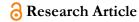
Journal of Computers for Science and Mathematics Learning

ISSN 3047-4876 (online) & 3047-6755 (print) August 2025, Vol. 2, No. 2, pp. 59-73





Integrating AI Simulations and Computational Grounded Theory to Explore Biodynamic Education in Science Museums

Tao-Hua Wang¹ , Ruei-Shan Lu² D, Hao-Chiang Koong Lin³ D

¹Science Education Department, National Museum of Natural Science, Taichung, Taiwan ²Department of Management Information System, Takming University of Science and Technology, Taipei 100, Taiwan

Abstract

This study investigates how science museums can serve as catalysts for public understanding of biodynamic agriculture by integrating AI-generated simulations and an AI-augmented grounded theory (CGT) approach. Forty-nine elementary school teachers in Taiwan participated in a workshop featuring six biodynamicthemed simulation videos created with Mootion AI, depicting insect, bird, and amphibian ecologies within biodynamic frameworks. Participants wrote reflective journals, and twelve were interviewed in focus groups. The study employed Lin et al.'s (2025) CGT model, incorporating traditional inductive coding with computational techniques such as term frequency-inverse document frequency (tf-idf) and N-gram analysis to analyze participants' interpretive responses. Results identified eight interconnected dimensions—including cognitive clarity, affective engagement, instructional relevance, and ethical reflection—that constitute a conceptual model titled "Human-Centered Biodynamics." Findings show that digitally mediated exhibits enhance comprehension of biodynamic principles and foster emotional and pedagogical resonance. Participants reported a shift from perceiving biodynamics as abstract to viewing it as relevant and actionable, suggesting science museums can be transformative platforms for ecological literacy when empowered by creative technologies. This study contributes to the literature on informal science education, sustainability communication, and AI-assisted qualitative research by offering a replicable framework for integrating digital storytelling and grounded theory in ecological pedagogy.

Keywords: Science Museums, Biodynamic Agriculture, AI-Generated Simulation, Computational Grounded Theory, Informal Science Education

Ruei-Shan Lu rslu@takming.edu.tw

Received April 9, 2025 Accepted June 2, 2025 Published August 1, 2025

Citation: Wang, T.-H., Lu, R.-S., & Lin, H.-C. K. (2025). Integrating AI simulations and computational grounded theory to explore biodynamic education in science museums. Journal of Computers for Science and Mathematics Learning, 2(2), 59-73.

DOI: 10.70232/jcsml.v2i2.37

© 2025 The Author(s). Published by Scientia Publica Media



This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial License.

1. INTRODUCTION

Science museums have increasingly evolved beyond their traditional role as repositories of artifacts into dynamic, participatory learning environments that address contemporary scientific and ecological challenges (Chen & Wang, 2015; Ramsurrun et al., 2024). As platforms that merge education, design, and public engagement, these institutions are uniquely suited to introduce complex, systems-based topics such as biodynamic agriculture. Rooted in the anthroposophical philosophy of Rudolf Steiner, biodynamics emphasizes cosmic rhythms, soil vitality, and holistic ecological interconnectedness (Paull, 2011; Steiner, 2013). However, due to its spiritual underpinnings and metaphysical language, biodynamic agriculture often faces skepticism from mainstream science educators and remains underrepresented in public science discourse (Reganold, 1995; Santoni et al., 2022).

The attempt to communicate biodynamic principles within science museum contexts brings forth several pedagogical and practical dilemmas. These include challenges in exhibit design, epistemological tensions between empirical science and spiritual philosophy, and difficulties in sustaining visitor engagement with non-mainstream ecological knowledge (Frosio, 2025; Bluteau et al., 2025). Existing



³Department of Information and Learning Technology, National University of Tainan, Tainan, Taiwan

research underscores that audiences frequently struggle with interpretive clarity when confronted with the symbolic language of biodynamics, leading to partial or distorted understandings (Ivancevic & Ivancevic, 2005). Additionally, exhibit creators often encounter institutional pressures to maintain scientific objectivity while attempting to evoke affective and ethical dimensions of sustainability (Macleroy, 2016; Torres, 2022).

To navigate these tensions, this study explores how AI-generated simulation videos—specifically produced using Mootion AI—might serve as mediating tools for interpreting and experiencing biodynamic content in a science museum setting. By simulating biodynamic concepts through digitally rendered environments and multispecies interactions, these immersive videos aim to bridge the gap between conceptual abstraction and sensory experience. However, how visitors interpret these simulations—cognitively, affectively, and pedagogically—remains an open question.

To address this, we employed grounded theory enhanced with computational support to analyze the reflective responses of 49 elementary school teachers who participated in a science museum workshop featuring the AI simulations. Twelve participants were further interviewed in focus groups to deepen our understanding of their interpretive processes.

Following Lin et al.'s (2025) AI-augmented grounded theory framework, which blends traditional inductive coding with computational techniques such as term frequency-inverse document frequency (tf-idf) and probabilistic N-gram analysis, this study integrates unsupervised lexical mining with interpretive qualitative coding to derive a theory grounded in participants' experiences. This methodology builds on the foundations laid by Nelson (2020) and Dehmamy et al. (2023), but places stronger emphasis on the human-machine synergy that characterizes contemporary research at the intersection of education, cognition, and AI-enhanced creativity.

Through this approach, our research asks: What are the experiential dimensions, interpretive challenges, and transformative potentials of biodynamic simulations in science museum settings? By focusing on participants' meaning-making processes, our study contributes to the broader discourse on informal science education, environmental literacy, and AI-enhanced creative learning (Ali et al., 2024; Popescu & Schut, 2023). In doing so, we respond to calls for more inclusive, human-centered, and computationally-supported frameworks for engaging with planetary-scale ecological challenges.

2. LITERATURE REVIEW

2.1. Historical and Philosophical Context of Biodynamics

Biodynamic agriculture began with Rudolf Steiner's 1924 Agriculture Course in Koberwitz, which laid the philosophical foundation for a farming practice emphasizing cosmic rhythms, spiritual science, and ecological harmony (Paull, 2011; Steiner, 2013). Steiner's vision expanded globally in subsequent decades, shaping biodynamics as a holistic and regenerative model for food systems (Koepf, 2005). His emphasis on the spiritual forces in nature, soil vitality, and planetary influence forms the metaphysical basis that continues to distinguish biodynamics from other organic approaches (Ivancevic & Ivancevic, 2005; Wildfeuer, 1995).

2.2. Scientific Investigations and Controversies

The scientific legitimacy of biodynamic methods has long been debated. Critics point to the metaphysical elements of Steiner's teachings, while proponents highlight empirical studies demonstrating positive outcomes. For instance, Reganold (1995) and Zaller & Köpke (2004) documented improved soil quality, microbial biomass, and yield performance under biodynamic management. Similarly, Carpenter-Boggs et al. (2000) and Döring et al. (2015) found that biodynamic preparations impacted composting rates and grapevine health. Yet, methodological variations and contextual variables across studies (Santoni et al., 2022) sustain ongoing controversy.

2.3. Science Communication through Informal Education

Science museums offer a unique opportunity to present biodynamic concepts to the public. Through interactive exhibits, narrative storytelling, and AR technology, complex agricultural ideas can be made accessible and engaging (Chen & Wang, 2015; Ramsurrun et al., 2024). These environments foster multimodal engagement that enhances retention and emotional resonance (Macleroy, 2016; DePalma & Alexander, 2018). The integration of biodynamics into such spaces requires balancing credibility, aesthetics, and participatory learning to avoid alienating visitors unfamiliar with its esoteric origins (Frosio, 2025).

2.4. Grounded Theory and Computational Creativity in Educational Research

Grounded theory offers a robust methodological approach to capture emergent insights in creative and educational settings. It prioritizes open-ended exploration and is especially effective for interpreting how participants negotiate meaning in complex, multimodal environments (Thornberg & Dunne, 2019; Mace & Ward, 1998). In the context of AI-enhanced museum exhibits, this method legitimizes researcher creativity while maintaining methodological rigor (Cutcliffe, 2000; Lassig, 2022). Recent developments in computational grounded theory (CGT) incorporate machine learning, lexical analysis, and statistical modeling to augment traditional coding (Nelson, 2020; Dehmamy et al., 2023). Lin et al. (2025) introduced a hybrid CGT framework using term frequency-inverse document frequency (tf-idf) and corpus-based N-gram analysis to surface subtle linguistic patterns. This approach balances human interpretation with data-driven scalability, supporting theoretical sensitivity. Studies have applied CGT to explore generative AI in multimodal composing and informal learning (Ali et al., 2024; Popescu & Schut, 2023), revealing how digital creativity tools reshape educational experiences. Our study follows this tradition, integrating computational tools to support grounded theoretical insights about how museum visitors engage with biodynamic content.

2.5. Literature Review Summary

The reviewed literature provides a multifaceted foundation for this study, spanning spiritual origins, empirical investigations, communicative strategies, and methodological innovations. Biodynamic agriculture, rooted in Steiner's metaphysical vision, continues to evoke both interest and skepticism. Scientific inquiry has validated some ecological benefits, though interpretive and methodological tensions persist. Science museums, as informal learning environments, offer unique opportunities to render these complex ideas tangible and relatable through multimodal engagement. Grounded theory—especially its computational extension—proves valuable in navigating such interdisciplinary terrain, allowing researchers to analyze how meaning is co-constructed at the intersection of environmental knowledge, digital technology, and human creativity.

3. METHODOLOGY

This study aims to explore how science museums can promote public understanding of biodynamic agriculture through the integration of AI-generated simulations and AI-enhanced grounded theory (CGT) methods. To achieve this goal, we employ a qualitative and exploratory research approach, framed within a grounded theory methodology. This methodological choice helps us construct an in-depth understanding of this phenomenon from participants' subjective experiences, which is particularly suitable for exploring complex and context-rich educational issues.

This study involved 49 elementary school teachers (21 male, 28 female) aged 32 to 51 who participated in a professional development workshop at a science museum in Taiwan. The researchers developed six AI-generated simulation videos using Mootion AI to introduce participants to the concept of biodynamic science exhibits—two each themed around insects, birds, and amphibians. These simulations featured stylized yet scientifically inspired creatures navigating biodynamic landscapes. As illustrated in Figure 1, one of the insect-themed videos depicted a beetle-like robot interacting with lunar-like biodynamic soil spheres under traditional Japanese interior settings, while another showed a larger mechanical beetle approaching a diorama within a natural history museum. The visual design, motion behaviors, and environmental elements were crafted to simulate the interplay between organism, habitat, and ecological

balance, allowing participants to engage with abstract biodynamic principles in an immersive and interpretive format. After viewing, participants were asked to write reflective feedback journals. Subsequently, a subset of 12 participants was randomly selected for focus group interviews. These semi-structured interviews explored themes including affective impressions, interpretive clarity, cultural relevance, instructional inspiration, and perceived cognitive demands.

The collected feedback journals and transcribed interviews were analyzed using grounded theory procedures. Data coding followed a three-phase structure: initial line-by-line coding, axial coding for thematic categorization, and selective coding for theory building. This was enhanced by computational techniques, including unsupervised text mining and tf-idf analysis to identify recurring lexical patterns. These methods allowed for the emergence of theory grounded in empirical data.

Grounded theory prioritizes emergent themes from qualitative data—ideal for analyzing open-ended roles of biodynamic knowledge in informal education. Following Charmaz (2014) and Strauss & Corbin (1998), our research adopted a constructivist grounded theory design. This was extended through computational grounded theory (CGT), which combines human-centered inductive coding with scalable AI-supported tools (Nelson, 2020; Dehmamy et al., 2023). We applied a three-step CGT approach: (1) pattern detection via term frequency-inverse document frequency (tf-idf) and unsupervised N-gram mining, (2) pattern refinement through interpretive coding, and (3) pattern validation through corpus analysis and theory generation (Lin et al., 2025).

This hybrid method enabled us to capture subtle dynamics in how museums present biodynamics and how visitors interpret them. Grounded theory's iterative nature also accommodated our creative and reflexive stance as researchers (Cutcliffe, 2000; Thornberg & Dunne, 2019). The process emphasized the dynamic interplay between human imagination and generative AI in making sense of complex environmental knowledge (Ali et al., 2024; Mace & Ward, 1998; Popescu & Schut, 2023).



Figure 1. Examples of Mootion AI-Generated Biodynamic Science Exhibit Simulations

Left: A stylized robotic beetle interacts with biodynamic soil spheres in a lunar-Japanese hybrid environment, evoking themes of soil vitality and cosmic rhythm.

Right: A black beetle-like AI figure traverses a science museum diorama featuring geological and ecological displays, symbolizing biodynamic interconnectivity across species and environments.

To ensure the rigor, credibility, and transferability of our research findings, and to minimize potential researcher bias, we implemented several strategies:

1. Data Source Triangulation: This study collected both written reflection feedback from participants and focus group interview data. These two different forms of data sources could be cross-referenced and verified, allowing for a more comprehensive and objective understanding of participants' experiences and perspectives, avoiding the potential one-sidedness of relying on a single data source.

- 2. Member Checking: After completing the preliminary data analysis and theme extraction, we provided summaries of the main findings and interpretations to some of the teachers who participated in the focus group interviews. We invited them to review whether these interpretations accurately reflected their experiences and views, and made necessary adjustments and corrections to the research results based on their feedback. This process helped ensure the interpretive validity of the research.
- 3. Inter-coder Reliability: Although the core coding in this study was primarily completed through collaborative discussion by the research team, in the initial coding stage, we invited a research peer who was not directly involved in the study design but was familiar with qualitative research and grounded theory to independently code some randomly sampled textual data (approximately 20% of the total data). Subsequently, we calculated the consistency coefficient (e.g., Cohen's Kappa) between the independent coding results and the research team's preliminary coding results, and conducted in-depth discussions on inconsistencies until consensus was reached. This helped enhance the objectivity and reliability of the coding process.
- 4. Reflexive Journal: Throughout the research process, the primary researchers maintained reflexive journals. The journal content included the researchers' personal thoughts, expectations, emotional responses, difficulties encountered, and decision-making processes during data collection, analysis, and interpretation. Through continuous self-reflection, researchers were able to recognize and examine how their personal values, experiential backgrounds, or theoretical assumptions might potentially influence the research process and results, thereby striving to maintain an objective and neutral research stance.
- 5. Detailed Methodological Description: As described in this chapter, we strive to provide detailed and transparent methodological descriptions, including research design, participant characteristics, data collection procedures, analysis steps, and the application of computational tools, so that other researchers can understand and evaluate the execution process and results of this study, thereby enhancing the credibility and potential replicability of the research.

Through the implementation of these multiple strategies, we hope to maximize the overall quality and academic value of this study.

4. RESULTS

4.1. Interpreting Human-Centered Biodynamics: A Conceptual Framework from AI-Augmented Grounded Theory

The data collection for this study consisted of two main components: written reflections and focus group interviews. First, 49 elementary school teachers who participated in a professional development workshop at a science museum in Taiwan were asked to write immediate reflective feedback after viewing six biodynamic science exhibit simulation videos generated by Mootion AI. These reflections were completed as part of the workshop activity in a specific session at the science museum, designed to capture participants' most direct viewing experiences and initial thoughts. We provided open-ended prompts such as "Please describe your feelings and thoughts after watching these simulation videos" and "What aspects of these simulations inspired or confused your understanding of biodynamic agriculture?" to encourage free expression.

Subsequently, 12 participants were randomly selected from the 49 teachers for follow-up focus group interviews. These interviews were conducted in a semi-structured format, each lasting approximately 60 to 90 minutes. The interviews were co-facilitated by two researchers, with one responsible for questioning and guiding the discussion, and the other for recording and observation. The main guiding questions revolved around participants' affective impressions of the AI simulation videos, interpretive clarity, cultural relevance, instructional inspiration, and perceived cognitive demands, with follow-up questions based on the interaction dynamics. All focus group interviews were audio-recorded with participants' consent and transcribed verbatim to ensure data completeness and accuracy.

4.1.1. Data Analysis

The written reflections and focus group interview transcripts collected in this study were analyzed using grounded theory procedures. The data coding strictly followed a three-phase structured process:

- 1. Open Coding: In this initial phase, the research team carefully read all textual data line by line, conducting preliminary decomposition, examination, comparison, conceptualization, and categorization of the data. We marked meaningful text segments as initial concepts or "codes," striving to stay close to participants' original expressions while exploring as many potential themes as possible.
- 2. Axial Coding: After generating numerous initial concepts through open coding, we entered the axial coding phase. The core task of this phase was to systematically relate the concepts and categories formed in open coding around the axis of a core category. Through constant comparison, we identified relationships between categories (e.g., causal relationships, contextual relationships, interaction strategies, etc.) and organized related codes into more generalizable thematic categories.
- 3. Selective Coding: This was the final stage of theory construction. Based on axial coding, the research team further distilled a core category that could integrate all major categories and clearly depict the core storyline of the phenomenon. Subsequently, we systematically related other categories to this core category and refined and validated the preliminary theoretical model until theoretical saturation was reached.

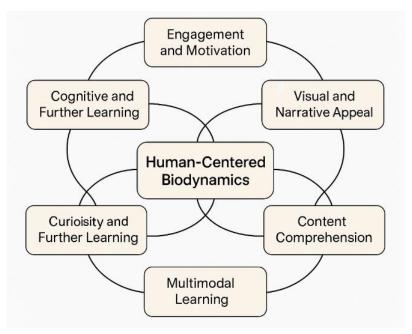


Figure 2. Human-Centered Biodynamics: A Conceptual Model Integrating Museum-Based Informal Learning and AI-Augmented Visualization. Science Museums as Informal Learning Platforms Science museums increasingly incorporate AR and digital tools to support interactive and engaging experiences (Chen & Wang, 2015; Ramsurrun et al., 2024). These tools are particularly effective in presenting complex topics like biodynamic cycles, composting, and planetary rhythms

To enhance the depth and efficiency of traditional grounded theory analysis, this study integrated computational assistance techniques, following the computational grounded theory (CGT) framework proposed by Lin et al. (2025). Specifically, we employed computational linguistics methods such as term frequency-inverse document frequency (tf-idf) analysis and N-gram phrase analysis. These techniques were primarily used to assist in the preliminary exploration of textual data and pattern recognition, such as quickly identifying high-frequency vocabulary, key phrases, and potential semantic associations, thereby providing valuable reference points and insights for interpretive coding. It must be emphasized that these computational techniques did not replace researchers' manual judgment and interpretation, but rather served as enhancement tools, helping researchers process large amounts of textual data more effectively and discover subtle patterns that traditional manual coding might overlook, thereby enhancing the rigor and richness of grounded theory construction.

1. Communicating Biodynamic Agriculture

Biodynamic agriculture remains controversial due to its spiritual and philosophical foundations. However, empirical and CGT-informed textual analysis revealed validation in soil health improvements, nutrient cycling, and bioaccumulation patterns (Hornberger, 2024; Reganold, 1995; Carpenter-Boggs et al., 2000).

2. Integration Through Exhibits

Findings indicate a trend toward using narrative-based, multimodal exhibits integrated with digital storytelling to communicate biodynamic knowledge. These strategies, guided by frameworks from Macleroy (2016) and DePalma & Alexander (2018), enhanced both cognitive retention and emotional resonance.

3. Institutional and Design Challenges

Despite their potential, museums face limitations related to funding, curatorial hesitancy, and exhibit design complexity. Biodynamic topics, given their metaphysical elements, require careful framing to maintain credibility while remaining engaging (Bluteau et al., 2025; Frosio, 2025).

4. Biodynamic Models and Visualization

Biodynamic modeling helps demystify abstract concepts for museum audiences. CGT-assisted analysis of modeling data (Guruguntla & Lal, 2025; Blechschmidt & Gasser, 2012; Lockman & Thelen, 1993) showed enhanced comprehension when complex data were paired with interactive visualization.

5. Soil, Health, and Productivity

Studies consistently demonstrate that biodynamic preparations improve soil structure, microbial activity, and crop yield (Döring et al., 2015; Zaller & Köpke, 2004). Grounded theory reveals that this narrative can be effectively embedded in interactive exhibits that simulate soil transformation or microbial processes.

6. Human-Centered Biodynamics

Grounded theory analysis revealed that biodynamics is not merely a set of agricultural practices, but an integrated worldview encompassing biophysical, psychological, and ethical dimensions (Masserman, 1953; Finkelstein, 1998; Torres, 2022). Teachers reported that the exhibits not only deepened their understanding of soil-plant-animal interactions but also prompted reflections on the interconnectedness of life and the responsibility of humans in ecological stewardship. Emotional responses such as awe, empathy, and ethical concern were frequently mentioned in the journals and interviews. These findings illustrate that biodynamics—when mediated through museum exhibits and supported by digital storytelling—can serve as a human-centered framework that brings together spiritual inquiry, environmental ethics, and scientific learning. This concept is illustrated in Figure 1, which maps the relationships between technological mediation, affective engagement, and ecological consciousness.

7. Cognitive and Pedagogical Outcomes

Grounded theory analysis of participants' feedback journals and focus group transcripts revealed that biodynamic-themed exhibits facilitated reflective, emotionally resonant learning. Teachers frequently described the simulations as "imaginative," "thought-provoking," and "helpful for classroom adaptation." This aligns with research on generative co-creation (Popescu & Schut, 2023) and the construction of designer voice through multimodal composing (Tan et al., 2024). Teachers reported that digital exhibits helped them visualize abstract ecological cycles, echoing Smith's (2019) emphasis on multimodal scaffolding in informal learning contexts.

Participants further suggested that narrative-based AR simulations enhanced not just subject comprehension, but professional self-efficacy in teaching sustainability concepts. This finding resonates with Ali et al. (2024), who underscore the synergy between Gen Z learners and AI-enhanced creative engagement. The interviews also reflected teachers' shifting perception of biodynamics from esoteric to actionable, revealing a key transformation in cognitive framing. Respondents expressed increased confidence in using visual and sensory modalities to explain complex ecological relationships—highlighting how computational visualization can act as a semiotic bridge between scientific abstraction and educational pragmatics (DePalma & Alexander, 2018; Nelson, 2020).

4.2. Interconnection of Themes

These eight categories coalesced into a dynamic model illustrating the museum's role as a multimodal interface linking ecological science with affective and conceptual learning. For instance, digital simulation (Theme 1), pedagogical framing (Theme 3), and biodynamic modeling (Theme 5) converge through personalized and contextualized museum storytelling. This framework supports Torres' (2022) argument that human imperfection is a necessary counterbalance to AI, fostering deeper ethical and philosophical inquiry. Together, the findings underscore that museum-based biodynamics education is not merely content transmission, but a co-creative, cognitive-affective experience that synthesizes ecological thought, sensory media, and generative technology. Biodynamics extends beyond agriculture into biophysical, psychological, and ethical domains (Masserman, 1953; Finkelstein, 1998; Torres, 2022). These dimensions inspire interdisciplinary exhibits linking food, embodiment, and planetary health.

5. DISCUSSION

The study contributes meaningfully to emerging discourse on the convergence of computational creativity, environmental humanities, and informal education. It demonstrates that biodynamic agriculture—despite its metaphysical complexity—can be meaningfully communicated in museum settings through AI-enhanced media. This confirms earlier claims (Popescu & Schut, 2023; Ali et al., 2024) that generative AI can support accessible, affective, and multimodal learning experiences.

In particular, the application of AI-augmented grounded theory opens a new methodological frontier. Unlike traditional qualitative studies that may be limited by researcher bias or time-intensive manual coding, our approach enabled efficient pattern recognition and deep semantic interpretation, preserving both inductive richness and analytic rigor (Nelson, 2020; Lin et al., 2025). This human-machine synergy was instrumental in distilling visitors' layered experiences into an integrated framework that holds theoretical and practical implications.

The concept of "Human-Centered Biodynamics" deserves special emphasis. It reframes biodynamics as not merely a farming technique, but as a cultural and ethical lens that engages visitors in questions about planetary well-being, multispecies futures, and the entangled agency of humans and non-humans. This has profound implications for museum design: rather than passively delivering knowledge, museums can co-create ontological shifts that reshape how people understand their place in the ecological web.

5.1. Dialogue with Existing Literature and Unique Contributions of This Study

The core findings of this study—the "Human-Centered Biodynamics" conceptual model and its eight interconnected dimensions—resonate with recent research trends in informal science education, environmental communication, and AI-assisted learning in multiple ways, while also presenting unique perspectives. First, regarding the potential of AI-generated simulations in enhancing understanding of complex scientific concepts, our findings align with those of Ali et al. (2024) and Popescu and Schut (2023). Their studies similarly indicate that digital narrative and simulation tools can effectively promote learners' cognitive clarity and emotional engagement with abstract knowledge. However, this study further extends this view to the specific field of biodynamic agriculture, which is often considered esoteric and difficult to comprehend, revealing that AI simulations can not only explain ecological principles but also trigger participants' (in this case, elementary school teachers) deep reflections on instructional relevance and ethical dimensions, aspects less explored in previous research.

Second, in terms of science museums as platforms for ecological literacy cultivation, our findings echo the views of Chen and Wang (2015) and Ramsurrun et al. (2024), who emphasize the importance of interactivity and technological integration in modern museum education. Through concrete AI simulation application cases, this study demonstrates how science museums can transcend traditional exhibitions to become catalysts for public understanding of sustainability issues. Notably, unlike Frosio (2025) and Bluteau et al. (2025), who explore the interpretive challenges of presenting non-mainstream knowledge in museums, this study finds that the intervention of AI simulations seems to alleviate, to some extent, the understanding barriers caused by the metaphysical nature of biodynamics, transforming abstract concepts into more

perceptible and resonant experiences. This provides new insights into how to effectively communicate complex and controversial scientific knowledge in museum contexts.

Furthermore, regarding the application of computational grounded theory (CGT), this study follows and extends the methodological foundations laid by Nelson (2020), Dehmamy et al. (2023), and Lin et al. (2025). Previous research has mostly focused on the advantages of CGT in processing large-scale textual data, enhancing coding efficiency, or discovering potential patterns. This study further demonstrates how CGT can assist researchers in distilling theoretically deep conceptual models from participants' subjective experiences in specific educational research contexts. We found that the combination of computational techniques (such as tf-idf and N-gram analysis) with researchers' manual interpretation not only enhanced the systematicity of analysis but, more importantly, increased the sensitivity of theoretical construction, allowing the multi-dimensional, contextualized conceptual model of "Human-Centered Biodynamics" to emerge. This provides a concrete practical case for how to more effectively integrate quantitative and qualitative methods in educational technology research.

Additionally, recent research such as Torres (2022) emphasizes the importance of balancing scientific objectivity with emotional and ethical dimensions in sustainability communication, while Macleroy (2016) focuses on how museum narratives promote visitors' critical thinking. The findings of this study align with these perspectives and further indicate that AI simulation, as a narrative medium, can simultaneously stimulate participants' cognitive understanding, emotional resonance, instructional association, and ethical reflection, thereby promoting a more holistic understanding of biodynamic agriculture. This multi-dimensional impact, especially for the teacher group, means they not only understand the knowledge of biodynamics but are also likely to transform it into motivation and material for teaching practice, which is a deeper contribution of this study compared to general public research.

In summary, through the integration of AI simulation and CGT methods, this study not only opens new pathways for public understanding of biodynamic agriculture but also contributes new empirical data and theoretical perspectives to the fields of informal science education, environmental communication, and AI-assisted qualitative research. Our findings engage in dialogue with recent literature on multiple levels, while also highlighting the unique insights that can be brought by applying emerging technologies and methodologies in specific contexts (such as teacher professional development in science museums).

5.2. Societal Benefits, Practical Implications, and Academic Contributions of the Research

The findings of this study not only deepen the understanding of the application of AI simulations in biodynamic agriculture education but also have multiple societal benefits, practical implications, and academic contributions.

5.2.1. Societal Benefits and Promotion of Public Understanding

The most important societal benefit of this study is demonstrating an innovative approach to promote public understanding and acceptance of biodynamic agriculture—a complex and often misunderstood sustainable agricultural model—especially through teachers as important mediators. Against the backdrop of global challenges such as climate change, food security, and ecological degradation, enhancing public ecological literacy and awareness of sustainable practices is crucial. By concretizing and contextualizing the abstract principles of biodynamics through AI simulations, the understanding threshold can be effectively lowered, stimulating public interest and emotional resonance, which may in turn encourage more environmentally friendly choices in daily life and support for sustainable agriculture development. Furthermore, this study targets elementary school teachers, whose understanding and transformation will directly influence the next generation's environmental values and ecological consciousness, having long-term social impact.

5.2.2. Implications for Science Museum Practices

This study provides concrete practical implications for how science museums can more effectively design and implement exhibitions and educational activities related to sustainability, ecology, and non-mainstream scientific knowledge:

- 1. Embrace Innovative Technology Integration: Digital tools such as AI-generated simulations can significantly enhance the interactivity, immersion, and educational effectiveness of exhibitions, especially when presenting abstract or difficult-to-directly-observe scientific concepts. Museums should actively explore and integrate emerging technologies such as AI, AR/VR, etc., to enrich exhibition means and enhance visitors' learning experiences.
- 2. Strengthen Narrative and Emotional Connection: This study found that AI simulations can effectively trigger participants' emotional resonance and ethical reflection. When designing exhibitions, museums should not merely focus on knowledge transmission but also emphasize establishing emotional connections with visitors through engaging narratives, aesthetic design, and interactive experiences, thereby deepening their understanding and identification with the exhibition themes.
- 3. Attend to Specific Audience Needs: Design differentiated educational activities and interpretive strategies for different audiences (such as teachers, students, family groups, etc.). The professional development workshop model for teachers in this study demonstrates the potential of museums in supporting formal education systems and enhancing teacher professional literacy.
- 4. Promote Interdisciplinary Dialogue and Understanding: Biodynamic agriculture itself integrates science, philosophy, and spiritual dimensions. Museums can serve as platforms for dialogue between different knowledge systems, encouraging the public to view complex issues with more open and diverse perspectives.

5.2.3. Contributions to Educational Technology Development and Academic Community

This study also has multiple contributions to educational technology development and related academic communities:

- 1. Expanding AI Application Scenarios in Education: It demonstrates the innovative application potential of AI-generated content (AIGC) in specific subject education (such as environmental education, agricultural science popularization), beyond the currently common applications like language models or recommendation systems, providing new directions for AI educational technology development.
- 2. Deepening Computational Assisted Qualitative Research Methods: This study implements and validates the effectiveness of computational grounded theory (CGT) in educational research, especially its value in processing complex qualitative data and distilling deep theoretical insights. This provides beneficial cases and inspirations for the development of qualitative research methodology and how to effectively combine human intelligence and machine intelligence for knowledge discovery.
- 3. Enriching Informal Science Education Theory: Through the construction of the "Human-Centered Biodynamics" conceptual model, this study provides new empirical foundations and analytical perspectives for the theoretical development of informal science learning, environmental communication, and museum learning, contributing to understanding the complex process of meaning construction by learners in technology-mediated environments.
- 4. Inspiring Future Research Directions: The findings of this study also point to directions for future research, such as further exploring the impact of different types of AI simulations (e.g., those emphasizing interactivity or gamification elements) on learning effects, the response differences of audiences of different age groups or cultural backgrounds to such exhibitions, and how to more effectively evaluate deep learning and attitude changes in AI-assisted learning environments.

In conclusion, through a concrete case, this study demonstrates how science museums, with the aid of AI technology, can play a more active and innovative role in promoting public understanding of complex scientific issues, advancing sustainable development goals, and deepening educational academic research.

5.3. Future Research

Future studies could extend this work in several directions. Longitudinal research could examine the persistence of interpretive change, professional adaptation, and behavioral transformation among

participants. Comparative studies could analyze how different age groups, cultural contexts, or prior familiarity with sustainability affect engagement with AI-mediated biodynamics.

In addition, there is growing potential in integrating participatory design, allowing museum visitors or students to contribute to or co-author simulation content using generative AI tools such as text-to-video or AI avatars. This would amplify inclusivity and deepen cognitive investment.

Further refinements in computational grounded theory techniques could also benefit future research. These might include real-time sentiment analysis, eye-tracking during simulations, or multimodal data fusion combining voice, gesture, and linguistic input. Cross-disciplinary collaborations—bridging AI, design, philosophy, and science education—could develop richer theoretical models to guide this emerging field.

Finally, broader investigations could explore the ethical dimensions of representing spiritual or metaphysical content through generative AI, ensuring cultural sensitivity and epistemic pluralism while promoting sustainability literacy.

5.4. Final Reflection

By demonstrating the interpretive power of AI-enhanced simulations and computationally supported grounded theory, this study advances both theoretical understanding and practical strategy for informal science education. It suggests that science museums, when paired with creative technologies and critical pedagogy, can not only inform but also inspire and transform ecological consciousness in ways that are urgently needed in our planetary moment.

6. CONCLUSION

This study explored how science museums can serve as transformative platforms for biodynamic agricultural education by employing AI-generated simulation videos and analyzing user experiences through Lin et al.'s (2025) computational grounded theory framework. By integrating immersive visual storytelling with AI-augmented qualitative analysis, we investigated how informal learning environments mediate complex ecological, spiritual, and scientific concepts.

Our findings suggest that AI simulations hold strong potential for mediating biodynamic content that is otherwise difficult to access or comprehend through conventional exhibits. Participants experienced enhanced affective engagement, cognitive clarity, and pedagogical inspiration when interacting with digital narratives that embodied biodynamic themes such as soil cycles, cosmic rhythms, and multispecies coexistence. Notably, eight thematic dimensions were identified, culminating in the "Human-Centered Biodynamics" conceptual model. This model illustrates how emotional resonance, spiritual reflection, ethical inquiry, and scientific literacy can converge within well-designed, technologically mediated museum experiences.

Among the most striking outcomes was the shift in participants' perception of biodynamics from being abstract or esoteric to personally meaningful and practically applicable. Teachers reported a heightened sense of ecological responsibility and expressed motivation to adopt such approaches in their own classrooms. Furthermore, narrative immersion, visual-sensory engagement, and symbolic metaphors all played key roles in facilitating interpretive clarity and lasting impact.

Despite the promising results, several limitations must be acknowledged. First, the study involved a relatively homogenous participant group of elementary school teachers, limiting generalizability to other demographics such as students, museum visitors from diverse cultural backgrounds, or agricultural professionals. Second, while the AI-generated simulations were effective, their aesthetic and symbolic interpretations may vary across audiences, especially those unfamiliar with the visual grammar of science fiction or artistic abstraction. Third, although the AI-augmented grounded theory methodology provided scalable analytic depth, it relied on researchers' interpretive judgment in later coding phases, which introduces potential subjectivity.

Moreover, the study focused exclusively on the reception of pre-designed simulations and did not include co-creation opportunities with participants. Thus, the role of agency and creative participation in simulation design remains underexplored. Finally, long-term impacts—such as changes in teaching practice or sustained ecological behaviors—were not assessed due to the short timeframe.

7. RESEARCH LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Despite this study's commitment to rigorous methods and in-depth analysis, there are inherent limitations that also provide possible directions for future research.

- 1. Sample Representativeness and Generalizability: The participants in this study were 49 elementary school teachers in Taiwan. While this group is significant for exploring educational applications, their perspectives and experiences may not fully represent broader public groups or individuals from different cultural backgrounds and professional fields. Therefore, caution should be exercised when generalizing the findings of this study to other groups or contexts. Future research could expand the diversity of samples, for example, including students of different age groups, the general public, or conducting cross-cultural comparative studies in different countries and cultural contexts to examine the universality and contextual specificity of this study's findings.
- 2. Contextual Specificity: This study was conducted in the specific context of a science museum professional development workshop, and the content and presentation of the AI simulation videos were designed for this specific purpose. The research results may be influenced by this specific context. In different exhibition designs, interaction modes, or informal learning environments, participants' responses and experiences may differ. Future research could explore the impact of AI simulations on understanding biodynamic agriculture in more realistic, diverse museum visiting contexts, or in online learning environments.
- 3. Potential Biases in AI Simulation Content and Design: Although we strived to make the AI-generated simulation videos scientifically inspiring and visually attractive, the AI algorithms themselves may contain unperceived biases, or the stylized presentation of the videos (such as designing insects as robot-style) may have guided participants toward specific interpretations. For example, the combination of the beetle robot and moon-like biodynamic soil spheres shown in Figure 1, while intended to inspire imagination, may have led some participants to form unintended associations about the actual appearance of biodynamics. Future research should more deeply explore the impact of different AI simulation design styles and narrative approaches on learners' cognition and emotions, and explore how to more effectively co-design AI simulation content to reduce potential biases and ensure its scientific accuracy and educational appropriateness.
- 4. Limitations of Data Collection Methods: This study primarily relied on participants' written reflections and focus group interviews. While these methods can provide rich qualitative data, they may also be influenced by social desirability effects or recall bias. Future research could consider integrating more diverse data collection methods, such as observational methods (observing participants' real-time reactions when watching simulation videos), physiological feedback measurements (such as eye tracking, skin conductance response to capture subconscious attention and emotional changes), or longitudinal tracking studies, to more comprehensively assess the impact of AI simulations.
- 5. Interpretive Challenges of Computational Grounded Theory: Although computational grounded theory (CGT) helps process large amounts of textual data and discover patterns, the interpretation of computational results still highly depends on researchers' manual judgment. How to ensure the objectivity of computational analysis, and how to effectively deeply integrate computational results with qualitative insights, remain ongoing challenges in CGT application. Future research could further explore the application potential and ethical considerations of more advanced natural language processing techniques or machine learning models in qualitative data analysis.

Addressing the above limitations, future research could deepen and expand in the following directions: First, conduct larger-scale, more diverse sample quantitative research to validate the universality of this study's qualitative findings and compare differences between different groups. Second, develop and evaluate AI simulation learning environments with higher interactivity and personalized adaptive

capabilities. Third, deeply explore the long-term effects of AI simulations in promoting critical thinking, ethical reflection, and practical action transformation. Finally, continue to optimize mixed methods research designs such as CGT to more comprehensively and deeply understand complex phenomena in technology-enhanced learning environments.

Acknowledgment. The authors would like to express their sincere gratitude to all individuals and institutions that contributed to this research. We extend our appreciation to the National Museum of Natural Science in Taichung, Taiwan, for providing the research venue and facilitating access to elementary school teachers for this study. Special thanks to the 49 elementary school teachers who participated in the professional development workshop and generously shared their insights through reflective feedback journals and focus group interviews. We also acknowledge the technical support provided by Mootion AI in generating the simulation videos used in this study. Additionally, we thank the research peers who assisted with inter-coder reliability verification and the anonymous reviewers whose constructive feedback significantly improved the quality of this manuscript.

Research Ethics. All procedures conducted in this study were performed in accordance with applicable laws and institutional regulations, with approval from the relevant institutional ethics committee. The research protocol was reviewed and approved by the Institutional Review Board (IRB) under reference number NCKU HREC-E-110-675-2. Informed consent was obtained from all participants prior to their involvement in the study. Participants were informed of their right to withdraw from the study at any time without penalty. All data collection procedures adhered to ethical guidelines for research involving human subjects, ensuring participant confidentiality and data protection throughout the research process.

Data Availability Statement. The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. Due to the qualitative nature of the data and privacy considerations related to participant responses, raw interview transcripts and reflective journals are not publicly available.

Conflicts of Interest. The authors declare no conflicts of interest, either financial or non-financial, that may be relevant to the research reported in this manuscript. None of the authors have any competing interests that could inappropriately influence the work presented. The research was conducted independently without any commercial or financial relationships that could be construed as potential conflicts of interest. The AI simulation tools used in this study were accessed through standard academic licensing agreements without any special arrangements or financial considerations that might bias the research outcomes.

Funding. This research was partially supported by funding from Ministry of Science and Technology, Taiwan (Grant Number: MOST 111-2410-H-024 -001 -MY2). The funding bodies had no role in the design of the study, data collection, analysis, interpretation of data, or in writing the manuscript. All research activities were conducted with full academic independence and integrity.

REFERENCES

- Ali, M. M., Wafik, H. M. A., Mahbub, S., & Das, J. (2024). Gen Z and generative AI: Shaping the future of learning and creativity. *Cognizance Journal of Creativity*, 12(2), 45–67. http://doi.org/10.47760/cognizance.2024.v04i10.001
- Andreea-Roxana Popescu, Alice Schut. (2023). Generative AI in creative design processes: a dive into possible cognitive biases. IASDR 2023: Life-Changing Design, 9-13 October, Milan, Italy. http://dx.doi.org/10.21606/iasdr.2023.784
- Blechschmidt, E., & Gasser, R. F. (2012). Biokinetics and biodynamics of human differentiation: Principles and applications. North Atlantic Books.
- Bluteau, G., Ponton, D. E., Rosabal, M., & Amyot, M. (2025). Biodynamics and environmental concentrations of the platinum group elements in freshwater systems. *Environmental Science & Technology*, 59(12), 6203-6213. http://doi.org/10.1021/acs.est.4c08750
- Carpenter-Boggs, L., Reganold, J. P., & Kennedy, A. C. (2000). Effects of biodynamic preparations on compost development. *Biological Agriculture & Horticulture*, 17(4), 313–329. https://doi.org/10.1080/01448765.2000.9754852
- Charmaz, K. (2014). Constructing grounded theory. Sage.
- Costa, S. D., Barcellos, M. P., & Falbo, R. A. (2021). Ontologies in human–computer interaction: A systematic literature review. *Applied Ontology*, 16(4), 379–410. https://doi.org/10.3233/AO-210255

- Creswell, J. W., & Poth, C. N. (2018). Qualitative inquiry and research design: Choosing among five approaches, Sage.
- Cutcliffe, J. R. (2000). Methodological issues in grounded theory. *Journal of Advanced Nursing*, 31(6), 1476–1484. https://doi.org/10.1046/j.1365-2648.2000.01430.x
- DePalma, M. J., & Alexander, K. P. (2018). Harnessing writers' potential through distributed collaboration. *System*, 77, 1–12.
- Döring, J., Frisch, M., Tittmann, S., Stoll, M., & Kauer, R. (2015). Growth, yield and fruit quality of grapevines under organic and biodynamic management. *PLOS ONE*, 10(10), e0138445. https://doi.org/10.1371/journal.pone.0138445
- Finkelstein, V. (1998). The biodynamics of disablement. Disability and Rehabilitation Systems Research workshop, Harare, Zimbabwe, 29 June 1998.
- Frosio, G. (2025). Should we ban generative AI or make it a medium for inclusive creativity? In A Research Agenda for EU Copyright Law. Elgar Publishing. https://doi.org/10.4337/9781803927329.00010
- Guruguntla, V., & Lal, M. (2025). A state-of-the-art review on biomechanical models and biodynamic responses. Ergonomics, 68(1), 1–16. https://doi.org/10.1080/00140139.2023.2288544
- Hornberger, M. I. (2024). A biodynamic model predicting copper and cadmium bioaccumulation in caddisflies. *PLOS ONE*, 19(2), e0267890. https://doi.org/10.1371/journal.pone.0297801
- Ivancevic, V. G., & Ivancevic, T. T. (2005). Natural biodynamics. World Scientific.
- Koepf, H. H. (2005). The biodynamic farm: Agriculture in service of the Earth and humanity. SteinerBooks.
- Lin, H.-C. K., Tseng, C.-H., & Chen, N.-S. (2025). Enhancing programming education: The impact of AI-based pedagogical agents on student self-efficacy, engagement, and learning outcomes. *Educational Technology & Society,* 28(2). https://doi.org/10.30191/ETS.202504_28(2).TP02
- Lockman, J. J., & Thelen, E. (1993). Developmental biodynamics: Brain, body, behavior connections. *Child Development*, 64(4), 953–959. https://psycnet.apa.org/doi/10.1111/j.1467-8624.1993.tb04181.x
- Mace, M. A., & Ward, T. B. (1998). Modeling the creative process. *Creativity Research Journal*, 10(2), 229–241. http://dx.doi.org/10.1207/S15326934CRJ1402_5
- Macleroy, V. (2016). Multimodal composition and creativity. *In: Multilingual Digital Storytelling: Engaging creatively and critically with literacy* (Jim Anderson & Vicky Macleroy ed.), Routledge (Taylor & Francis). http://dx.doi.org/10.4324/9781315758220-9
- Masserman, J. H. (1953). Psycho-analysis and biodynamics. The International Journal of Psycho-Analysis, 34(2), 97–109.
- Muhie, S. H. (2023). Concepts, principles, and application of biodynamic farming. *Circular Economy and Sustainability*, 3(1), 35–50. http://dx.doi.org/10.1007/s43615-022-00184-8
- Nelson, L. K. (2020). Computational grounded theory: A methodological framework. *Sociological Methods & Research*, 49(1), 3–42. https://doi.org/10.1177/0049124117729703
- Paull, J. (2011). Biodynamic agriculture: The journey from Koberwitz to the world, 1924–1938. *Journal of Organic Systems*, 6(1), 27–38.
- Ramsurrun, H., Elaheebocus, R., & Chiniah, A. (2024). Digital tools in informal science education sites. *Journal of Science Education and Technology*, 33(1), 569–589. http://dx.doi.org/10.1007/s10956-024-10105-z
- Reganold, J. P. (1995). Soil quality and profitability of biodynamic and conventional farming systems. *American Journal of Alternative Agriculture*, 10(1), 36–45.
- Santoni, M., Ferretti, L., Migliorini, P., Vazzana, C. & Pacini, G. (2022). A review of scientific research on biodynamic agriculture. Organic Agriculture, 12(2), 373–396. https://doi.org/10.1007/s13165-022-00394-2
- Steiner, R. (2013). Agriculture course: The birth of the biodynamic method. Rudolf Steiner Press.
- Strauss, A., & Corbin, J. (1998). Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. Sage.
- Thornberg, R., & Dunne, C. (2019). Literature review in grounded theory. In A. Bryant & K. Charmaz (Eds.), *The SAGE Handbook of Current Developments in Grounded Theory* (pp. 58–78). SAGE Publications Ltd.
- Wildfeuer, S. (1995). What is biodynamics. Stella Natura.

Zaller, J.G., Köpke, U. Effects of traditional and biodynamic farmyard manure amendment on yields, soil chemical, biochemical and biological properties in a long-term field experiment. Biol Fertil Soils 40, 222–229 (2004). https://doi.org/10.1007/s00374-004-0772-0