2024). At the graduate level, specialized curricula like the PERCCOM master's program have been developed to combine advanced Information and Communication Technologies (ICT) with environmental awareness, training professionals to build greener cyber-physical systems (Porras et al., 2016). Furthermore, research in specific technical domains, such as the Finnish software industry, highlights a growing interest in integrating sustainability into agile software development processes and related engineering education (Shamshiri et al., 2024). While these formal educational models are highly effective at building deep, domain-specific knowledge, they primarily target specialized professionals or engineering students. This work compares to these existing models by extracting their core experiential learning principles and adapting them into accessible, daily life skill education for the broader public.

Technological Nudging and Behavioral Shifts:

ISSN: P-2455-0515
E- 2394-8450

Educreator Research Journal

Volume–XIII, Issues–III May – June 2026

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The second category focuses on the utilization of artificial intelligence and smart algorithms to actively nudge user behavior toward sustainable daily habits. Recent advancements have explored the use of Large Language Models (LLMs) to enhance smart home automation, demonstrating the potential of conversational agents to generate routines that optimize electrical consumption based on environmentally focused prompts (Giudici et al., 2025). Similarly, in the domain of dietary choices, recommendation systems like the Green Recommender Aligned with Personalized Eating (GRAPE) have been developed to prioritize sustainable food options while accommodating users' evolving personal preferences (Jing et al., 2025). In the context of residential appliance scheduling, meta-learning approaches combined with multi-objective reinforcement learning have proven highly effective in adapting to shifting environments and balancing user comfort with energy efficiency (Lu et al., 2024). These technologies excel at providing immediate, localized interventions, but they often act as invisible optimizations rather than conscious educational tools. The present work distinguishes itself by explicitly framing these AI nudges as pedagogical instruments intended to build long-term, internalized life skills rather than merely automating user decisions.

Environmental Awareness through Immersive Monitoring:

The third category encompasses the deployment of immersive technologies and continuous monitoring systems to foster environmental awareness and community resilience. For instance, Augmented Reality (AR) mobile applications have been designed to enhance public engagement with cultural heritage sites while simultaneously raising awareness about the local impacts of climate change and environmental hazards (Urbanelli et al., 2025). In more remote settings, sustainable live sonar analytics systems provide continuous underwater monitoring, supporting wildlife restoration and environmental anomaly detection despite severe resource constraints in wild ecosystems (Xu et al., 2024). Pushing the boundaries of closed-loop monitoring even further, theoretical evaluations of self-sustaining living habitats in extraterrestrial environments illustrate the ultimate extremes of resource conservation and biologically generated survival ecosystems (Wordsworth & Cockell, 2024). While these systems demonstrate the power of data visualization and monitoring in building environmental awareness, they are often disconnected from mundane household routines. Our proposed framework integrates the core idea of continuous, immersive feedback found in these systems into the domestic sphere, utilizing smart residential homes to observe and educate users on lifestyle choices such as resource usage and mobility (Fontan et al., 2023).

Method/Approach:

The Cyber-Physical Pedagogical Framework:

To effectively instill sustainable life skills, we propose a structured framework that merges traditional pedagogical techniques with cyber-physical smart home technologies. The architecture of this framework is divided into three interconnected modules: Cognitive Foundation, Cyber-Physical Practice, and Social Reinforcement. The Cognitive Foundation module acts as the traditional educational layer, providing users with the necessary background knowledge regarding climate change, carbon footprints, and the environmental impact of electricity production (Lu et al., 2024). The Cyber-Physical Practice module represents the core innovation, utilizing domestic IoT ecosystems to translate abstract concepts into tangible actions. By integrating conversational agents and LLM-based smart assistants, the system can interpret user commands and generate automated, sustainable household routines, thereby demonstrating practical energy optimization in real time (Giudici et al., 2025). Finally, the Social Reinforcement module leverages digital networks to connect individual households into inclusive communities, facilitating the diffusion of sustainable behaviors through peer observation and social interaction (Fontan et al., 2023).

Key Design Choices and Rationale:

The primary rationale behind this multi-layered design is to transition users from passive recipients of environmental data to active participants in sustainable living. Relying solely on manual habit formation is frequently overly demanding for the average individual (Jing et al., 2025). Therefore, we incorporate recommendation systems that actively nudge users toward greener choices—such as suggesting sustainable meal plans—thereby lowering the cognitive barrier to entry (Jing et al., 2025). Furthermore, drawing inspiration from engineering education models, the framework utilizes hands-on, hardware-based feedback loops, such as monitoring small urban gardens or compost boxes via IoT sensors (Bilbao et al., 2024). This design choice ensures that the educational experience is grounded in physical reality, allowing individuals to visibly track the outcomes of their sustainable actions. The integration of meta-learning algorithms is also crucial, as it enables the system's nudging mechanisms to quickly adapt to non-stationary residential settings without frustrating the user with obsolete rules (Lu et al., 2024).

Implementation Pipeline:

To operationalize this framework, we define a structured pipeline for deploying the educational intervention in a residential setting. This step-by-step process ensures a seamless integration of education and technology. The proposed pipeline operates as follows:

1. **Baseline Assessment**: The smart home network monitors initial consumption patterns, dietary habits, and energy usage without intervention to establish a behavioral baseline.
2. **Cognitive Onboarding**: Users interact with a conversational agent to receive tailored educational modules explaining the environmental impact of their baseline behaviors.
3. **Active Nudging**: The system deploys context-aware recommendations, such as suggesting energy-efficient appliance schedules (Lu et al., 2024) or providing personalized green food options (Jing et al., 2025).
4. **Experiential Feedback**: Users receive daily visual data reports regarding their resource savings, generated via localized IoT sensors tracking elements like water usage or compost health (Bilbao et al., 2024).
5. **Community Synchronization**: Anonymized progress and sustainability indicators are shared within a localized social network to stimulate positive peer pressure and community-driven behavioral diffusion (Fontan et al., 2023).

Evaluation Plan:

To rigorously assess the efficacy of the proposed framework, we outline a hypothetical evaluation plan utilizing a longitudinal experimental study design. Inspired by smart residential setups such as the KTH Live-In Lab (Fontan et al., 2023), we propose recruiting a hypothetical cohort of 200 diverse households equipped with

ISSN: P-2455-0515
E- 2394-8450

Educreator Research Journal

OPEN ACCESS

Volume–XIII, Issues–III

May – June 2026

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standardized IoT monitoring infrastructure. The primary benchmark datasets will consist of continuous time-series data capturing electricity consumption, water usage, and self-reported dietary purchases over a 12-month period. The evaluation will measure three specific metrics: the percentage reduction in utility consumption compared to the baseline, the adoption rate of green food recommendations, and qualitative user engagement scores derived from interacting with the LLM-based automation assistants (Giudici et al., 2025). By tracking these metrics over a full calendar year, the study will determine whether the technologically assisted nudges successfully transition into permanent, internalized life skills, even when the digital prompts are artificially reduced in the final quarter of the experiment.

Discussion:

Practical Implications and Deployment:

The practical implications of deploying this educational framework are substantial, extending from individual household economics to broader municipal climate strategies. By embedding life skill education directly into the domestic environment via smart assistants, municipalities can effectively scale sustainability initiatives without relying solely on costly public awareness campaigns. Furthermore, the integration of open hardware-based IoT devices ensures that the monitoring infrastructure can be developed and maintained cost-effectively, promoting knowledge transfer from academic institutions to everyday society (Bilbao et al., 2024). As individuals learn to optimize their electrical consumption and reduce waste through real-time feedback (Giudici et al., 2025), utility companies may also benefit from stabilized grid demands and improved integration of renewable energy sources. Ultimately, this cyber-physical approach transforms the home into an interactive classroom, making sustainable living an accessible, daily practice rather than an abstract ideological goal.

Limitations and Failure Modes:

Despite its potential, the proposed framework is subject to several critical limitations and failure modes that must be addressed.

- First, the reliance on continuous IoT monitoring and AI-driven recommendations introduces the risk of user fatigue, where individuals may eventually ignore or disable nudges if they become overly intrusive or demanding (Jing et al., 2025).
- Second, traditional multi-objective reinforcement learning and rule-based systems often struggle with limited data in non-stationary settings, meaning unexpected context shifts (e.g., changes in household occupancy or sudden schedule changes) can invalidate previously learned policies and lead to inappropriate system behavior (Lu et al., 2024).
- Third, the hardware and algorithmic infrastructure required to support this framework may present a significant socioeconomic barrier, limiting access for low-income demographics and potentially widening the digital divide in sustainability education.

Ethical Considerations:

ISSN: P-2455-0515
E- 2394-8450

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OPEN ACCESS

Volume–XIII, Issues–III

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The deployment of pervasive computing and continuous monitoring within residential environments raises profound ethical concerns.

- The most pressing issue is data privacy; transforming a household into an observable node within a social network requires the rigorous safeguarding of highly sensitive behavioral data regarding food, resources, mobility, and consumption (Fontan et al., 2023).
- Additionally, there is an ethical tension regarding user autonomy and the nature of algorithmic nudging. If a conversational agent or smart home assistant heavily prioritizes environmental sustainability over user comfort without transparent consent, it crosses the line from educational assistance to coercive behavioral engineering.

Future Work:

To overcome these limitations and expand the scope of life skill education, several avenues for future research are identified.

- First, future work should focus on conducting multi-year longitudinal studies to assess whether the digital nudges successfully translate into intrinsic behavioral changes that persist even when the technological scaffolding is removed.
- Second, there is significant potential in adapting these domestic educational frameworks for extreme, resource-constrained environments. Drawing inspiration from the theoretical parameters of self-sustaining living habitats in extraterrestrial environments (Wordsworth & Cockell, 2024), future systems could teach radical resource circularity and biological resilience, providing valuable insights for human life support and sustainability in both space exploration and deeply isolated terrestrial ecosystems.

Conclusion:

The transition toward a sustainable global society requires more than the passive acquisition of environmental knowledge; it demands the active cultivation of daily life skills. This paper has introduced a comprehensive educational framework that harnesses the capabilities of cyber-physical-human systems to teach sustainable living directly within the domestic environment. By integrating formal educational concepts with IoT monitoring, large language model automation, and AI-driven behavioral nudging, the proposed system bridges the critical gap between environmental theory and practical application.

Through the proposed modules of cognitive learning, practical technological reinforcement, and social community integration, individuals can be effectively supported in making complex lifestyle decisions regarding energy consumption, waste management, and dietary choices. While challenges related to data privacy, user fatigue, and hardware accessibility remain, the utilization of smart technologies as active pedagogical tools represents a highly promising frontier. Ultimately, fostering these life skills through innovative, integrated educational frameworks is essential for developing resilient communities capable of addressing the pressing realities of climate change and resource conservation.

ISSN: P-2455-0515
E- 2394-8450

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OPEN ACCESS

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May – June 2026

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Cite This Article:

Dr. Bhurale V.B. (2026). *Life Skill Education for Sustainable Living: A Cyber-Physical-Human Framework.* **In Educreator Research Journal: Vol. XIII (Issue III),** pp. 160-166