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Designing ESD-integrated outdoor learning to enhance students' systems thinking skills

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Abstract. This study aimed to develop and examine the feasibility and preliminary effectiveness of an Education for Sustainable Development (ESD)-integrated outdoor learning design to enhance students' systems thinking skills in science classrooms, responding to the urgent need for instructional approaches that address students' limited ability to understand complex sustainability issues at the primary education level. The study employed a Design and Development (D&D) research approach, consisting of needs and context analysis, design development, expert validation, and limited implementation. The study involved 200 elementary school students selected through purposive sampling from public schools representing diverse learning contexts. Research instruments included validation sheets, learning implementation tools, and a systems thinking test. Data were analyzed using descriptive statistics, Percentage Agreement (PA) for reliability, paired difference testing, and N-gain analysis. The results indicated that the developed design, learning worksheets, and instruments were highly valid and reliable. Limited evaluation results indicated a significant improvement in students' systems-thinking skills, with a moderate N-gain score. These findings suggest that ESD-integrated outdoor learning can foster a holistic understanding of sustainability issues. It is recommended that future studies implement large-scale programs and investigate the long-term impacts on sustainability-oriented behaviors.

Introduction

Systems thinking ability constitutes a cognitive and affective competence that is conceptually positioned as a foundational component of 21st-century learning in responding to the complexity of global sustainability challenges (Stefaniak et al., 2024). Systems thinking enables individuals to understand phenomena as networks of interdependent, dynamic, and cross-scale relationships (Bozkurt & Bozkurt, 2024; Elsawah et al., 2022). Ideally, this competence develops through learning experiences that foster interdisciplinary knowledge integration, relational understanding, and critical reflection on sustainability realities. The Education for Sustainable Development (ESD) framework developed by UNESCO (2017) emphasizes that sustainable education requires learning approaches capable of addressing such complexity holistically and meaningfully.

Nevertheless, empirical studies indicate that students' systems thinking achievement has not yet aligned with the conceptual demands of ESD (Kurent & Avsec, 2024). Numerous studies report that students tend to perceive sustainability issues in a fragmented manner, with reasoning patterns that do not fully reflect an understanding of reciprocal relationships, feedback loops, and cross-temporal consequences within systems (Avsec et al., 2023; Oschepkov et al., 2022). This limitation is not merely attributable to instructional delivery methods, but rather to a misalignment between the nature of systems thinking, which requires contextual, exploratory, and reflective experiences, and the learning designs commonly provided in educational practice (Evi Yupani & Widana, 2023).

Furthermore, previous research findings suggest that students' sustainability awareness related to systems thinking often remains at a cognitive-declarative level and has not developed into reflective or transformative awareness. Wiek et al. (2011) assert that without mastery of systems thinking, students tend to view sustainability challenges as isolated issues rather than systemic problems requiring cross-dimensional and cross-scale understanding. Consequently, the resulting attitudes and decision-making processes are reactive and short-term, with limited consideration of long-term systemic impacts. This condition indicates a gap between the normative goals of sustainable education and the quality of students' learning experiences. Findings from the researchers' preliminary study further substantiate this issue. Students demonstrated the ability to identify environmental components and sustainability issues separately, but struggled when required to explain the interconnections among phenomena, such as the relationships among human activities, ecosystem changes, and their accompanying socio-economic implications. Analysis of students' responses revealed a tendency toward linear, static thinking, with limited capacity to model system dynamics or to consider alternative sustainability scenarios. This condition reflects that existing learning experiences have not optimally facilitated the relational and reflective thinking processes essential for the development of deep sustainability awareness.

Theoretically, systems thinking develops most effectively through direct engagement with complex, non-reductive real-world contexts. Learning experiences detached from authentic contexts tend to limit students' opportunities to observe system dynamics directly, test assumptions, and reflect on the relationship between conceptual knowledge and empirical realities (Alford et al., 2025; Widana & Ratnaya, 2021). In this regard, the primary issue does not lie in the presence or absence of learning activities, but rather in the quality of the learning design, which has not explicitly guided students toward systemic meaning-making and a sustainability orientation. Outdoor learning holds significant pedagogical potential to address this challenge, as it provides learning spaces that allow students to engage directly with real, dynamic, and contextual environmental and social systems. Numerous studies have demonstrated that outdoor learning experiences can enhance observational skills, causal analysis, and cross-scale understanding (Lorenzo et al., 2025). However, without an integrated conceptual framework, outdoor learning risks failing to produce conceptually meaningful and reflective learning outcomes.

Therefore, there is a need to develop an outdoor learning design that consciously and systematically integrates ESD principles. Such integration positions sustainability issues as the focus of systemic analysis, directs students to explore interrelationships among environmental, social, and economic components, and encourages critical reflection on the sustainability implications of various courses of action (El-Aasar et al., 2024). With an integrated design, outdoor learning functions not merely as a learning context but as an epistemic medium for simultaneously developing systems thinking and sustainability awareness. Accordingly, research on the development of ESD-integrated outdoor learning designs becomes both relevant and urgent, theoretically and practically. Theoretically, this study contributes to strengthening sustainability-oriented learning frameworks grounded in systems thinking. In practice, it is expected to produce a learning design capable of bridging the gap between the demands of sustainability competencies and the realities of students' learning experiences, enabling learning outcomes that extend beyond conceptual understanding toward reflective, future-oriented sustainability awareness.

Although research on systems thinking, Education for Sustainable Development (ESD), and outdoor learning has expanded in recent years, several critical gaps remain. Existing studies predominantly focus on secondary or higher education contexts, while empirical research explicitly targeting the development of systems thinking in primary science education remains limited (Sá et al., 2022; Green et al., 2022). Moreover, most studies are situated in Western or developed educational contexts, resulting in a lack of contextualized evidence from developing countries, particularly Indonesia, where curricular structures and learning environments differ substantially (UNESCO, 2017). From a methodological perspective, prior research often examines ESD or outdoor learning through descriptive or quasi-experimental approaches, without systematically developing and validating an integrated instructional design that aligns ESD principles, outdoor learning activities, and systems-thinking objectives within a coherent pedagogical framework (Elsawah et al., 2020; Widana et al., 2020). Conceptually, outdoor learning is often presented merely as an experiential context rather than as an epistemic medium for fostering systemic reasoning, causal analysis, and cross-dimensional understanding of sustainability (Wiek et al., 2011; Lorenzo-Rial et al., 2025; Syam et al., 2024). Addressing these conceptual, methodological, and empirical gaps, this study develops and evaluates an ESD-integrated outdoor learning design specifically situated in primary science education in Indonesia, thereby contributing validated pedagogical guidance and empirical evidence to advance sustainability-oriented learning practices grounded in systems thinking.

Based on the preceding assumptions and discussions, this study aims to develop an outdoor learning design integrated with Education for Sustainable Development (ESD) principles to enhance students' systems thinking abilities. The design development is intended to facilitate understanding of the dynamic interconnections among environmental, social, and economic dimensions through contextual outdoor learning experiences, while promoting causal analysis and long-term implication assessment of sustainability issues. Thus, this study is expected to bridge the gap between the systemic and complex demands of sustainability competencies and the quality of students' learning experiences, while contributing both theoretically and practically to the advancement of sustainable learning practices that are relevant and future-oriented.

The research questions are: (a) how is the feasibility of the ESD-integrated outdoor learning design; and (b) how does the implementation of ESD-integrated outdoor learning improve students' systems thinking skills. Based on the research questions, the research hypotheses are: (a) the ESD-integrated outdoor learning design is feasible for implementation in science classrooms, as indicated by expert validation and learning implementation results; and (b) the implementation of ESD-integrated outdoor learning significantly improves students' systems thinking skills.

This study aims to develop and examine the feasibility of an Education for Sustainable Development (ESD)-integrated outdoor learning design for science classrooms through expert validation and limited implementation. In addition, the study seeks to investigate the extent to which implementing the proposed learning design enhances students' systems thinking skills by comparing their performance before and after the learning intervention. Through these objectives, the research intends to provide empirical evidence regarding the pedagogical potential of ESD-integrated outdoor learning as an instructional approach that supports the development of higher-order and holistic thinking skills in science education.

Method

Research Method and Design

This study employed a Design and Development Research (D&D) (Richey & Klein, 2007). The research design focused on the development of a pedagogical product in the form of an ESD-integrated outdoor learning design intended to enhance students' systems thinking skills. The development framework adapted the main stages of D&D research, comprising: (1) needs and context analysis, (2) design planning, (3) design development and validation, and (4) limited evaluation of design effectiveness. These stages are consistent with established instructional design models within D&D research, such as those proposed by Richey & Klein (2007) and further elaborated by Richey, Klein, and Tracey (2011). The use of a Design and Development Research (D&D) approach was methodologically appropriate because this study aimed not only to examine instructional effectiveness, but also to systematically design, validate, and refine an ESD-integrated outdoor learning design grounded in sustainability education theory and classroom realities. D&D research is well-suited to addressing complex educational challenges that require integrating conceptual frameworks, contextual considerations, and iterative expert validation. Furthermore, this approach enables the assessment of feasibility and preliminary effectiveness prior to large-scale implementation, thereby ensuring that the developed design is pedagogically sound, contextually relevant, and practically applicable for enhancing students' systems thinking skills and sustainability awareness in authentic learning contexts.

The Research Procedure

The first phase was needs analysis, which aimed to identify students' characteristics related to systems thinking and sustainability awareness, as well as the alignment of the learning context with ESD principles. This analysis was carried out through literature review, preliminary studies, and analysis of the learning environment. *The second phase* involved design planning, during which the structure of outdoor learning integrated with ESD principles articulated by UNESCO was formulated. At this stage, learning objectives, outdoor learning scenarios, sustainability contexts, and reflective activities were determined to support the development of systems thinking and sustainability awareness. *The third phase* was design development and validation, which included the construction of a prototype outdoor learning design along with its supporting instructional tools. Validation was conducted through expert judgment involving learning experts, sustainability education experts, and educational practitioners to assess the conceptual, pedagogical, and contextual feasibility of the developed design. Previous methodological literature in educational design research indicates that involving 2 to 5 experts is sufficient to obtain stable, credible judgments when evaluators possess relevant expertise and the validation focuses on product refinement rather than statistical generalization (Lynn, 1986).

The experts were purposively selected based on clearly defined criteria to ensure the credibility and relevance of the validation process. These criteria included: (1) holding a doctoral degree in science education, curriculum studies, or sustainability education; (2) having a minimum of five years of professional experience in teaching, curriculum development, or educational research; and (3) possessing demonstrated scholarly engagement through publications or professional involvement related to Education for Sustainable Development (ESD), outdoor learning, or systems thinking. This selection strategy ensured that the validation judgments were grounded in both theoretical expertise and practical classroom experience. Regarding the validation method, this study employed quantitative expert judgment, using mean score analysis and inter-rater reliability testing via the Percentage Agreement (PA) index. The use of PA was intended to assess the consistency of expert evaluations across validation dimensions. While formal indices such as the Content Validity Index (CVI) or Aiken's V are commonly used to quantify content validity, the present study prioritized formative validation within a design-oriented research framework. Consequently, expert judgment was operationalized through structured validation instruments that captured both quantitative ratings and qualitative feedback for design refinement. This approach is consistent with D&D research conventions, which emphasize iterative expert feedback and reliability consistency to ensure product feasibility and pedagogical robustness prior to broader empirical testing (Thiagarajan, 1974; Richey & Klein, 2007).

The fourth phase was a limited evaluation aimed at providing an initial overview of the design's contribution to strengthening students' systems-thinking skills and sustainability awareness. This evaluation was formative in nature and served as the basis for design refinement. The evaluation was conducted with 200 grade 5 students from elementary schools in Bandung Regency, Indonesia. The research was conducted during the second semester of the 2025/2026 academic year. The study involved three main parties. The researcher was responsible for designing the ESD-integrated outdoor learning framework, developing the learning materials and research instruments, conducting data collection, and analyzing the research data. The classroom teacher served as a facilitator, implementing the learning design in the classroom and during outdoor learning activities, guiding students throughout the learning process, and supporting the administration of the research procedures. The elementary school students served as research participants who engaged in ESD-integrated outdoor learning activities and completed the pretest and posttest to measure changes in their systems-thinking skills.

Data Collection Techniques and Research Instruments

Research instruments were developed in accordance with the objectives of each phase. The needs analysis instruments consisted of preliminary study guidelines and learning context analysis sheets. Design validation instruments included expert evaluation forms covering alignment with ESD principles, clarity of learning flow, relevance of outdoor contexts, and the potential to foster systems thinking and sustainability awareness. During the limited evaluation phase, a systems thinking test consisting of 9 items representing 8 indicators of systems thinking was administered. The distribution of test items across systems thinking indicators is presented in Table 1.

Table 1. Distribution of Systems Thinking Test Items

Numb.	System Thinking Skills Indicators	Definition	Item Distribution
1	Identifying system components	The ability to recognize and identify elements that constitute a system.	1
2	Identifying relationships among system components	The ability to identify direct and simple relationships between two or more components within a system.	2
3	Identifying dynamic relationships among system components	The ability to understand that relationships among system elements are dynamic, change over time, and influence one another through complex interactions.	3
4	Organizing system components and processes within relational frameworks	The ability to organize and structure components into a system framework that reflects hierarchical and functional relationships.	4
5	Understanding the cyclical properties of systems	The ability to identify recurring patterns within systems, including positive and negative feedback loops that affect system stability or change.	5
6	Identifying hidden dimensions of systems	The ability to recognize latent, indirect, or unobservable factors that influence system behavior.	6

Numb.	System Thinking Skills Indicators	Definition	Item Distribution
7	Making generalizations	The ability to draw general conclusions from observed system patterns that can be applied to similar systems.	7
8	Temporal thinking (retrospective and prospective)	The ability to analyze past causes (retrospective) and predict future consequences (prospective) within a system context.	8, 9

(Ben-Zvi-Assaraf & Orion, 2010)

Data Analysis Techniques

Data analysis employed a mixed qualitative and quantitative approach. Qualitative data derived from needs analysis, expert validation, observations, and students' reflections were analyzed using thematic analysis using triangulation to identify patterns, tendencies, and areas for design improvement. Quantitative data from the systems thinking test were analyzed descriptively to examine trends in improvement and levels of indicator achievement. Quantitative findings were used complementarily to support qualitative results in evaluating the contribution of the developed ESD-integrated outdoor learning design.

Results and Discussion

Design Development

Based on the results of the needs and context analysis, an outdoor learning design integrated with the principles of Education for Sustainable Development (ESD) was formulated. This design was developed by positioning the issue of "waste and environmental pollution" as the focal point of systems analysis, while coherently integrating environmental, social, and economic dimensions within a unified learning sequence. The conceptual framework underpinning the outdoor learning design is presented in Table 2.

Table 2. Conceptual Framework of Outdoor Learning Design

No.	Component	Description
1	Key Concept	
	Outdoor Learning	Learning experiences that are grounded in direct engagement with natural or authentic environments
	Sustainable Development (SD)	Developmental objectives that integrate environmental integrity, social equity, and economic viability
	Education for Sustainable Development (ESD)	An educational framework aimed at fostering sustainable values, behaviors, and practices
2	Core Principles of ESD	
	Interdisciplinary Approach	Integration of concepts, methods, and perspectives across multiple academic disciplines
	System Thinking and Problem Solving	Examination of sustainability challenges through systemic analysis and solution-oriented reasoning
	Active Participation	Active involvement of learners through experiential tasks and collaboration with the community
3	Learning Objectives	
	Awareness and Knowledge	Developing comprehension of environmental issues and sustainability concepts
	Skills Development	Strengthening practical competencies related to outdoor engagement and environmental stewardship

No.	Component	Description
	Attitude and Values	Cultivating environmental ethics, social responsibility, and respect for nature
4	Curriculum and Activities	
	Experiential Learning	Learning through direct participation in outdoor activities that support sustainability learning
	Place-Based Education	Utilization of local environmental issues and socio-cultural contexts as learning resources
	Assessment Strategies	Measurement of learners' understanding and application of ESD-oriented knowledge and skills
5	Technology	
	Students' Developed Technologies	Facilitating learners' engagement in designing and producing simple technological solutions
	Innovation and Creativity	Providing opportunities for idea generation and prototyping of sustainable technologies within outdoor contexts
	Practical Applications	Applying student-developed technologies in authentic, real-world situations
	Showcasing Solutions	Showcasing learning outcomes through exhibitions or presentations to the wider community.
6	Collaboration with Stakeholders	
	Community Involvement	Collaboration with local communities and relevant institutions
	Interdisciplinary Collaboration	Cooperation among educators from diverse disciplinary backgrounds
	Feedback Mechanisms	Development of structured feedback mechanisms involving learners, teachers, and community stakeholders
7	Evaluation and Reflection	
	Assessment of Outcomes	Systematic assessment of the effectiveness of the learning framework
	Reflection Practices	Encouraging critical reflection on learning experiences and their impacts
	Adaptation and Improvement	Ongoing improvement of the framework based on evaluative findings

The conceptual framework presented in Table 3 illustrates the construction of ESD-integrated outdoor learning as a holistic, multidimensional, and sustainability-oriented learning system. Within this framework, outdoor learning is positioned not merely as a location-based instructional strategy but as a pedagogical approach that connects students' direct experiences with sustainable development goals through reflective and transformative learning processes. It integrates pedagogical dimensions, learning objectives, instructional strategies, the role of technology, and learning evaluation into a coherent structure. This framework serves as a reference for the design and implementation of learning activities to develop students' systems-thinking skills and sustainability awareness.

In this framework, outdoor learning is understood not simply as relocating learning activities to outdoor settings, but as an instructional approach that enables students to engage directly with real socio-ecological systems, thereby rendering learning experiences contextual, reflective, and meaningful. This perspective aligns with the ESD framework, which emphasizes the integrated consideration of environmental, social, and economic dimensions within learning processes and adopts a long-term sustainability orientation (Segara et al., 2023). The structure of the conceptual framework demonstrates coherence among learning objectives, pedagogical strategies, learning activities, the role of technology, and evaluation mechanisms. Such coherence is essential, as the development of systems thinking and sustainability awareness requires learners to understand interrelationships among system components rather than acquiring isolated concepts. Previous studies indicate that experiential learning in authentic environments significantly contributes to the development of systems thinking by training learners to identify patterns, causal relationships, and complex system dynamics (Karaarslan & Teksöz, 2020; Karaarslan & Teksöz, 2024; Karaarslan, 2022).

Furthermore, integrating ESD principles into this framework strengthens the participatory and contextual dimensions of learning. Community involvement and the incorporation of local issues into outdoor learning activities are consistent with place-based education approaches, which emphasize the importance of local contexts in fostering relevance and awareness of sustainability among learners (Wardani et al., 2025; Kusumaningrum et al., 2023). Through interaction with the environment and the community, students not only develop conceptual understanding but also cultivate a sense of values, responsibility, and commitment to sustainable practices. The conceptual framework also positions technology as an integral component of learning, not as an end goal, but as a means to translate systemic understanding into tangible solutions. The development of simple technologies by students within outdoor learning contexts reflects an ESD-oriented approach focused on problem-solving and sustainable innovation. Prior research suggests that student engagement in technology-based solution design can enhance creativity, technological literacy, and awareness of the environmental impacts of actions or products (Komariah & Sa'ud, 2024; Mickelsson et al., 2019).

Development and Validation of the Design

The development stage resulted in a prototype of an ESD-integrated outdoor learning design along with its supporting instructional components. The outcomes of the ESD-integrated outdoor learning design development are presented in Image 1.

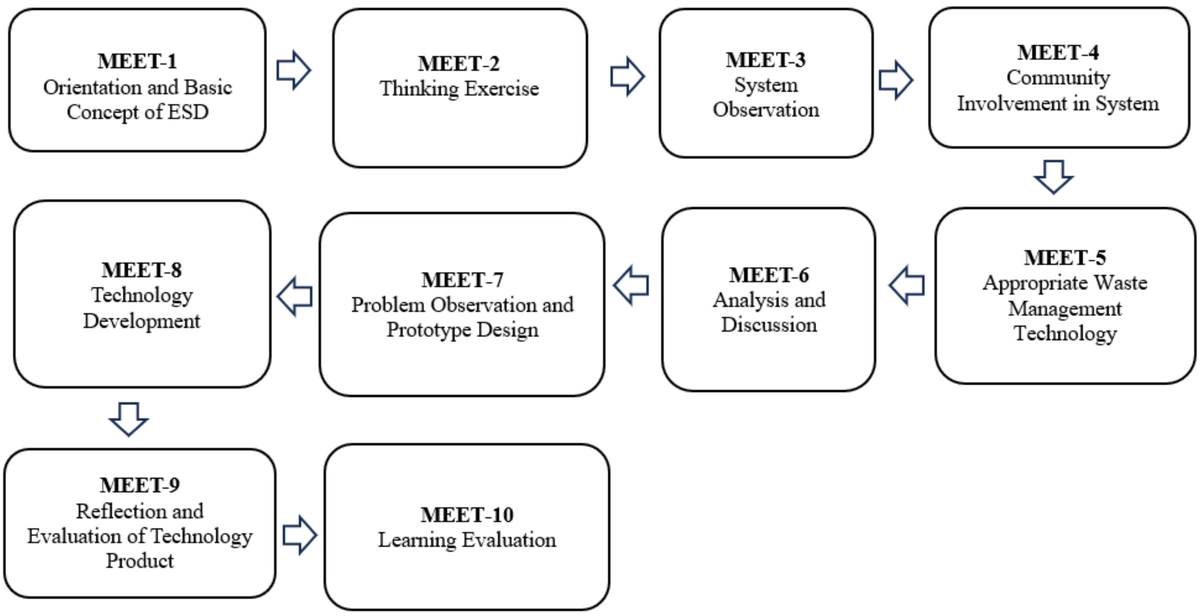

Image 1. ESD-Integrated Outdoor Learning Design

Based on Image 1, the design positions outdoor learning not merely as an extension of the learning venue, but as an authentic pedagogical space that enables learners to interact directly with complex socio-ecological systems. The MEET-1 stage (Orientation and Basic Concept of ESD) functions as the epistemological and axiological foundation of learning. At this stage, learners are equipped with a conceptual understanding of ESD as an educational framework that integrates the environmental, social, and economic dimensions of sustainable development. This initial orientation is essential for establishing conceptual alignment and value awareness, ensuring that subsequent learning activities are guided by explicit sustainability-oriented goals. The MEET-2 stage (Thinking Exercise) is designed to develop learners' cognitive readiness through analytical and reflective thinking exercises. Activities at this stage aim to stimulate systems thinking skills, particularly in identifying interconnections, patterns, and causal relationships within a system. Consequently, learners are encouraged not to perceive phenomena in a fragmented manner but to begin constructing a holistic perspective on sustainability issues. The emphasis on conceptual orientation to ESD and systems thinking exercises in the early stages of learning is consistent with findings that the development of systems thinking and sustainability awareness requires a clear value foundation and cognitive framework before learners engage with complex empirical contexts (Lasekan et al., 2023; Georgakopoulos et al., 2023). This approach strengthens transformative learning, in which outdoor experiences serve as a medium for integrating conceptual understanding with holistic analysis of socio-ecological systems (Chen et al., 2022).

Subsequently, MEET-3 (System Observation) situates learners within an empirical context through direct observation of real systems in the surrounding environment. Observations are conducted systematically to identify system components, process flows, and interaction dynamics among elements. This stage reinforces experiential learning and provides authentic data for sustainability analysis. MEET-4 (Community Involvement in System) expands the learning scope by involving local communities as an integral part of the observed system. Community engagement enables learners to recognize that sustainability issues are inseparable from social, cultural, and everyday practices. This stage emphasizes the participatory dimension of ESD and fosters awareness of the role of social actors in managing sustainable systems. Building on observational findings and social interactions, MEET-5 (Appropriate Waste Management Technology) directs learners toward exploring solutions based on appropriate technology. The focus on context-sensitive waste management reflects sustainability principles, including resource efficiency, social acceptability, and minimal environmental impact. This stage integrates technological aspects within a systems thinking framework. The integration of system observation, community involvement, and exploration of appropriate technology reflects the contextual and participatory characteristics of ESD learning, in which sustainability understanding is constructed through direct interaction with real socio-ecological systems (van Kraalingen, 2023). This approach aligns with evidence that experiential learning and community collaboration are effective in strengthening sustainability awareness and learners' capacity to formulate socially and ecologically relevant solutions (Debrah et al., 2021).

The MEET-6 stage (Analysis and Discussion) serves as a space for integrating conceptual and empirical elements. Learners conduct critical analysis of field data through collaborative discussions while considering the interconnections among sustainability dimensions. This process enhances reflective, argumentative, and evidence-based reasoning skills. Subsequently, MEET-7 (Problem Observation and Prototype Design) directs learning toward a design-based learning approach. Learners identify priority problems and design solution prototypes to address the complexity of systems observed in the school environment. This stage emphasizes problem-solving skills, creativity, and the application of knowledge in authentic contexts. MEET-8 (Technology Development) represents the implementation phase, in which designed prototypes are developed and refined. This stage strengthens technological literacy and sustainable innovation while training learners to consider functionality, sustainability, and social impact. The integration of collaborative analysis, prototype design, and technology development reflects ESD-oriented learning that emphasizes higher-order thinking and authentic problem-solving, in which learners construct solutions based on empirical evidence and systemic understanding (Kolb, 1984). Design-based learning within a sustainability context has been shown to be effective in fostering creativity, technological literacy, and social responsibility, while bridging conceptual knowledge with sustainable action (Vinet & Zhedanov, 2011).

The MEET-9 stage (Reflection and Evaluation of Technology Product) emphasizes critical reflection and continuous evaluation of the developed products. Learners assess the effectiveness of the solution, its alignment with ESD principles, and its implications for social and environmental systems. This reflective process plays a crucial role in developing metacognitive awareness and responsible attitudes. Finally, MEET-10 (Learning Evaluation) represents a comprehensive evaluation of the entire learning process and outcomes. The evaluation focuses not only on cognitive achievements but also on the development of systems-thinking skills and sustainability awareness as primary learning outcomes. Thus, evaluation is positioned as an instrument for continuous improvement. The emphasis on critical reflection and ongoing evaluation aligns with the characteristics of ESD learning, which place metacognition and social responsibility at the core of fostering long-term sustainability awareness (Hariyono et al., 2024). Comprehensive, continuous-improvement–oriented evaluation approaches have been shown to be effective in assessing transformations in learners' ways of thinking, particularly in the development of systems thinking and sustainability-oriented action (Mokski et al., 2023).

The prototype was subsequently validated through expert judgment to assess the conceptual, pedagogical, and contextual feasibility of the design. Validation results indicated that the developed design is valid and reliable, particularly in systematically integrating sustainability dimensions and promoting the development of higher-order thinking. Experts agreed that the learning flow effectively facilitates learners' ability to identify causal relationships, system dynamics, and long-term implications of the sustainability issues examined. The validation results for the outdoor learning design and its supporting components are presented in Table 3, and the reliability analysis based on these results is presented in Table 4.

Table 3. Validity Test Results

Product	Mean Score	Category
ESD-Integrated Outdoor Learning Design	3.70	Highly valid
Student Worksheet (LKPD)	3.66	Highly valid
Research Instruments	3.63	Highly valid

Table 4 presents the results of the validity test of the developed products, including the ESD-integrated outdoor learning design, student worksheets (LKPD), and research instruments. Validity was determined based on the mean scores provided by validators, reflecting the degree of alignment with the criteria of content relevance, construct clarity, and operational feasibility. All products achieved mean scores above 3.60 and were categorized as very valid, indicating that the developed components met content validity standards and aligned with the intended learning objectives. The high validity score of the ESD-integrated outdoor learning design demonstrates that the developed learning framework aligns with ESD principles and experiential learning characteristics, emphasizing coherence among learning objectives, contextual activities, and the development of systems thinking (Sato & Kitamura, 2023).

The highly valid category achieved by the LKPD and research instruments further supports the finding that coherently designed, context-based learning tools effectively facilitate the achievement of sustainability-oriented learning outcomes (Thiagarajan, 1974; Pálsdóttir & Jóhannsdóttir, 2021). Therefore, the validation results provide empirical evidence that the developed products are suitable for broader implementation and learning evaluation.

Nevertheless, the validation process also generated several recommendations for improvement, particularly regarding the clarity of instructions in field exploration activities and the strengthening of reflective guidance to enhance system-level meaning-making. These suggestions were incorporated into revisions to refine the design prior to the limited evaluation stage. Subsequently, a reliability test was conducted using validation scores and the percentage agreement method to assess the consistency of the developed products. The results of the reliability test are presented in Table 4.

Table 4. Reliability Results of the Outdoor Learning Design and Supporting Components

Product	PA Value (Validators)			Mean Percentage Agreement (PA)	Category
	V_{1-2}	V_{1-3}	V_{2-3}		
Outdoor Learning Design	90.86	95.12	96.78	94.25	Reliable
Student Worksheet	92.04	93.21	90.62	91.96	Reliable
Research Instrument	91.84	94.10	95.36	93.77	Reliable

Table 5 presents the results of the reliability testing of the ESD-integrated outdoor learning design and its supporting components using the Percentage Agreement (PA) index among validators. Overall, all developed products demonstrate high PA values, with mean scores exceeding 90%, indicating that they quantitatively meet the criteria for reliability and reflect strong inter-rater consistency among expert evaluators.

However, a more critical examination reveals moderate variations in PA values across validator pairs, particularly in the student worksheet, where the lowest PA score was 90.62% (V2–3). Although this value still falls within the reliable category, it suggests that certain aspects of the student worksheet, such as the clarity of field activity instructions or the depth of ESD principle integration, may allow for differing interpretations among validators. This finding indicates the need for further refinement in both editorial clarity and operational guidance to ensure greater explicitness and reduce ambiguity. For the outdoor learning design, the highest PA value was observed for the V2–3 validator pair (96.78%), while the lowest was found for V1–2 (90.86%). This pattern suggests that, although the design was generally evaluated consistently, differences in evaluative perspectives may arise when assessing the complexity of learning stages, particularly those involving community engagement and technology development. Such variation reflects the conceptual richness of the design while simultaneously highlighting the need for more detailed implementation guidelines.

Meanwhile, the research instruments exhibited relatively stable inter-rater agreement, with a mean PA value of 93.77%, indicating that the indicators for measuring systems thinking ability and sustainability awareness were formulated in a sufficiently operational and interpretable manner. Overall, the findings in Table 5 not only confirm that the developed products fall within the reliable category but also identify potential areas for further refinement of the learning design and its supporting components. Consequently, the reliability results serve not only as empirical justification for product feasibility but also as a reflective basis for continuous improvement in the development of ESD-integrated outdoor learning designs.

The high reliability across all products strengthens the argument that the ESD-integrated outdoor learning design and its supporting components exhibit adequate evaluative consistency for use in development research contexts. High Percentage Agreement values among validators are consistent with previous studies, which indicate that expert agreement above the 80–90% threshold reflects construct stability and operational clarity in educational products (Zihlmann & Mazzaia, 2022). Within the context of Education for Sustainable Development, high reliability is particularly crucial, as sustainability-oriented learning designs involve multidimensional integration that is susceptible to interpretive variation if not explicitly articulated.

The observed variation in PA values, especially in the student worksheet component, suggests that context-based learning materials are inherently challenged by issues related to instructional clarity and the depth of sustainability integration. This finding aligns with prior research by Calamaan & Trinidad (2025), which emphasizes that outdoor and ESD-based learning materials often require iterative refinement to ensure alignment between conceptual objectives and practical implementation. Accordingly, differences in expert judgment should not be interpreted solely as weaknesses but rather as reflections of the pedagogical complexity embedded in contextual and experiential learning designs (Panduwinata et al., 2025).

Similarly, variations in inter-rater agreement for the outdoor learning design can be understood as a consequence of its integrative and transformative nature. Learning designs that combine community engagement, technological development, and critical reflection demand explicit procedural articulation to ensure consistent interpretation across diverse stakeholders (Kelley & Knowles, 2016). Thus, PA variations that remain within reliable ranges further underscore the importance of detailed procedural documentation and implementation guidelines, as commonly recommended in design-based research. In contrast, the stability of reliability scores for the measurement instruments indicates that the indicators of systems thinking ability and sustainability awareness were sufficiently operationalized and consistently understood by validators. This finding supports previous work by Assaraf & Orion (2010), who argue that assessing systems thinking and sustainability competencies requires clearly structured indicators grounded in interrelationships among system components. Consequently, reliable instruments constitute a critical foundation for evaluating ESD-oriented learning outcomes that aim to shift learners' ways of thinking.

Overall, the reliability results presented in Table 5 not only confirm the technical feasibility of the developed products but also provide reflective insights into aspects of the design that warrant further enhancement. This perspective is consistent with the view that reliability in development research is not a final endpoint but rather part of an ongoing cycle of improvement aimed at producing adaptive, contextual, and sustainable learning designs (Plomp, 2013).

Limited Evaluation of Design Effectiveness

A limited evaluation was conducted to provide an initial overview of the contribution of the ESD-integrated outdoor learning design to strengthening students' systems-thinking abilities. The evaluation results indicate a tendency toward improvement in students' ability to identify interconnections among system components and to explain cause–and–effect relationships more comprehensively after participating in learning activities using the developed design. The results of the pretest and posttest measurements in the limited evaluation are presented in Table 5.

Table 5 . Results of Pretest and Posttest Analysis of Systems Thinking Ability

Data	*Pretest*	*Posttest*
Number of Groups	50	50
Minimum Score	44.44	56.48

Data	*Pretest*	*Posttest*
Maximum Score	65.00	92.22
Mean	56.59	78.60
Standard Deviation	8.42	11.73
Normality Test	0.000 (not normally distributed)	0.000 (not normally distributed)
Mean Difference Test	Sig.(2-tailed) = 0.000 (significantly different)	
N-Gain	0.52 (moderate)	

The analysis presented in Table 6 shows a statistically significant difference between pretest and posttest mean scores, with the level of improvement classified as moderate. These findings indicate that implementing an ESD-integrated outdoor learning design is highly effective at enhancing elementary school students' systems thinking skills. This result is consistent with the view that situated learning in authentic environmental contexts enables learners to identify interconnections among system components and to understand cause–and–effect relationships more deeply than conventional classroom-based instruction (Karaarslan & Teksöz, 2016).

The N-Gain value of 0.52, categorized as moderate, suggests that the improvement in systems thinking ability does not occur instantaneously but develops gradually through learning processes that require repeated observation, analysis, and reflection. This finding aligns with the characterization of systems thinking as a higher-order cognitive skill that requires time and sustained learning experiences to develop (Ben-Zvi, Assaraf, & Orion, 2010). The integration of ESD into outdoor learning design reinforces this process, as students are not only exposed to abstract concepts but also to real-world problems that involve environmental, social, and technological dimensions simultaneously (UNESCO, 2020). More critically, the increase in the maximum score from 65.00 to 92.22 indicates that some students achieved a very high level of systemic understanding following the learning intervention. However, the increase in standard deviation from 8.42 to 11.73 suggests variability in learning outcomes across student groups. This variation may be attributed to differences in prior readiness, environmental literacy, and previous learning experiences that influence how students respond to outdoor and ESD-oriented learning. These findings reinforce the argument that sustainability-oriented learning implementation should be accompanied by differentiated instructional strategies and pedagogical support to ensure more equitable learning benefits for all students (Wiek et al., 2011; Supardi & Rahman, 2025).

The non-normal distribution of both pretest and posttest data further indicates that changes in systems thinking ability do not occur in a linear manner. This observation is consistent with previous research suggesting that the development of systems thinking is inherently nonlinear and influenced by complex interactions among learning experiences, social contexts, and environmental stimuli (Karayol & Umdu Topsakal, 2025). Therefore, the use of nonparametric statistical tests in this evaluation is appropriate and strengthens the validity of the resulting inferences. Overall, the findings of this limited evaluation confirm that the ESD-integrated outdoor learning design has the potential to effectively enhance elementary school students' systems thinking ability, particularly in identifying relationships among system elements and understanding sustainability implications. However, given that the observed improvement falls within the moderate category, these findings also emphasize the need for long-term implementation and strengthened reflective cycles to support more optimal and sustainable development of systems thinking skills. Thus, this limited evaluation serves not only as preliminary evidence of design effectiveness but also as an empirical basis for further development and refinement of ESD-oriented learning designs at a broader implementation stage.

The findings of this study are consistent with previous research indicating that outdoor learning and Education for Sustainable Development (ESD) approaches can enhance students' higher-order thinking skills, particularly systems thinking in science education in primary schools. Prior studies have emphasized the role of experiential and context-based learning in fostering a holistic understanding of sustainability issues (Lugg, 2007); however, most have focused on conceptual outcomes without explicitly integrating systems thinking as a core analytical skill (Waite, 2020). This study extends the existing literature by empirically demonstrating that an ESD-integrated outdoor learning design can significantly improve students' systems-thinking skills through structured learning activities and guided reflection. The novelty of this study lies in the systematic design of an ESD-integrated outdoor learning framework specifically oriented toward developing systems thinking in primary science classrooms. Unlike previous studies that implemented outdoor learning in a fragmented, activity-based manner, this research offers a structured, validated learning design, accompanied by supporting instructional tools and assessment instruments. Additionally, the use of a design and development research approach provides a replicable model that bridges theoretical ESD principles with practical classroom implementation, particularly at the primary education level.

Despite its contributions, this study has several limitations. The implementation was conducted on a limited scale with a single group of students and without a control group, which restricts the generalizability of the findings. The intervention's duration was also relatively short, limiting the ability to examine long-term impacts on students' development of systems thinking and sustainability-oriented behaviors. Furthermore, contextual factors such as teacher experience and school environment were not extensively analyzed, which may influence the effectiveness of the learning design. Theoretically, this study contributes to the field by strengthening conceptual linkages among ESD, outdoor learning, and systems thinking and by offering empirical support for integrating these approaches into science education. In practice, the findings provide educators and curriculum developers with a feasible, adaptable learning design that can be implemented to enhance students' systems-thinking skills in authentic environmental contexts. The results also highlight the potential of outdoor learning as a pedagogical strategy to operationalize ESD in primary education.

Future research is recommended to conduct large-scale implementations involving diverse school contexts and experimental designs to further validate the effectiveness of the proposed learning design. Longitudinal studies are also suggested to investigate the sustained impact of ESD-integrated outdoor learning on students' systems thinking and pro-sustainability behaviors. Additionally, further studies may explore teacher professional development and institutional support as moderating factors in the successful implementation of ESD-oriented outdoor learning.

Conclusion

This study demonstrates that the developed Education for Sustainable Development (ESD)-integrated outdoor learning design exhibits a high level of feasibility and consistency, as evidenced by expert validation results categorized as highly valid and by high inter-rater Percentage Agreement reliability values. The implementation of the design in a limited evaluation also contributed positively to strengthening students' systems thinking ability, as reflected in the significant difference between pretest and posttest scores with a moderate level of improvement. These findings indicate that systematically designed, contextually grounded, and sustainability-oriented outdoor learning can support students in understanding the interconnections among system components, cause–and–effect relationships, and the complexity of environmental issues in a more holistic manner. Accordingly, the ESD-integrated outdoor learning design can be considered feasible and potentially effective as an innovative instructional alternative for developing systems-thinking skills in elementary education.

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