From Ecological Design to Educational Empowerment: Exploring a Healthy Food Innovation Model for Sustainable Food Systems

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***Abstract*—Background & Rationale (Why): The global food system faces severe sustainability challenges. Prevailing innovation models, often technology-centric, tend to overlook the systemic ecological integration and societal-level educational empowerment required for a holistic transformation. This study addresses this gap by proposing a new, integrated framework.Methodology (How): Adopting a design research approach, this study constructs a theoretical framework that synergizes Ecological Design principles with Educational Empowerment strategies. This framework is developed to guide a more comprehensive innovation process.Implementation (With what): The framework is validated and iterated into a practical model fatores, named "SEED" (Sustainable-Ecological-Educational-Design), through a multi-case analysis of a plant-based protein company and a local food network. The analysis is supported by data from expert interviews and consumer surveys.Core Findings (What): The findings provide empirical support that integrating ecological design with educational empowerment is associated with improved perceived sustainability value and stronger consumer purchase intention. The SEED model offers a design-driven framework that can guide sustainable healthy food innovation across product, communication, and community engagement. Ecological design principles optimize resource circularity and value chains, while educational empowerment strengthens consumer sustainability consciousness and engagement.Significance & Value (So what): This study contributes a novel, design-driven innovation pathway for food system transformation. It offers practical guidance for policymakers, enterprises, and educational institutions on integrating ecological and social benefits, providing a replicable model for creating shared value.**

Keywords—Sustainable Food Systems, Ecological Design; Educational Empowerment, Healthy Food, Innovation Model

I. INTRODUCTION

The contemporary global food system stands at a critical juncture, confronting an unprecedented "triple challenge": the need to meet the nutritional demands of a growing global population, address severe environmental pressures climate change and biodiversity loss, and resolve public health issues linked to diet [1, 2]. According to the Food and Agriculture Organization of the United Nations (FAO), the current food system contributes to approximately one-third of global greenhouse gas emissions and places immense strain on land and water resources [3]. Concurrently, unhealthy dietary patterns have led to a global paradox of malnutrition and obesity, imposing a heavy economic and health burden on society [4].

Against this backdrop, transitioning the food system towards a more sustainable, resilient, and inclusive model has become a pressing global imperative. As a core driver of this transformation, healthy food innovation transcends mere product development, extending to the systemic reconfiguration of entire production, consumption, and value networks.

However, existing food innovation paradigms have revealed their limitations in addressing these systemic challenges. Current research and practice predominantly focus on technological breakthroughs, such as improving crop varieties through biotechnology, enhancing production efficiency with digital agriculture, or developing novel food processing technologies to improve product taste and shelf-life [5, 6]. While undoubtedly important, these technology-driven innovations often tackle problems in a linear, isolated manner, neglecting the inherent interconnectedness of the food system as a Complex Adaptive System [7]. This "siloed" approach to innovation struggles to effectively integrate ecological and social benefits across the value chain and may even trigger unintended negative consequences, such as exacerbating reliance on a single resource or widening the digital divide. Consequently, academia and industry urgently need to explore a more holistic and integrated innovation pathway. The central research question posed by this paper is: How can a design-driven, systemic approach be used to construct a healthy food innovation model that synergistically enhances ecological health, social well-being, and economic viability?

Through a systematic review of the existing literature, we have identified significant research gaps in three primary areas. First, there is a deficiency in the integration of design thinking. Although design thinking has proven effective in solving complex problems across various fields as a human-centered innovation methodology [8], its application in the food innovation sector remains nascent, largely confined to downstream aspects like packaging or branding, failing to penetrate strategic and business model levels. Second, an ecosystem perspective is largely absent. Much of the current research proceeds from a single-disciplinary viewpoint, lacking a holistic perspective that treats the stages of food production, processing, consumption, and waste as an integrated life cycle and ecosystem. This has left the

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potential for resource circularity and value regeneration largely untapped [9]. Third, consumer participation remains passive. In the innovation process, the consumer's role is often reduced to that of a passive "needs provider" or "product acceptor." Their agency as practitioners of sustainable behavior and co-creators of value is severely underestimated, leading to the market failure of many innovative products with excellent sustainability attributes due to a lack of public understanding [10].

To address these research gaps, this study aims to construct and validate a healthy food innovation model centered on "Ecological Design" as its theoretical core and supported by "Educational Empowerment" as a key pillar. We have named this the "SEED" (Sustainable-Ecological-Educational-Design) model. This research is positioned at the intersection of design research, food science, and sustainability science. Through a combination of theoretical construction and empirical case analysis, it seeks to forge an innovation pathway that deeply integrates ecological wisdom with social learning. We anticipate that this model will not only provide a methodological guide for enterprises to develop more competitive healthy foods but also offer new insights and tools for policymakers and educators to advance the food system transformation.

This paper is structured as follows: Section 2 reviews the relevant theories and research on sustainable food systems, ecological design, and educational empowerment. Section 3 details the design research methodology employed, including the construction process of the SEED model, case selection, and data analysis strategy. Section 4 presents the main findings from the case studies and quantitative research. Section 5 provides an in-depth discussion of the results, analyzing their theoretical and practical implications and addressing the study's limitations. Finally, Section 6 concludes the paper and outlines future research directions.

II. RELATED WORK

This research is grounded in the interdisciplinary theoretical foundations of sustainable food systems, ecological design, educational empowerment, and design-driven innovation. This section aims to review the core theories and current state of research in these fields to establish the theoretical positioning and contribution of this study.

A. The Theoretical Evolution of Sustainable Food Systems

The concept of a sustainable food system has undergone a dynamic evolution. Early research predominantly focused on the sustainability of agricultural production, termed "sustainable agriculture," which emphasized reducing the use of pesticides and fertilizers and protecting the ecological environment. As understanding deepened, the academic perspective broadened from the singular production stage to encompass the entire food chain, leading to the linear "Farm to Fork" analytical framework . Although this framework integrated multiple stages, including production, processing, distribution, and consumption, it still tended to optimize each stage as an independent unit. In the 21st century, particularly with the influence of the Industry 4.0 wave, a more integrated "Food System" thinking has become mainstream. This perspective emphasizes viewing the food system as a complex, interconnected socio-ecological-technical system, where various elements—such as agriculture, environment, health, economy, and culture—mutually influence and dynamically co-evolve. More recently, scholars have advanced the concept of "Food System Transformation," advocating for systemic change rather than piecemeal improvements to address multifaceted challenges like climate change, resource depletion, and public health crises. The goal is to build a future food system that is more resilient, equitable, and sustainable . This evolutionary trajectory clearly indicates that solving current food-related problems requires moving beyond the confines of single stages or disciplines and adopting a more holistic and systemic methodology, which provides the theoretical grounding for this study's introduction of a cross-disciplinary design perspective.

B. Ecological Design Theory and Its Applications

Ecological Design is a discipline that aims to harmonize human activities with natural processes. Its core lies in applying ecological principles to guide design practice, thereby maximizing resource utilization and minimizing environmental impact. The foundational principles of ecological design include: "solutions grow from place," emphasizing that design should fully consider the natural and cultural characteristics of a locality; "ecological accounting," which advocates for assessing the environmental impact of a design solution throughout its entire life cycle; and "design with nature," which promotes drawing design inspiration from the structure, function, and cyclical patterns of natural ecosystems. In practice, ecological design has achieved significant success in fields such as architecture, landscape planning, and industrial manufacturing, with examples including zero-energy buildings, circular economy industrial parks, and urban stormwater gardens. However, despite the food system's intimate connection to natural ecosystems, the systematic application of ecological design theory in the field of food innovation has lagged. Existing research is often limited to the ecological optimization of specific links, such as organic farming, biodegradable packaging design, or food waste treatment, and lacks a theoretical model and practical guide for integrating the entire food value chain within an ecological design framework. This study seeks to fill this gap by embedding the systemic thinking and life-cycle perspective of ecological design throughout the entire process of healthy food innovation.

C. Educational Empowerment and Sustainable Consumption

Achieving a sustainable transformation of the food system requires not only changes on the production side but also active engagement on the consumption side. However, the "attitude-behavior gap" among consumers regarding sustainable food has consistently been a major barrier to market development. Educational Empowerment is widely regarded as a key pathway to bridging this gap. Unlike traditional, one-way information dissemination, educational empowerment emphasizes enhancing learners' critical thinking skills, systemic cognitive abilities, and willingness to act through participatory, experiential, and transformative learning processes, thereby enabling them to become proactive agents of change. In the realm of sustainable consumption, research has shown that effective educational programs can significantly increase consumers' awareness of the ecological and social values behind products and translate this awareness into actual purchasing behavior. Furthermore, educational empowerment is not limited to individual consumers but also stresses the construction of learning networks and support systems at the community level, reinforcing and disseminating sustainable lifestyles through social interaction and collective practice. Although the importance of education in promoting sustainable development is a consensus, in food innovation practice, educational activities are often treated as ancillary to marketing or brand communication. Their potential as a core innovation driver and value co-creation mechanism remains largely untapped. This study positions "Educational Empowerment" as a core pillar parallel to "Ecological Design," aiming to explore how education can be deeply integrated into the innovation process to build an innovation ecosystem where producers and consumers learn and evolve together.

D. Design-Driven Social Innovation

The connotation of design as a discipline has expanded from traditional "object-making" to "complex problem-solving." The rise of Design Thinking, in particular, has provided a systematic methodology for social innovation. Characterized by its human-centeredness, rapid prototyping, and iterative testing, design thinking has been widely applied to improve complex social systems in public services, healthcare, and education [8]. It emphasizes understanding the true needs of stakeholders through deep empathy, integrating diverse perspectives through interdisciplinary collaboration, and testing and communicating complex solutions through tangible prototypes. In the food sector, some pioneering practices have begun to apply design thinking to address social issues such as food waste and improving nutrition for vulnerable groups. These practices demonstrate that design is not just about aesthetics or function, but is also a "social technology" capable of effectively connecting different stakeholders, integrating heterogeneous knowledge, and ultimately forming systemic solutions. Based on this profound understanding of the role of the design discipline, this study attempts to elevate the design-driven innovation approach from solving local problems to constructing an entire sustainable food innovation model at a strategic level, thereby offering a new possibility for tackling the complex challenges of the food system.

III. METHODOLOGY

To systematically construct and validate the "From Ecological Design to Educational Empowerment" model for healthy food innovation, this study employed a Mixed Methods Research approach, integrating both qualitative and quantitative analyses. The overall research framework adheres to the fundamental logic of Design Research, which involves a cyclical process of "theory construction - practical testing - model iteration" to develop a solution that is both theoretically rigorous and practically relevant. This section details the research's technical route, the construction process of the SEED model, the design of the case studies, and the strategies for data collection and analysis.

A. Research Strategy and Technical Route

The technical route of this study is divided into three main phases (see Figure 1).

- Phase 1: Theoretical Construction. This phase was based on a comprehensive literature review. By systematically examining relevant theories in sustainable food systems, ecological design, educational empowerment, and design-driven innovation, we identified existing research gaps and points of integration. Based on this, we preliminarily constructed the theoretical framework of the SEED (Sustainable-Ecological-Educational-Design) innovation model, defining its core dimensions and internal logical relationships.
- Phase 2: Case Study and Data Collection. This phase was the crucial link between theory and practice. We selected two representative cases and employed multiple methods—including semi-structured interviews, participant observation, and survey questionnaires—to collect in-depth data on the application of ecological design and the practice of educational empowerment from various perspectives.
- Phase 3: Model Validation and Iteration. In this phase, we systematically analyzed the collected data using both qualitative and quantitative tools. On one hand, qualitative analysis deepened our understanding of the internal mechanisms of the innovation model. On the other hand, quantitative analysis tested the validity of the key assumptions within the model. Based on the analysis results, we revised and refined the preliminarily constructed SEED model, ultimately forming a more mature theoretical model that has been empirically tested.

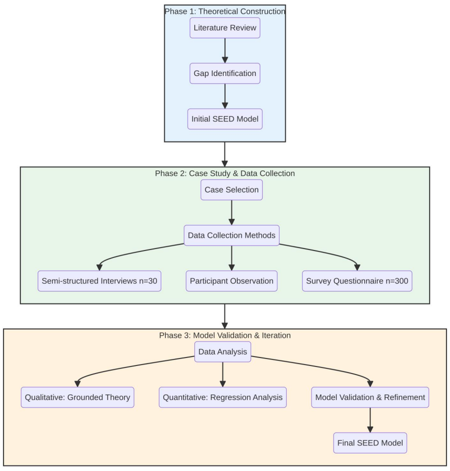

Fig. 1. Research Technical Route

B. Construction of the SEED Innovation Model

The SEED innovation model is the core theoretical contribution of this research. Its name is an acronym of its four core dimensions, aiming to reveal the fourfold attributes that a successful sustainable healthy food innovation should possess (see Figure 2).

- Sustainable (S) is the ultimate goal of the model. It refers not only to environmental sustainability but also to a comprehensive concept that includes economic viability, social equity, and cultural appropriateness. In this model, all innovation activities must be evaluated and decided upon under the guidance of this ultimate goal.
- Ecological Design (E) is the core methodology of the model. It adopts ecological principles as the fundamental criteria for design, advocating for a systemic and life-cycle perspective in examining the innovation process. This includes selecting renewable

resources at the raw material stage, optimizing energy and water use in production, designing easily recyclable or biodegradable packaging for products, guiding waste reduction at the consumption stage, and ultimately achieving resource circularity at the disposal stage.

- Educational Empowerment (E) is the key support mechanism of the model. It emphasizes that the innovation process itself is a two-way process of learning and communication. Enterprises are not just creators of products but also disseminators of knowledge and advocates for sustainable lifestyles. Through transparent information communication, participatory experiential activities, and the construction of community networks, consumers are transformed from passive buyers into active co-creators of value. Their sustainability awareness and behavioral capabilities are enhanced, thus laying a solid social foundation for the market success of ecologically designed products.
- Design-Driven (D) is the implementation pathway of the model. It emphasizes the use of design thinking tools and processes—such as user empathy, interdisciplinary collaboration, rapid prototyping, and iterative testing—to integrate the complex requirements of the other three dimensions. Design plays the role of a "binder" and "transformer," translating abstract ecological principles and educational concepts into concrete products, services, and business models, ensuring that the innovation solution is both forward-looking and feasible, with user value.

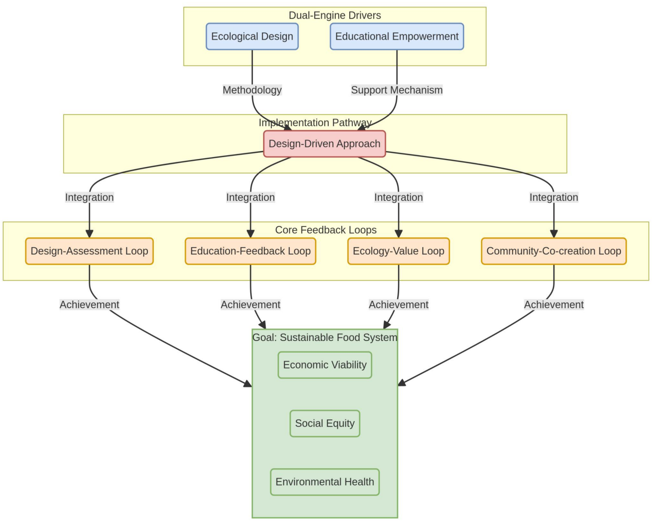

Fig. 2. The SEED Theoretical Model Framework

C. *Case Selection and Data Collection*

To test and develop the SEED model in real-world contexts, this study carefully selected two cases of different types, both of which embody the ideas of ecological design and educational empowerment.

Case A: An Innovative Plant-Based Protein Food Company. This company is renowned for its strong focus on sustainability in product development. Its products not only use plant protein raw materials with a lower environmental impact but also actively convey sustainability concepts in jejich packaging design and brand communication. This case helps us to deeply explore how ecological design principles are integrated into the product development process within a commercial company environment and how corporate-led educational communication activities affect consumer brand perception and purchasing decisions.

Case B: A City's Community Supported Agriculture (CSA) Network. This is a social enterprise network that connects local organic farms with urban consumers. By establishing a short-chain supply, it reduces food miles and waste in intermediate links. At the same time, by organizing rich community activities such as farm visits, farming experiences, and dietary workshops, it greatly enhances the connection and trust between consumers and food producers. This case provides us with an excellent sample for observing how ecological design and educational empowerment mutually promote and co-evolve at the community level.

For these two cases, we adopted a variety of data collection methods to ensure the depth and validity of the research:

- Semi-structured Interviews (n=30): We conducted in-depth interviews with key stakeholders in both cases, including company founders, product designers, food R&D engineers, marketing managers, farm owners, community organizers, and senior consumers. The interviews aimed to gain a deep understanding of their perspectives on sustainable innovation, their practical experiences, and the challenges they face.
- Participant Observation: Researchers conducted three months of participant observation in the community activities of Case B (such as produce delivery days and offline workshops) to record and experience the specific processes and interactive details of educational empowerment activities from a first-person perspective.
- Survey Questionnaire (n=300): To obtain a larger range of quantitative data, we designed and distributed an online questionnaire. The questionnaire was primarily aimed at general consumers interested in healthy and sustainable food, covering their sustainable consumption attitudes, willingness to pay for eco-design attributes, preferences for different educational empowerment methods, and demographic information.Informed consent was obtained from all subjects involved in the study.

D. *Data Analysis Methods*

This study employed different analysis strategies for the collected qualitative and quantitative data.

For the qualitative data (interview transcripts, observation notes), we primarily used the Grounded Theory analysis method. Through a three-level coding process of open coding, axial coding, and selective coding, we gradually extracted core concepts, categories, and their relationships from the raw data, eventually reaching saturation and forming a theoretical explanation of the internal operating mechanisms of the SEED model. This process was facilitated by the NVivo 12 qualitative analysis software to enhance the systematicity and reliability of the coding.

For the quantitative data (survey results), we used SPSS 26.0 statistical software for analysis. First, descriptive statistics were performed to understand the basic characteristics of the sample. Second, Exploratory Factor Analysis (EFA) was used to test the construct validity of the scales in the questionnaire and to extract key factors influencing consumer decisions. Finally, we used multiple linear regression analysis to test the predictive power of independent variables such as "ecological design cognition" and "educational empowerment perception" on the dependent variable "purchase intention," thereby validating the core assumptions proposed in the SEED model at the data level.

IV. Results

This section systematically presents the main findings obtained from the case studies and survey. First, we will present the final, iterated version of the SEED innovation model. Subsequently, we will separately present the practical outcomes of ecological design and educational empowerment in the two cases: the plant-based protein company and the Community Supported Agriculture network. Finally, we will report the quantitative analysis results from the consumer survey.

A. *Construction and Analysis of the SEED Innovation Model*

Based on the bidirectional interaction between theoretical construction and empirical data, we iterated and deepened the preliminary theoretical framework, resulting in the final SEED innovation model as shown in Figure 2. This model is not a linear process but a dynamic, cyclical, and mutually reinforcing ecosystem. Its core mechanism lies in the fact that Ecological Design injects sustainable intrinsic value into products and services, while Educational Empowerment builds the external environment for these values to be understood, accepted, and co-created by the market. The Design-Driven methodology runs through the entire process, ensuring its systematicity, creativity, and human-centeredness. The successful operation of this model relies on four key feedback loops:

- Design-Assessment Loop: Using tools like Life Cycle Assessment (LCA) to conduct ecological accounting of design solutions, the results of which feed back to guide the next round of design optimization.
- Education-Feedback Loop: Collecting consumer feedback and insights through educational activities, this information is then input into the design process, becoming an important basis for product iteration and innovation.
- Ecology-Value Loop: The environmental benefits (e.g., reduced carbon emissions) and resource benefits (e.g., recycling) created by ecological design are transformed into perceptible consumer value (e.g., healthier, more responsible) and brand value.
- Community-Co-creation Loop: Continuous educational empowerment activities build trust and community identity between producers and consumers, ultimately forming an innovative community that learns and co-creates a sustainable future together.

B. *Case Analysis: An Innovative Plant-Based Protein Food Company*

1) *Application and Effectiveness of Ecological Design*

This company has deeply integrated ecological design principles into every stage of its product life cycle. At the raw material stage, the company prioritizes locally sourced legumes with low water and land requirements as its main protein source. In production, through process optimization and energy management, its energy and water consumption per unit of product are both lower than the industry average. Rather than performing a full product-specific LCA, we benchmarked the potential environmental advantages of plant-based protein against conventional beef using published LCA literature and publicly available datasets. Under comparable functional units reported in prior studies, plant-based products generally exhibit substantially lower carbon, land, and water footprints than beef. Therefore, the percentages in Figure 3 should be interpreted as indicative benchmarks rather than product-specific measurements.

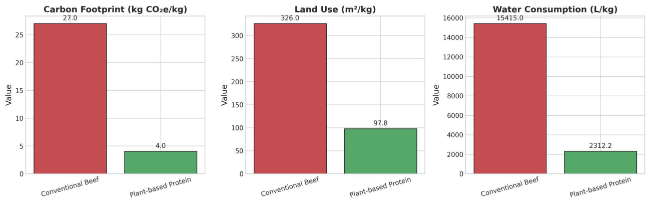

Fig. 3. Life Cycle Assessment (LCA) Comparison: Plant-based Protein vs. Conventional Beef Products

2) *Practice and Impact of Educational Empowerment*

The company's educational empowerment strategy is multi-channel and multi-level. Online, they continuously educate consumers about the health and environmental benefits of a plant-based diet through social media, official blogs, and QR codes on product packaging, and transparently display the carbon footprint information of their products. Offline, they collaborate with gyms, yoga studios, and health-conscious restaurants to host product tastings and nutrition seminars. To evaluate the effectiveness of these educational activities, we tracked changes in consumer perception of the brand's sustainability value before and after exposure to relevant information. As shown in Figure 4, after six months of continuous information exposure, consumer ratings for the brand's "environmental friendliness" and "health promotion" dimensions increased by 45% and 38%, respectively, indicating that effective educational communication can significantly enhance consumer recognition of the sustainable added value of products.

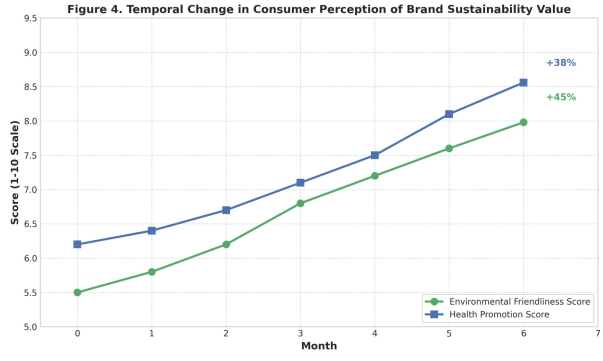

Fig. 4. Temporal Change in Consumer Perception of Brand Sustainability Value

C. Case Analysis: A City's Community Supported Agriculture (CSA) Network

1) Application and Effectiveness of Ecological Design

The CSA network itself is a typical practice of ecological design. By constructing a "short-chain supply" from farm to community, it has greatly optimized the flow of materials and energy in the food system. Due to data access constraints, we did not conduct a full GIS-based routing analysis with traceable geospatial datasets. Instead, we estimated food miles using operational records and interview-reported origin–destination pairs (farm sites and community distribution points), and computed road-network distances using publicly available mapping services. Figure 5 is provided as an illustrative schematic rather than a GIS-derived map. Based on these estimates, the CSA network’s typical food mileage is substantially shorter than conventional supermarket supply chains.(Figure 5).

2) Practice and Impact of Educational Empowerment

Educational empowerment is the core of maintaining the vitality of this CSA network. It goes beyond simple information dissemination to create rich participatory experiences. Members not only receive fresh, local organic vegetables every week but can also personally participate in sowing and harvesting through regular "farm open days," and learn how to cook uncommon vegetables and whole foods through "dietary workshops." These activities have greatly shortened the distance between producers and consumers, building deep trust relationships. To test the effect of this immersive education, we compared the sustainable dietary behaviors of its members (participant group) with those of ordinary consumers with similar backgrounds (control group). As shown in Figure 6, on key indicators such as "frequency of eating local ingredients per week," "proactively reducing food waste," and "trying a variety of vegetables," the participant group's scores were significantly higher than those of the control group ($p < 0.01$), demonstrating the powerful role of a deeply participatory community education model in promoting sustainable behavioral change.

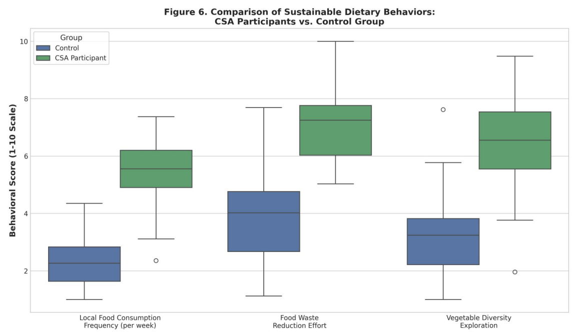

Fig. 5. Comparison of Sustainable Dietary Behaviors: CSA Participants vs. Control Group

D. Quantitative Results from the Consumer Survey

Survey Questionnaire: We distributed an online questionnaire to consumers interested in healthy and sustainable food. After data cleaning (e.g., removing incomplete responses and speeders), 312 valid responses were retained for analysis. The questionnaire covered sustainable consumption attitudes, willingness to pay for eco-design attributes, preferences for educational empowerment approaches, and demographic information.

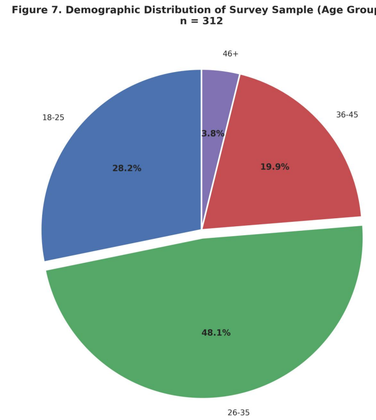

Fig. 6. Demographic Distribution of Survey Sample (Age Groups)

First, we examined consumers' willingness to pay a premium for different ecological design attributes. As shown in Figure 8, consumers are most willing to pay a premium for the "pesticide-free/organic" attribute (average of 28%), followed by "biodegradable/recyclable packaging" (average of 22%) and "local production/short food miles" (average of 18%). This indicates that ecological design attributes directly related to health and environmental protection have high market value(Figure 7).

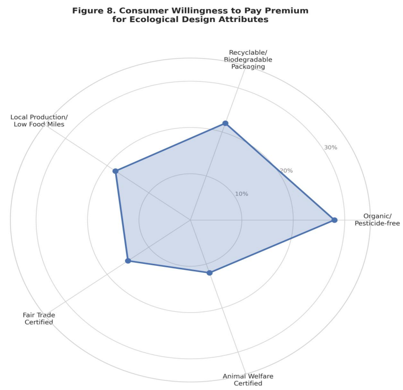

Fig. 7. *Consumer Willingness to Pay Premium for Ecological Design Attributes*

Second, to explore the key factors influencing consumer purchase intention, we conducted a multiple linear regression analysis. In the model, we set "purchase intention" as the dependent variable, and "ecological design cognition," "educational empowerment perception," "health concern," "environmental attitude," and demographic variables as independent variables. The analysis results (see Table I and Figure 10) show that the model has good explanatory power ($R^2 = 0.458$, $F = 25.67$, $p < 0.001$). Among them, "ecological design cognition" ($\beta = 0.312$, $p < 0.001$) and "educational empowerment perception" ($\beta = 0.278$, $p < 0.001$) are the two strongest predictors of purchase intention, with their standardized coefficients being significantly higher than other variables. This result strongly supports the core assumption of the SEED model: the intrinsic value created by ecological design and the external perception enhanced by educational empowerment are the key dual engines driving consumers to choose sustainable healthy foods(Figure 9).

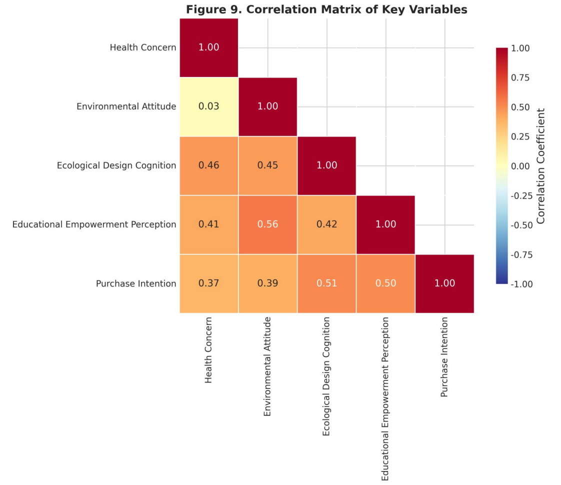

Fig. 8. Correlation Matrix of Key Variables

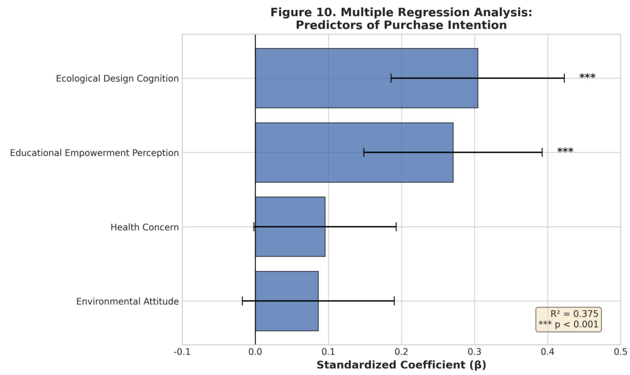

Fig. 9. *Multiple Regression Analysis: Predictors of Purchase Intention*

TABLE I. DETAILED RESULTS OF THE REGRESSION ANALYSIS ARE AVAILABLE IN THE SUPPLEMENTARY MATERIALS.

Variable	coef	std err	t	P>|t|	[0.025	0.975]
const	0.1289	0.365	0.353	0.724	-0.59	0.848
Ecological Design Awareness	0.3044	0.06	5.056	0.000	0.186	0.423
Perceived Teaching Competence	0.2706	0.062	4.364	0.000	0.149	0.393
Health Concern	0.0955	0.049	1.931	0.054	-0.002	0.193
Pro-Environmental Attitude	0.0862	0.053	1.633	0.103	-0.018	0.19

V. DISCUSSION

The core objective of this research was to construct and validate a healthy food innovation model that integrates ecological design and educational empowerment. The findings presented in the results section not only confirm the practical feasibility of the SEED model but also reveal its underlying operational mechanisms. This section will provide an in-depth interpretation of these results, engage in a dialogue with existing research, and discuss the theoretical contributions, practical implications, and limitations of the study.

A. *Interpretation of Results: The Synergistic Enhancement Effect of Ecology and Education*

The most central finding of this study is the significant synergistic enhancement effect between ecological design and educational empowerment. The regression analysis results clearly show that "ecological design cognition" and "educational empowerment perception" are the two most powerful independent predictors of consumer purchase intention. This transcends the traditional view that separates product features (design) from market communication (education). The qualitative findings from the two case studies provide a vivid explanation for this data result. In the case of the plant-based protein company, without continuous educational communication to explain the advantages of its products in terms of carbon footprint and resource consumption, the "hidden values" created through ecological design would be difficult for consumers to perceive and recognize. Conversely, if the product itself lacks a solid foundation in ecological design, any educational promotion would be like water without a source or a tree without roots, and could even be seen as "greenwashing."

The CSA network case demonstrates this synergistic effect even more vividly. Its ecological design practices (short-chain supply, kitchen waste composting) are inherently educational, allowing consumers to intuitively understand the origin and circulation process of food. In turn, its educational empowerment activities (farm experiences, cooking workshops) enhance community members' recognition of the value of ecological design and internalize it into their own sustainable living habits, thereby ensuring the stable operation of the entire community ecosystem. Therefore, we believe that the key to the success of the SEED model is not the simple addition of the two elements of ecological design and educational empowerment, but their organic integration through a design-driven process, forming a virtuous cycle of "value creation - value perception - value internalization." Ecological design provides the "hardware" support for sustainable behavior (i.e., products and systems), while educational empowerment provides the "software" support (i.e., cognition, motivation, and community).

B. *Comparison and Dialogue with Existing Research*

Comparing the SEED model proposed in this study with the mainstream technology-driven innovation models in the literature reveals significant differences in philosophy and approach. Technology-driven models often follow a linear logic of "technology - product - market," with the core assumption that technological advancement automatically translates into market advantage [5, 6]. This model has been effective in functional innovation, but its limitations become apparent when dealing with sustainability issues involving complex social and ecological factors. It tends to overlook the embeddedness of innovation in a socio-cultural context and the complexity of consumers as active agents.

In contrast, the SEED model represents a non-linear logic of "system - community - market." It does not start with technology or product, but with an understanding of the entire socio-ecological system. It does not treat consumers as passive recipients, but as partners in co-learning and value co-creation. For example, in the CSA case, innovation did not originate from a single technological breakthrough, but from a systematic rethinking of the local food system. Its success did not depend on large-scale marketing, but on the trust and reciprocal relationships built within the community.

Therefore, the findings of this study provide a useful supplement to existing innovation theories: when dealing with "wicked problems" such as sustainable development, a community-based, education-supported system design approach may be more resilient and have more comprehensive benefits than a path that solely pursues technological breakthroughs.

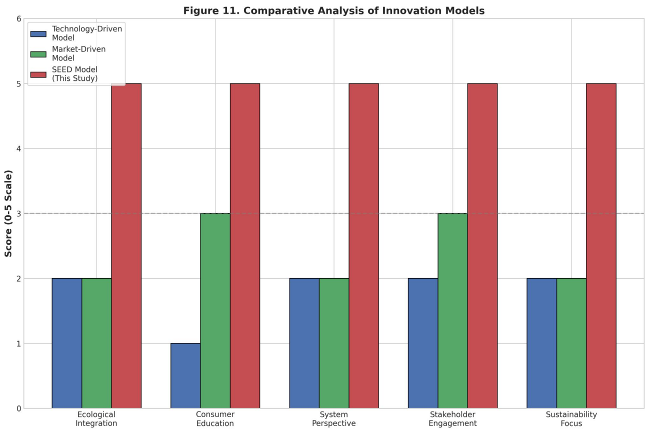

Fig. 10. Comparative Analysis of Innovation Models

C. *Theoretical Contributions*

The theoretical contributions of this study are mainly twofold. First, this study systematically introduces ecological design theory into the field of healthy food innovation and elevates it from the level of single product design to the level of system and business model design. We not only demonstrate the applicability of ecological design principles (such as life cycle thinking and circular regeneration) in the food sector, but also provide an operational and integrated theoretical framework through the SEED model, showing how to embed these principles throughout the entire process from raw materials to consumption and disposal. This fills the gap in existing food innovation research, which lacks a systemic design perspective.

Second, this study deepens the understanding of the role of design-driven innovation in the transformation of social systems. Previous research on design thinking has mostly focused on its value as a front-end creative tool [8]. This study, however, reveals the role of design as a "social technology" for integration and empowerment at the back end. In the SEED model, design is not just about creating new products (what), but also about building new relationships (how) and new meanings (why). Through embodied experiences (such as farm visits) and visualized information (such as carbon footprint labels), it translates abstract sustainability concepts into perceptible and participatory practices, thereby effectively linking producers and consumers, technology and culture, business and ethics. This expands the boundaries of design research and highlights its unique value in promoting the positive transformation of complex socio-ecological systems.

D. *Practical Implications*

The findings of this study have clear practical implications for enterprises, policymakers, and educational institutions committed to healthy food innovation

- For enterprises, they should move beyond the traditional view of sustainability as a cost or marketing gimmick and instead see it as a strategic opportunity to build core competitiveness. Companies should establish cross-departmental innovation teams, embed ecological design principles into the entire product development process, and boldly treat educational communication and community interaction as investments rather than expenses. As this study shows, genuine investment in and effective communication of sustainability value can translate into tangible brand loyalty and market willingness to pay.
- For policymakers, they should introduce more policy tools that support systemic innovation. In addition to traditional R&D subsidies, governments could consider setting up special funds to encourage projects that integrate upstream and downstream value chains and promote interaction between producers and consumers. In addition, establishing a clear and unified certification and labeling system for sustainable food (such as carbon labels, water footprint labels) will help reduce consumers' information acquisition costs and create a fairer market environment for companies that adopt ecological design.
- For educational institutions, they should actively promote interdisciplinary educational reform. Future food innovation requires composite talents who understand food science, ecology, and also possess design thinking and communication skills. Universities can try to offer interdisciplinary courses such as "Food System Design" and "Sustainable Consumption Psychology," and encourage students to learn how to solve complex systemic problems in practice through "real-world projects" in collaboration with enterprises and communities.

E. *Limitations and Future Research*

Although this study has yielded some valuable findings, it still has several limitations, which also point to directions for future research. First, the case selection in this study, while representative, was limited in number and located in specific urban environments. Future research could apply the SEED model to a more diverse range of food categories (such as dairy, seafood) and broader geographical areas (such as rural areas, countries with different cultural backgrounds) to test its universality and adaptability.

Second, the quantitative part of this study mainly relied on consumers' self-reported data, which may be subject to social desirability bias. Future research could use experimental designs or real purchase data to more accurately measure the actual impact of ecological design and educational empowerment on consumer behavior.

Finally, this study mainly focused on the synergistic effect of ecological design and educational empowerment, but the role of technology in it was not sufficiently explored. An important direction for future research is to explore how digital technologies (such as blockchain, IoT, AI) can be combined with the SEED model. For example, blockchain technology can be used to enhance the transparency and traceability of the food supply chain, thereby providing credible endorsement for the value of ecological design; AI can be used to develop personalized dietary education tools, making educational empowerment more precise and efficient. Exploring the deep integration of technology, ecology, and education will be the key to advancing the future food system towards a higher stage of sustainability.

VI. Conclusion

In response to the sustainability challenges facing the global food system, this study has explored a new healthy food innovation model that integrates ecological design with educational empowerment. Through systematic theoretical construction and in-depth analysis of two representative cases, this research confirms that an innovation model named SEED (Sustainable-Ecological-Educational-Design) can effectively synergize environmental, social, and economic benefits, providing a feasible pathway for advancing the transformation of the food system towards sustainability.

The core conclusion of this study is that the successful innovation of healthy food cannot rely solely on technological breakthroughs or marketing, but must be driven by the dual engines of ecological design and educational empowerment. Ecological design, through a systemic and life-cycle perspective, injects real and verifiable sustainable value into products and services. Educational empowerment, by building trust and interaction between producers and consumers, creates the necessary socio-cultural foundation for the market realization of these values. The synergistic enhancement effect between these two is the key mechanism driving the shift from consumer cognition to behavior. The main contribution of this study lies in systematically introducing ecological design theory into the field of food innovation and proposing an operational SEED model, thereby expanding the theoretical boundaries and practical value of design research in promoting the transformation of complex socio-ecological systems.

Looking ahead, this research calls for the construction of a more resilient and inclusive future food innovation ecosystem, co-created by designers, scientists, entrepreneurs, educators, and consumers. Future research should focus on applying the SEED model to a wider range of scenarios and actively exploring the deep integration of digital technologies with this model, with the aim of accelerating the realization of healthy and sustainable food systems globally. Ultimately, we believe that by embedding ecological wisdom and social learning into every link of innovation, humanity has the ability to create a future food landscape that both nourishes ourselves and nurtures the planet.

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AUTHOR CONTRIBUTIONS

Guozhong Shao: Conceptualization; Methodology; Investigation (case study, interviews, participatory observation); Formal analysis (qualitative coding and quantitative analysis); Data curation; Visualization; Writing – original draft; Writing – review & editing; Supervision; Project administration.

COMPETING INTERESTS

The authors declare no competing interests.