EAI Endorsed Transactions
on Pervasive Health and Technology Research Article **EAI.EU**

Active Prevention of Nature-Deficit Disorder in Urban Children: An IoT-Based Interactive Ecological Intervention System Design

Cheng Zhai[1], Hongchen Li[1,*], Yan Chen[1], Yuyang Zeng[1], Shanshan Liang[1,**]

[1]Zhongkai University of Agriculture and Engineering, 24 Dongsha Street, FangzhiRoad, Haizhu District, Guangzhou, China

Abstract

INTRODUCTION: Modern urban lifestyles have fundamentally transformed children's growth environments, indirectly contributing to the proliferation of Nature-Deficit Disorder (NDD). This condition has elevated the prevalence of childhood obesity, attention deficit disorders, and mental health issues to epidemic levels. Existing interventions face significant limitations, particularly in their inability to seamlessly integrate into the daily routines of urban children.
OBJECTIVES: Grounded in Socio-Ecological Theory, Self-Determination Theory (SDT), and the Technology Acceptance Model(TAM), this study aims to propose and design a novel IoT-based interactive ecological intervention system. The goal is to create a unified framework that effectively bridges the gap between urban living and nature engagement.
METHODS: The system incorporates modular hardware design and a gamified task-driven mechanism, organically integrating outdoor exploration with indoor planting. Through user surveys involving 100 urban children aged 6–12, we constructed and applied partial least squares structural equation modeling (PLS-SEM) to evaluate the intervention's effectiveness. This analysis examined the impact paths of perceived ease of use(PEOU)and gamification experience(GAM)on nature connectedness (NC)and pro-nature behavioral intention(BI), while testing the mediating role of gamification experience. Field observations were also conducted with representative users.
CONCLUSION: The structural equation modelling (SEM)results indicate strong explanatory power for the model, with R^2values for key variables ranging from 0. 396 to 0. 477. The study confirms that gamification experience plays a critical and significant mediating role between perceived ease of use and nature connectedness (indirect effect β=0. 241, p=0. 003). A more noteworthy finding is that the primary driver of children's future pro-nature behavioral intention is gamification experience itself (β=0. 376, p<0. 001), rather than the nature connectedness it fosters. This research thus concludes that, in digital health interventions for children, intrinsic enjoyment derived from gamification experience serves as a more pivotal long-term motivator for sustained engagement than the educational value of nature connectedness. These insights not only validate a promising prototype intervention system but, more importantly, offer essential theoretical and practical guidance for designing more effective child-focused intervention products in the future.

Keywords: Nature-deficit disorder, user research, digital health, Internet of Things, gamification, system design, preventive medicine

Received on 22 November 2025, accepted on 06 January 2026, published on 19 January 2026

doi:10. 4108/eetpht.11.11036

1. Introduction

Rapid urbanization has significantly diminished children's direct contact with nature, bringing the issue of nature deficit disorder(NDD)into sharp focus [1]. This disconnection has driven rates of childhood obesity, attention deficit disorders, and mental health problems to epidemic proportions. Although various nature-oriented educational programs exist,

*Corresponding author. Email:675290915@qq.com
**Corresponding author. Email:2302857772@qq.com

most rely on fragmented, teacher-led offline activities, such as field trips. Similarly, many existing IoT-based educational toys and smart gardening systems remain limited to passive data display or automated functions. While these interventions hold value, they struggle to integrate into children's daily lives in ways that foster sustained behavioral change. Moreover, they rarely offer data-driven feedback and tend to be rigid, failing to adapt to the evolving needs of growing children[2]. Consequently, there remains a clear gap in research on effective, sustainable intervention tools that can seamlessly fit into family routines and proactively prevent NDD.

To address this challenge, the present study proposes and develops a novel proactive intervention approach: an IoT-based interactive ecological system. This model combines guided outdoor exploration with data-driven indoor micro-ecosystem cultivation. It transforms children's interactions with nature from passive and sporadic experiences into active, ongoing daily practices. By using soil sensors (technological intervention) to detect plant needs, trigger reminders, and guide watering interactions (behavioral guidance), the system cultivates a sustained sense of responsibility and emotional attachment to natural life (psychological mechanism). Ultimately, this heightens children's interest in and affinity for the natural environment. The model posits that this Arduino-powered interactive plant care system will markedly increase the frequency and proactivity of children's nature engagement, thereby enhancing their nature connectedness. Initial validation has confirmed the system's effectiveness in gamified intervention pathways.

2. Related Work

2.1 Nature-Deficit Disorder and Health

"Nature-Deficit Disorder" is a term coined by Richard Louv in his book Last Child in the Woods to describe the range of physical and mental health problems caused by the reduced direct contact between children and nature[3]. For the new generation, the experience of direct contact with nature—whether in backyards, neighborhood fields, or woods—is being replaced by indirect experiences through electronic media[4][5]. Louv's concept emphasizes the health costs of alienation from nature and is widely cited in public health and environmental psychology. Contemporary medical research supports the link between nature exposure and various health indicators, including weight management and immune function. For instance, reviews have correlated nature exposure with NK cell activity and inflammatory factors[6], while others link increased green cover to lower obesity rates[7].

2.2 Existing Interventions

International empirical research on NDD has increased, with high-quality Randomized Controlled Trials (RCTs) and systematic reviews confirming that regular nature exposure and outdoor education significantly enhance children's connectedness to nature (CNS) and mental health. Fyfe-Johnson et al. showed in a park prescription RCT (n=78) that weekly nature activities improved overall mental health and stress levels ($p<0.01$) [8]. Meta-analyses by Dankiw et al. and Becker et al. further confirmed small-to-moderate effect sizes for outdoor learning on emotional well-being and reduced depression / anxiety risks [9][10].

Current interventions generally fall into two categories: scenario-dependent interventions (e. g. , forest schools) and traditional educational interventions. The former are often costly, passive, and hard to scale, while the latter rely on theoretical knowledge transfer. There is an urgent need for "active prevention" tools that are sustainable and family-integrated. IoT and gamification offer a solution by applying cognitive evaluation theories and systematic design strategies [12][13]. Research by Wang et al. and Mazéas et al. [14] [15] indicates that gamified interventions with real-time feedback significantly improve physical activity and motivation. This study builds on these findings and previous interactive designs [16] to create a system that combines hardware and adaptable content for long-term engagement.

3. Methodology and System Design

3.1 Theoretical Framework

The study did not use the three theories in isolation, but constructed a cross-layer organic integration framework, combined the literature review research gap and the original design research on the basis of the integration of the interaction model framework to solve the pain point of traditional intervention methods difficult to integrate into daily life.

- Macro-level perspective (Social Ecosystem Theory): Building a Digital-Physical Hybrid Ecosystem. The Social Ecosystem Theory provides a top-level structural design framework for the system. It expands the intervention environment from a single physical space (school or home) to a "digital-physical" hybrid space. By leveraging IoT technology, the system breaks down the physical barriers between the home and the natural environment, creating a macro-level ecosystem that integrates natural interactions into children's social ecology. This macro-level digital–physical hybrid ecosystem emphasizes the dynamic interaction between individuals and their environments as a foundation for long-term health behavior formation [17].
- Meso-level perspective (Self-Determination Theory): Psychological motivation transformation. Within the macro-ecological framework, Self-Determination Theory serves as the driving force connecting environment and behavior. The system employs gamification mechanisms to fulfill children's three core psychological needs: autonomy (granting children the choice to care for plants), competence (allowing them to visually observe their cultivation efforts through growth

data), and belonging (establishing emotional bonds with anthropomorphic plant characters). This level converts external environmental stimuli into internal behavioral motivations.

- Micro-level perspective (Technology Acceptance Model): Interaction touchpoints for technology implementation. The model focuses on specific interaction interfaces and hardware experiences. By optimizing perceived ease of use and perceived usefulness, it lowers the technical operation threshold for children. This integrated Macro-Meso-Micro theoretical framework, which guides the entire system design, is visually represented in Figure 1.

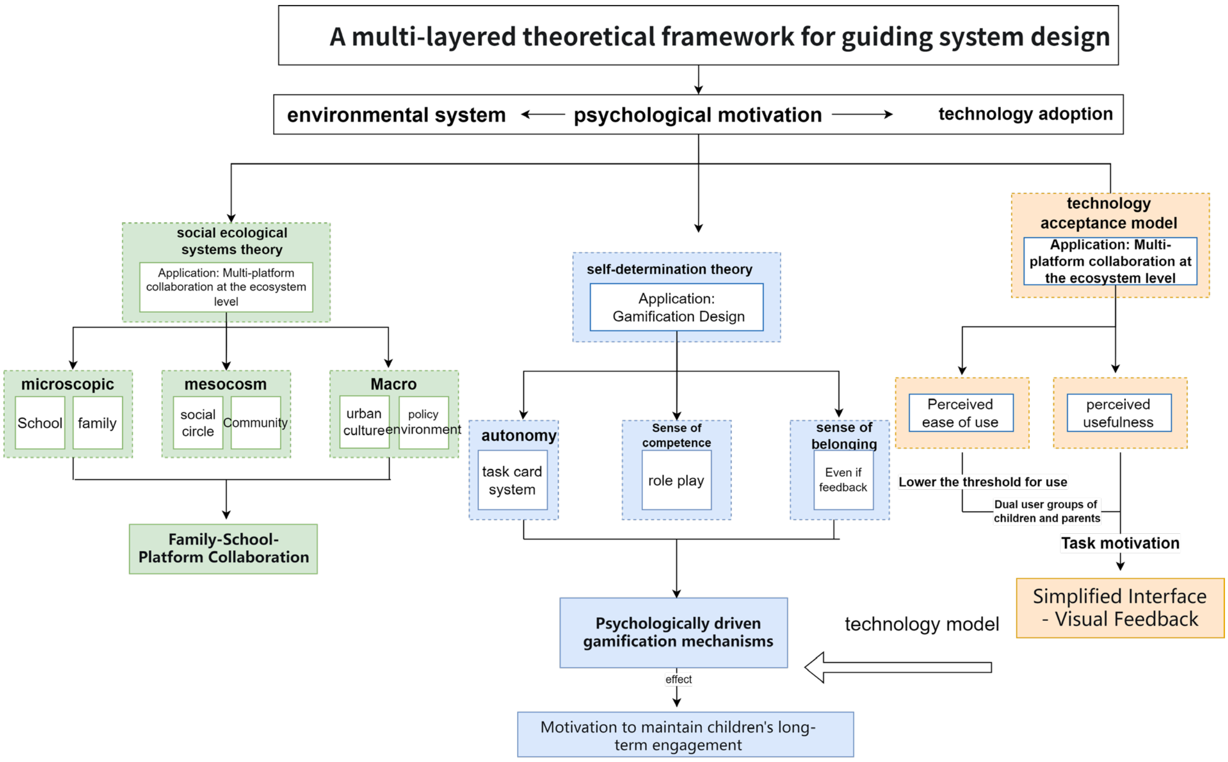


Figure 1. Theoretical framework diagram

3.2 Research Contribution

The innovation lies in integrating these theories across different layers. Socio-ecological theory provides the macro view; SDT drives the core gamification content; and TAM3 ensures usability at the interface level. This integrated" Macro-Meso-Micro" framework ensures the intervention is effective, sustainable, and capable of seamless integration into real-world social ecosystems.

3.3 Design Requirements

Based on the core needs inferred from user research, this study establishes four requirements for the interactive ecological intervention system: the emotional learning characteristics of children, the fragmentation of activity spaces, and the developmental needs of sociology.

- Requirement 1: A hybrid interactive urban space integrating indoor and outdoor environments. Children's fragmented activity spaces, influenced by living environments and limited learning opportunities, result in minimal exposure to nature. Previous computational studies on urban public spaces have demonstrated that environmental attributes and spatial perception play a critical role in shaping users' behavioral engagement and place identity, highlighting the importance of designing perceptible and continuous urban–nature interfaces [18]. To address this, the system must bridge outdoor exploration with indoor nurturing, creating a cohesive and sustainable interactive ecosystem.
- Requirement 2: Contextualized Learning Experiences. The user research demonstrates that children's innate

connection to nature is deeply intertwined with their cognitive development needs. Conventional knowledge-based teaching methods prove ineffective and problematic, whereas hands-on, multisensory learning better aligns with the cognitive patterns of 7-12-year-olds. The system delivers an immersive "learning through play" experience, transcending mere information presentation. It transforms abstract ecological concepts into tangible objects that children can physically collect, assemble, and observe, creating authentic learning scenarios. Similar principles of contextualized, play-based interaction design have been validated in prior child-oriented interactive hardware systems, demonstrating the effectiveness of tangible and scenario-driven learning experiences in sustaining children's engagement [19].

- Requirement 3: Sociological Development Needs–Multi-role Social Interaction. Children develop social relationships through play, such as parent-child bonds and peer partnerships. In nature observation games, diverse role-playing experiences foster varied social connections, enabling children to collaborate or compete with others. This process simultaneously enhances children's communication and teamwork skills.
- Requirement 4: Sociological Development Needs–Sustaining Long-Term Engagement. To transform interactions with nature from one-off activities into enduring habits, consistent motivation is essential. Research shows children's enthusiasm for fun, role-playing, and challenges validates the necessity of gamification mechanisms. This requirement emphasizes that the system must establish an effective, multi-tiered incentive framework to effectively maintain children's engagement and exploration drive.

These four requirements are visually summarized in the Needs Model presented in Figure 2, which guided the subsequent system design.

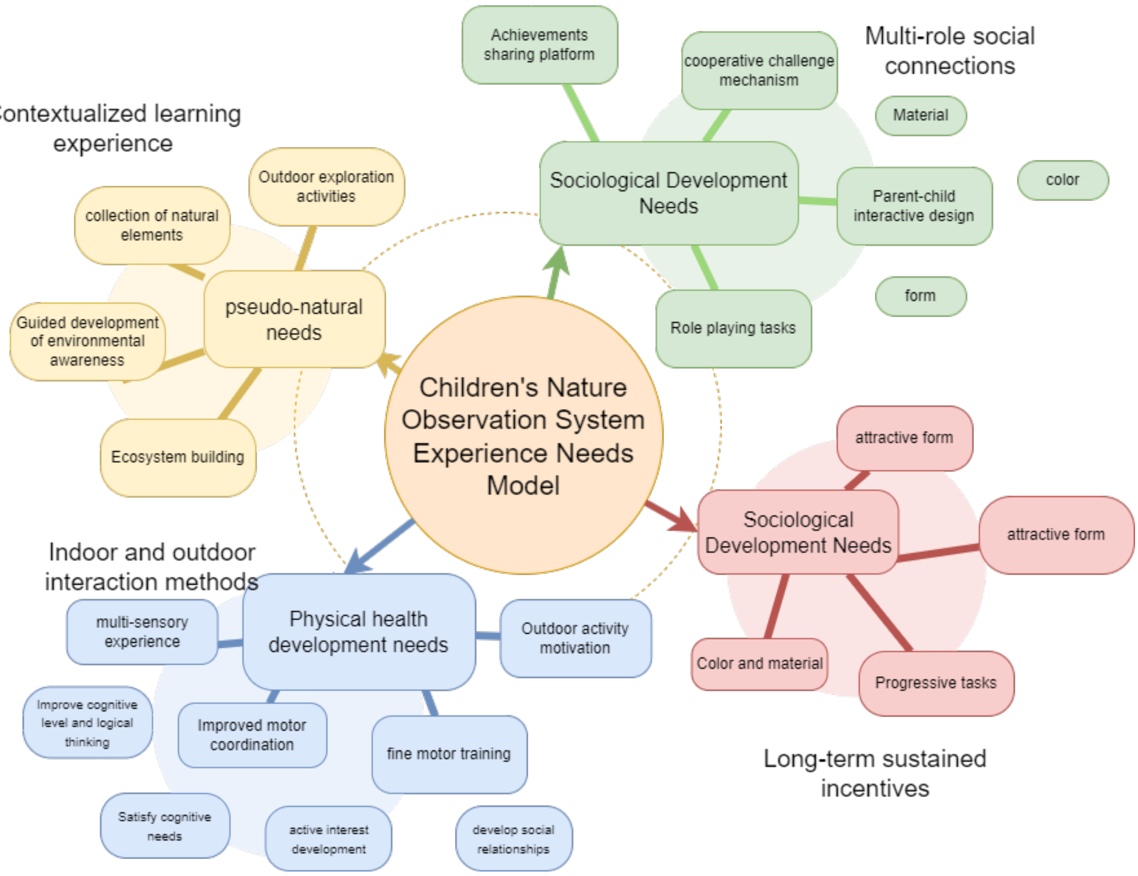


Figure 2. Needs Model of Children's Nature Observation Intervention System

3.4 System Architecture

To achieve gamified guided exploration, the system utilizes a three-layer Perception-Processing-Interaction architecture, as illustrated in Figure 3.

- Physical Perception Layer: Arduino platform collects environmental data (humidity, temperature) and user actions.
- Digital Processing Layer: Handles task distribution, logic judgment, and data analysis via the Cloud.
- Hybrid Interaction Layer: Includes physical task cards, reward stickers, and the App interface for feedback.

4. Methodology and Results

4. 1 Participants and Procedure

To test the proposed theoretical model, the study employed Partial Least Squares Structural Equation Modeling (PLS-SEM) for data analysis. The research constructs and their corresponding measurement indicators are detailed in Table 1. The study recruited 100 children (ages 6–12; balanced gender ratio; mean age = 9, SD = 1. 84) from schools and community centers in Guangzhou, China. Under the guidance of an instructor, each participant engaged in a 15-minute prototype experience involving both hardware operation and application-based tasks. Questionnaires were completed with parental assistance. Reliability analysis confirmed the validity of all 100 collected samples for further analysis. All constructs were measured using a 5-point Likert scale.

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The research protocol was reviewed and approved by the Research Ethics Committee at Zhongkai University of Agriculture and Engineering, following endorsement from the School of He Xiangning Art and Design. Prior to the commencement of the study, written informed consent was obtained from the legal guardians of all child participants. Both guardians and children were fully briefed on the study's objectives, procedures, and their right to withdraw at any time without consequence. Participant anonymity and data confidentiality were strictly maintained throughout the research process. Based on these constructs and hypotheses, the full structural equation model was established, as shown in Figure 4.

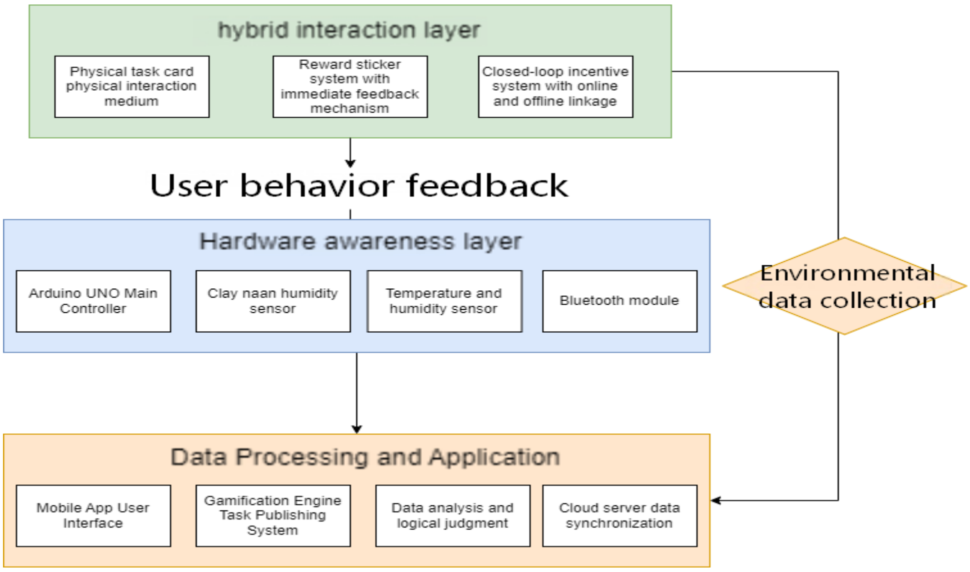


Figure 3. System Architecture Diagram

Table 1. Research on the Definition and Measurement Index of Construct Intervention

Construct	Theoretical basis	Operational definition	Measurement indicators
PEOU	TAM	Children's perception of the ease and fun of using this system (hardware + APP)	I find the system's task cards easy to understand, and it's really fun to water plants through the app.
PU	TAM	Children believe that using the system will help them better understand and connect with nature	"The system has made me more attentive to plant growth", "Through this system, I've gained knowledge about nature", and so on.
GAM	SDT	The system fulfills children's sense of autonomy, competence, and belonging	"Doing tasks gives me a sense of accomplishment" "I enjoy collecting different plant cards"

		through tasks, rewards, and role-playing.	
NC	CNS	The degree of emotional resonance and psychological identification between children and nature	Questions 2, 3, 4, 8, and 11 of the CNS Scale
PA	PANA-S	Children experience positive emotions after using the system	Use the "happy, excited, proud, joyful, energetic" emotions in PANA-S
NA	Pana-S	Negative emotions experienced by children after using the system	Use the "sad, afraid, angry, nervous, lonely" emotions in PANA-S”
BI	TPB	Children's Willingness to Explore and Maintain Nature Actively in the Future	"I will want to plant more plants in the future" and "I want to explore more in the park"

Hypotheses:

- H1: The system's perceived ease of use (PEOU) positively influences its perceived usefulness (PU).
- H2: The system's perceived ease of use (PEOU) positively influences users' gamification experience (GAM).
- H3: Gamified user experience (GAM) positively influences perceived usefulness (PU).
- H4: Gamification of user experience (GAM) positively influences their sense of natural connection (NC).
- H5: Gamified experience (GAM) positively influences users' biophilia (BI).
- H6: Natural connection (NC) positively influences users' positive affect (PA).
- H7: The user's natural connection (NC) negatively affects their negative affect (NA).
- H8: Users' natural connection (NC) positively influences their biophilia intention (BI).
- H9: A user's positive affect (PA) positively influences their biophilia intention (BI).
- H10: Users' negative emotions (NA) negatively affect their biophilia intention (BI).

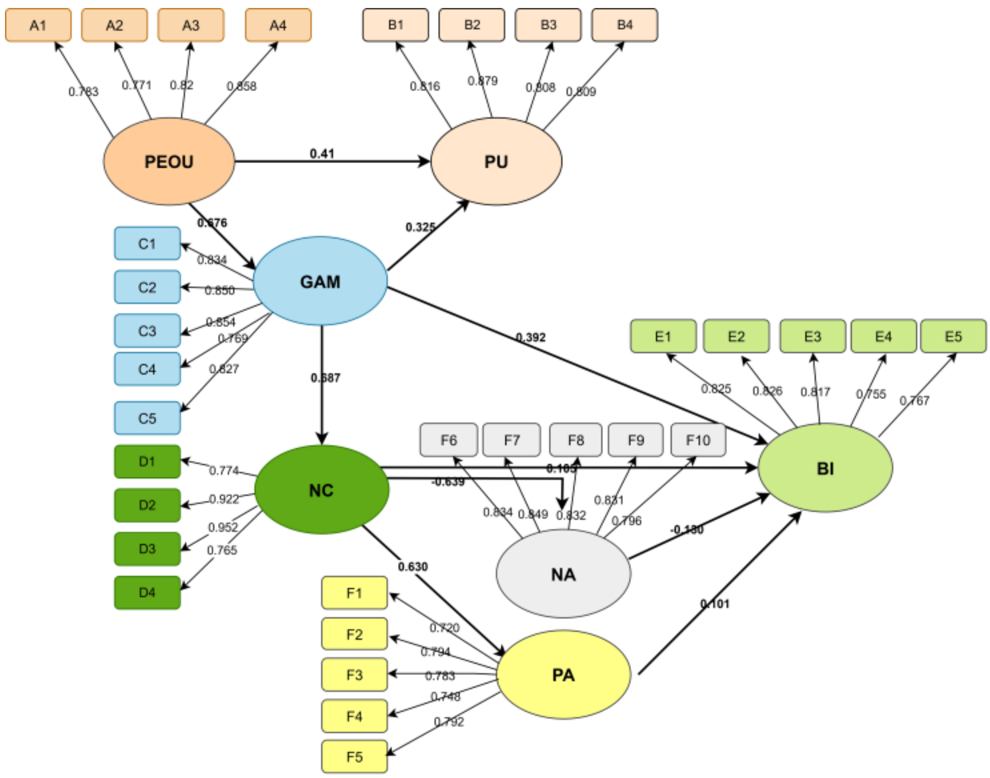


Figure 4. Structural Equation Modeling (SEM) Diagram

4. 2 Measurement Model Assessment

As shown in Table 2, all constructs demonstrated excellent internal consistency (Cronbach's α>0.8) and validity (KMO>0. 8, p<0. 001).

4. 3 Structural Model and Hypothesis Testing

The evaluation of the modeling model demonstrated strong reliability and convergent validity. All external loadings exceeded 0. 70 (ranging from 0. 711 to 0. 874), with composite reliability (CR) values between 0. 879 and 0. 918, and average variance extraction (AVE) values ranging from 0. 59 to 0. 69—all meeting or approaching recommended thresholds. The R^2 values indicated moderate to strong explanatory power for the endogenous constructs: gamified experience (GAM, R^2=0. 457), natural connection (NC, R^2=0. 477), pro-nature attitude (PA, R^2=0. 301), natural aversion (NA, R^2=0. 406), and pro-nature behavioral intention (BI, R^2=0. 396).

The results of the structural model analysis are presented in Table 3. The analysis provides support for the majority of the proposed hypotheses, while also revealing several unexpected non-significant paths that warrant further discussion

- PEOU→PU (H1: β=0. 397, p=0. 003)
- PEOU→GAM (H2: β=0. 676, p<0. 001)
- GAM→PU (H3: β=0. 344, p=0. 008)
- GAM→NC (H4: β=0. 691, p<0. 001)
- GAM→BI (H5: β=0. 376, p<0. 001)
- NC→PA (H6: β=0. 548, p<0. 001)
- NC→NA (H7: β=-0. 412, p<0. 001)
- NC→BI (H8: β=0. 633, p<0. 001)
- PA→BI (H9: β=0. 280, p=0. 116)
- NA→BI (H10: β=0. 242, p=0. 027)

To further explore the complex interaction mechanisms among variables in the model, the core mediating role of Generalized Additive Models (GAM) was examined. This study constructed a key mediating model to thoroughly analyze the core internal pathways through which system characteristics influence the final intervention outcomes.

The results of the Bootstrapping analysis (5,000 resamples), as shown in Table 4, revealed a crucial mediating path. The findings clearly indicate that "Gamified Experience" (GAM) plays a significant partial mediating role between" Perceived Ease of Use" (PEOU) and "Nature Connectedness" (NC) (indirect effect β=0. 241, p=0. 003).

Table 2. Reliability and Validity Assessment Form for PLS-SEM Measurement Model

Construct	items	Loadings	CR	AVE	R2	P
PEOU	A1	0. 779	0. 884	0. 656		0. 000
	A2	0. 777				
	A3	0. 821				
	A4	0. 859				
PU	B1	0. 824	0. 898	0. 689	0. 461	0. 000
	B2	0. 874				
	B3	0. 81				
	B4	0. 805				
GAM	C1	0. 841	0. 918	0. 692	0457	0. 000
	C2	0. 852				
	C3	0. 862				
	C4	0. 768				
	C5	0. 823				
NC	D1	0. 798	0. 884	0. 655	0. 477	0. 000
	D2	0. 818				
	D3	0. 858				
	D4	0. 765				
PA	F1	0. 711	0. 879	0. 593	0. 301	0. 000
	F2	0. 79				
	F3	0. 791				
	F4	0. 757				
	F5	0. 788				
NA	F6	0. 835	0. 916	0. 686	0. 400	0. 000
	F7	0. 851				
	F8	0. 832				
	F9	0. 827				
	F10	0. 794				
BI	E1	0. 83				

	E2	0. 83	0.	0.645	0.396	0.000
	E3	0. 825				
	E4	0. 755				
	E5	0. 762				

Table 3. Hypothesis Testing Results: Path Coefficients and Significance in the Structural Model

Hypotheses	path relationship	T	p	conclusion	β
H1	PEOU→PU	2. 963	0. 003	support	0. 397
H2	PEOU→GAM	6. 051	<0. 001	support	0. 676
H3	GAM→PU	2. 653	0. 008	support	0. 344
H4	GAM→NC	6. 271	<0. 001	support	0. 691
H5	GAM→BI	3. 540	<0. 001	support	0. 376
H6	NC→PA	4. 938	<0. 001	support	0. 548
H7	NC→NA	5. 224	<0. 001	support	-0. 412
H8	NC→BI	5. 224	<0. 001	support	0. 633
H9	PA→BI	1. 570	0. 116	support	0. 280
H10	NA→BI	2. 212	0. 027	support	0. 242

Table 4. The Mediating Role of Gamified Experience Between Perceived Ease of Use and Nature Connectedness

Hypotheses	path relationship	β	SE	t/z	p	95%CI
H1	PEOU→GAM→NC	0. 241	0. 080	3. 018	0. 003	[0. 099, 0. 412]

The validation of this mediation model provides decisive evidence for the core intervention mechanism of the system. The results reveal the internal logic of "how" the system works:a well-designed, easy-to-use system (high PEOU) does not primarily act directly, but rather most effectively enhances children's connection to nature by allowing them to more fully enjoy the gamified process.

This finding confirms that Gamified Experience is not just a conduit bridge between technical features and intervention outcomes, but also the amplifier and engine of the entire system. It validates a core driving path: Technical Characteristics → Psychological Mechanism → Intervention Outcome. This empirical evidence provides a solid foundation for the subsequent selection of typical users for field observation to verify the reasonableness of the theoretical framework.

4.4. Typical User Profiles

This paper provides the empirical evidence for the validity of the system. Based on this evidence, three typical user models are selected, combined with field investigation and the verification of the theoretical framework and its rationality. Three distinct user profiles were identified: the Nature-Avoidant, the Nature-Explorer, and the Deeply Immersed user, as detailed in Table 5. These profiles were synthesized from qualitative data gathered during offline field research, highlights of which are shown in Figure 5 (a-c).

Table 5. User model

User (Child):	User A: Nature-Avoidant	User B: Nature-Explorer	User C: Deeply Immersed
Male, 5th Grade (Math Rep)	Female, 6th Grade (Student Leader)	Female, 5th Grade (Student)	Female, 5th Grade (Student)
Personal Characteristics	High interest in video games; prefers virtual interaction over physical nature.	Prefers reading ("Bookworm"); enjoys quiet observation (e.g., rainy weather).	Skilled in construction toys (e.g. blocks); enjoys breeding tasks.
Nature Preferences	Interested in microbes but averse to insects and weather changes.	Prefers making plant crafts (bookmarks) over direct soil contact; dislikes bugs.	Engages in diverse activities like planting flowers and raising ants.

Motivation Source	Motivated by school assignments and intergenerational family guidance	Driven by peer influence (classmates) and spontaneous curiosity	Influenced by family routines (balcony gardening) and farm experience

Figure 5. Offline research map

5. System Design and Implementation

5.1 Interaction Prototype

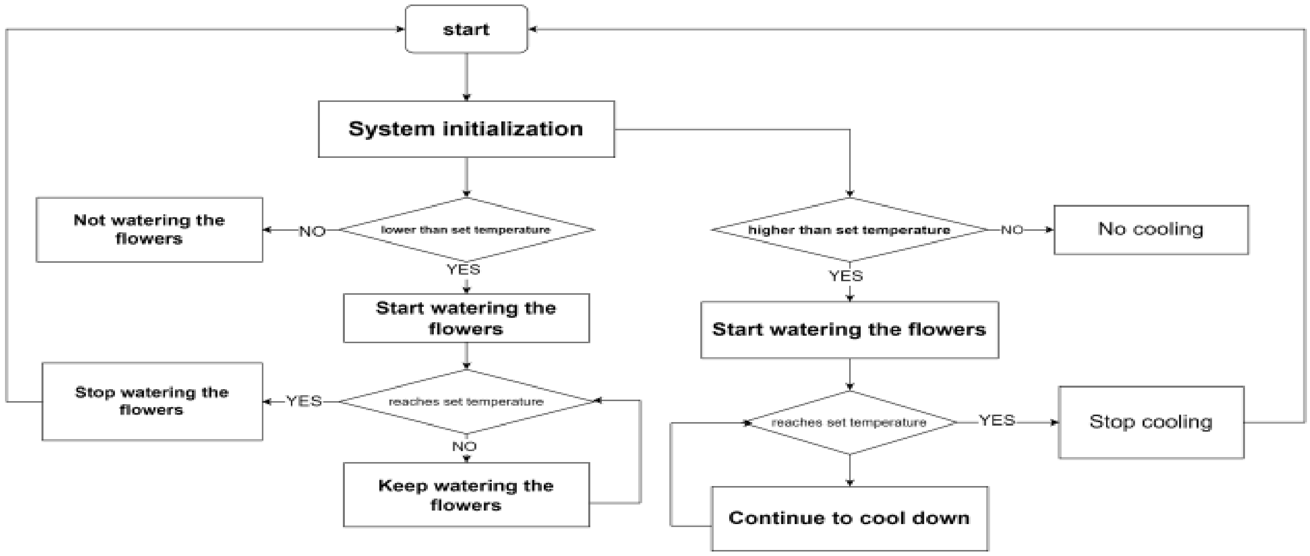
The prototype includes a soil moisture detection module and an outdoor exploration kit.

Logic: Soil sensors detect plant needs (Technical Intervention) → App sends reminder → Child performs watering (Behavioral Guidance) → App unlocks "Virtual Nutrients" (Reward)

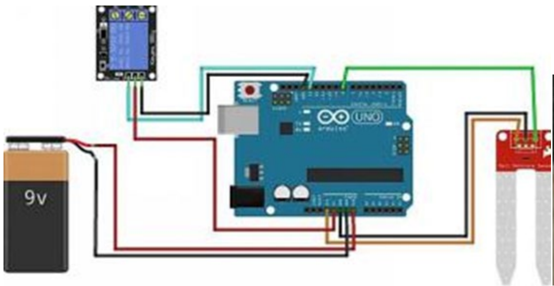
5.1.1 Interaction Prototype Case: Remote Watering Interaction Based on Cloud Data

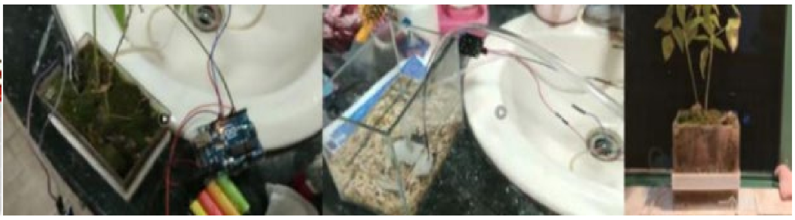
The system interaction prototype comprises experimental components including an automated irrigation system, second-generation prototype design for the indoor cultivation module, and outdoor task cards. Detailed implementations are illustrated in Figures 9, 11, 12, and 13. Figure 9 demonstrates the Arduino hardware configuration, featuring a main control board, sensor connections, 9V battery power supply, irrigation logic flow (initiation-detection of humidity-irrigation decision-making-irrigation-execution-termination) and irrigation decision flow (humidity below threshold? yes-irrigate-no-wait). To validate the effectiveness of networked intervention, the system incorporates a remote empathetic irrigation mechanism that merges physical and digital realms. The hardware configuration, logical flow, and a physical prototype of this automated watering system are collectively illustrated in Figures 6(a-c).

- Digitalization process: Capacitive sensors embedded in soil collect real-time humidity data, which is transmitted to a cloud server via the Arduino main control board through network modules. When humidity drops below a preset threshold (e. g. , <30%), the system converts the plant's physiological dehydration status into digital signals rather than directly activating the water pump.
- Network-triggered emotional engagement: The cloud instantly sends notifications to parents 'mobile apps, displaying a' thirsty 'emoji through anthropomorphic plant characters on the interface. This step leverages the internet to make plants' latent needs visible, breaking time and space constraints. No matter where children are, they can monitor plant conditions via the network.
- Remote control and physical feedback: Children tap the 'water' button on the app to complete the task. The command is transmitted via the internet to the Arduino device at home, which activates the water pump to perform the physical watering action.



(a)



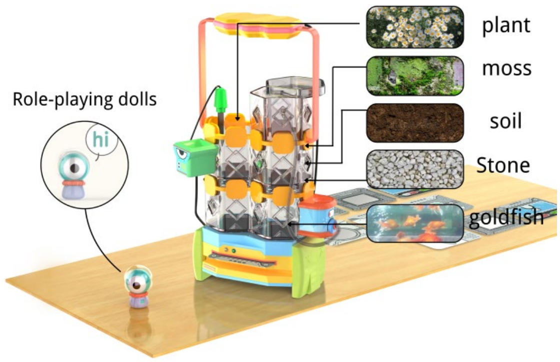


(b) (c)

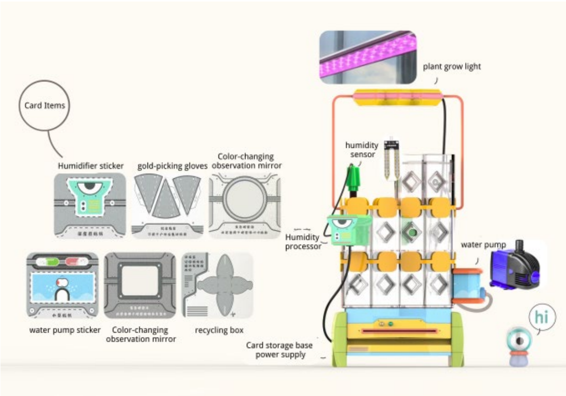
Figures 6 a, b, c. Logic diagram of automatic watering system

5.2 Implementation Details

- Core controller: The system utilizes Arduino UNO Rev3 as the main control board, which is open-source, features multiple interfaces, and benefits from robust community support, facilitating future expansion.
- Core sensors: Capacitive soil moisture sensor v1.2 (corrosion-resistant); Temperature and humidity detection uses DHT22 (temperature/humidity). The accuracy exceeds that of the commonly used DHT11.
- Communication: HC-05 Bluetooth module (current<10mA in low-power mode).
- Algorithm: A threshold-based watering logic (activating the pump when humidity drops below 30%) and a gamified points system (using KNN classifiers to predict user engagement). A physical representation of the prototype, including the modular components and user interface elements, is depicted in Figures 7(a-b).



(a)



(b)

Figures 7 a, b Physical model display diagram

6. Discussion

6.1 The Logical Self-consistency of Theoretical Model and Its Preliminary Verification

The "macro-meso-micro" cross-level theoretical framework developed in this study has been preliminarily validated through statistical analysis. Structural equation modeling (SEM) revealed that perceived ease of use(micro-technical layer) significantly correlates with natural connection (macro-environmental layer) via positive mediating effects of gamified experience (meso-psychological layer). This finding suggests a potential intervention pathway: fulfilling children's psychological needs (SDT) can effectively bridge the gap between technological interventions and natural experiences. The data confirmed the logical consistency of the theoretical model, demonstrating that integrating social ecology theory with technology acceptance models provides an effective perspective for interpreting IoT intervention behaviors. Meanwhile, gamified experience (GAM) could significantly predict pro-natural intentions (BI) (H5 was supported), revealing a valuable insight: in children's digital health interventions, the core drivers of future behavioral intentions may stem more from immediate enjoyment during the experience process than from abstract meanings or emotional elevation derived from the experience.

6.2 Feasibility Analysis of Network Interaction Mechanism

Testing through watering scenarios demonstrates the high feasibility (Feasibility) of the proposed "network interaction loop" in both technical implementation and user experience. Unlike traditional automated irrigation, this system employs IoT technology to create a closed-loop process of "sensing, network transmission, remote decision-making, and physical feedback," successfully transforming physical plant care into children's familiar digital interactions. User feedback data indicates that this "remote empathy" mechanism effectively maintains children's attention to plants. This suggests that leveraging IoT technology to transcend physical space limitations and establish continuous natural touchpoints in the lives of Digital Natives represents a highly promising system design.

6.3 Limitations and Exploratory Nature

It should be emphasized that this study is exploratory in nature and has the following limitations: flaws in core methodologies, lack of control group studies and baseline measurements. The single-group post-test design employed in this study cannot exclude the influence of potential confounding factors such as novelty effects and social expectations, nor can it conduct genuine before-and-after comparisons. This represents the most significant limitation in terms of evidence quality. Additionally, the study involves confounding variables: parental involvement. The questionnaire completion and certain procedures required parental assistance, making it difficult for researchers to fully distinguish whether the intervention effects originated from the system itself or enhanced parent-child interactions.

Future research could address this by incorporating measures of parent-child interaction quality as a potential moderating variable. The study also has short-term effects and sample limitations: a 15-minute short-term experience and a sample of 100 children from Guangzhou region significantly restrict the predictive power of conclusions regarding long-term behavioral habit changes and population generalizability. However, as a proof-of-concept study for novel intervention tools, this research lays crucial design foundations and theoretical hypotheses for subsequent large-scale longitudinal randomized controlled trials (RCTs).

7. Conclusion

7.1 Research Summary

To address the growing prevalence of nature deficit disorder (NDD) among urban children, this study proposes and explores a novel IoT-based proactive prevention model.

- Theoretical Construction: The study innovatively proposes an integrative theoretical framework that combines social ecosystem theory (macro), self-determination theory (meso) and technology acceptance model (micro). This framework provides a new theoretical perspective for understanding how technology intervenes in nature education.
- Design Exploration: Based on the above theories, we designed and implemented a prototype of an interactive ecological intervention system combining software and hardware. Through features like "remote network

interaction," we successfully explored how to seamlessly integrate nature conservation into digital home life.
- Preliminary validation: User research and model analysis have preliminarily confirmed that the system demonstrates excellent perceptual usability and sustained engagement mechanisms, validating the potential effectiveness of the intervention pathway: "technology-driven-psychological satisfaction-natural connection".

7.2 Contributions and Prospects

The core value of this study lies in its methodological and design paradigm innovation. We demonstrate that digital technology should not merely serve as a barrier isolating children from nature, but can instead become a bridge through well-designed approaches (such as IoT integration and gamification). This work provides a low-cost, scalable proactive prevention design model for the field of Digital Health. While long-term health benefits still require rigorous validation at the medical level, this study confirms the logical and experiential validity of this "digital-physical hybrid intervention" model, paving the way for future exploration in smart education and family health.

Appendix: Fund Projects

Funding Projects: 1. Maoming Rural Science and Technology Commissioner Program under Guangdong Provincial Department of Science and Technology's "Hundred-Thousand Project" – "Bohe Seawater Fish Industry and Cultural Tourism Innovation Plan" (Project ID: KTP20240596); 2. Modern Industry College under Guangdong Provincial Quality Engineering – "Ecological Design Industry College" (Project ID: KA23YY082); 3. 2021 Guangdong Provincial First-Class Specialty Construction Program – "Product Design" (Project ID: 400102).

Funding: This research was funded by the 2024 Guangdong Provincial Department of Science and Technology "Guangdong Rural Science and Technology Commissioner Project: Jiangdong Vegetable, Rice, and Agro-Cultural Tourism Industry Brand Building and Promotion" (Project No. KTP20240829); the Construction of science and technology plan project content in Jiangdong Town, Chaoan District, Chaozhou City (Project No. D125211E7); and 2024 Chaozhou City Chaoan District Science and Technology Special Fund: Construction of Ecological Industry Innovation Talent Cultivation Base under the "Hundred, Thousand, Ten Thousand Project" (Specialized Town Transformation and Upgrading Project).

1.Hexiangning College of Art and Design, Zhongkai University of Agriculture and Engineering, No. 24, Dongsha Street, Haizhu District, Guangzhou City, Guangdong Province, China

2.People's Government of Jiangdong Town, No. 1 Fuqian Street, Jiangdong Town, Chaoan District, Chaozhou City, Guangdong Province, China

References

[1] Huang X. The children-nature relationship: Contact, cognization and emotion. Human Geogr. 2020;35(6):9-17, 75. doi:10. 13959/j. issn. 1003-2398. 2020. 06. 002
[2] Lei W. Does preschool education experience help disadvantaged students become academically resilient? Empirical evidence from CEPS data. Best Evid Chin Educ. 2023;13(1):1665-1670. doi:10. 15354/bece. 23. or 005
[3] Driessnack M. Children and nature-deficit disorder. J Spec Pediatr Nurs. 2009;14(1):73-75. doi:10. 1111/j. 1744-6155. 2009. 00180. x
[4] Edwards RC, Larson BMH. When screens replace backyards: strategies to connect digital-media-oriented young people to nature. Environ Educ Res. 2020;26(7):950-968. doi:10. 1080/13504622. 2020. 1776844
[5] Bezeljak Cerv P, Büssing AG, Möller A. Only green time, and not screen time, predicts connectedness to nature among urban middle school students. People Nat. 2025;7(3):e70143. doi:10. 1002/pan3. 70143
[6] Andersen L, Corazon SS, Stigsdotter UK. Nature exposure and its effects on immune system functioning: a systematic review. Int J Environ Res Public Health. 2021; 18(4): 1416. doi:10.3390/ ijerph18041416
[7] Tillmann S, Tobin D, Avison W, Gilliland J. Mental health benefits of interactions with nature in children and teenagers: a systematic review. J Epidemiol Community Health. 2018;72(10):958-966. doi:10. 1136/jech-2018-210436
[8] Fyfe-Johnson AL, Hazlehurst MF, Perrins SP, et al. Nature and children's health:a systematic review. Pediatrics. 2021;148(4):e2020049155. doi:10. 1542/peds. 2020-049155
[9] Dankiw KA, Tsiros MD, Baldock KL, Kumar S. The impacts of unstructured nature play on health in early childhood development:a systematic review. PLoS One. 2020;15(2):e0229006. doi:10.1371/journal.pone.0229006
[10] Becker C, Lauterbach G, Spengler S, Dettweiler U, Mess F. Effects of regular classes in outdoor education settings:a systematic review on students'learning, social and health dimensions. Int J Environ Res Public Health. 2017;14(5):485. doi:10. 3390/ijerph14050485
[11] Hsu CL. Applying cognitive evaluation theory to analyze the impact of gamification mechanics on user engagement in resource recycling. Inf Manag. 2022;59(2):103602. doi:10. 1016/j. im. 2022. 103602
[12] Darejeh A, Salim SS. Gamification solutions to enhance software user engagement—a systematic review. Int J Hum Comput Interact. 2016;32(8):613-642. doi:10. 1080/10447318. 2016. 1183330

[13] Xiao T, Wu Y, Hamari J. Internet of Gamification: A Review of Literature on IoT enabled Gamification for User Engagement. In: Proceedings of the 54th Hawaii International Conference on System Sciences. Kauai, HI:HICSS; 2021. p. 1355-1364.
[14] Xiao R, Wu Z, Hamari J. Internet-of-gamification: a review of literature on IoT-enabled gamification for user engagement. Int J Hum Comput Interact. 2022; 38(12):1113-1137. doi:10. 1080/10447318. 2021. 1990517
[15] Wang M, Xu J, Zhou X, Li X, Zheng Y. Effectiveness of gamification interventions to improve physical activity and sedentary behavior in children and adolescents: systematic review and meta-analysis. JMIR Serious Games. 2025; 13:e68151. doi:10. 2196/68151
[16] Mazéas A, Duclos M, Pereira B, Chalabaev A. Evaluating the effectiveness of gamification on physical activity: systematic review and meta-analysis of randomized controlled trials. J Med Internet Res. 2022;24(1):e26779. doi:10. 2196/26779
[17] Jiayi CH. Research on Ecological Co-creation Design Theory and Methodology for Future-oriented Sustainable Health Engineering. Green Design Engineering. 2024 Oct 1; 1(1): 20-32.
[18] Gao, Y. , & Lai, X. (2025). The Chromatic Evolution of Public Spaces in a Global-Local City: A Computational Analysis of Macau's Urban Identity. BIG. D, 2(3), 84-93.
[19] Zhai C, Chen X, Cheng Z, Yao Y, Zhang J. Portable interactive nebulizer design for children. In: Ciancarini P, Di Iorio A, Hlavacs H, Poggi F, editors. Entertainment Computing–ICEC 2023. Lecture Notes in Computer Science, vol 14455. Springer;2023. p. 484-496. doi:10. 1007/978-981-99-8248-6_46