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AI-Enabled Education for Sustainable Development: Framework Integration and Contextualization in Vietnam

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Abstract

Digitalization and Artificial Intelligence (AI) are reshaping Education for Sustainable Development (ESD) by enabling personalized learning, adaptive feedback, and data-driven competency assessment. Although Vietnam is advancing its national digital transformation agenda, the integration of AI into vocational and higher education remains uneven, particularly in rural regions where infrastructure, digital skills, and faculty readiness vary considerably. This study develops a contextualized AI-enabled ESD framework using a design-based research (DBR) methodology. The framework comprises four constructs: Digital Sustainability Competence (DSC), Ecological Value Orientation (EVO), Institutional Adaptation Capacity (IAC), and AI-enabled ESD as the outcome construct. Together, 21 operational variables explain how AI can enhance sustainability-oriented learning within Vietnam's diverse educational contexts. The framework provides actionable guidance for curriculum redesign, faculty digital upskilling, and institutional readiness, supporting alignment between digital transformation policies and national sustainability goals. Future research should empirically validate the model using PLS-SEM techniques.

Keywords.
Artificial Intelligence, Digitalization, Digital Transformation, Education for Sustainable Development, Vocational & Higher Education.

1. Introduction

The rapid expansion of digital technologies and Artificial Intelligence (AI) is reshaping educational practice globally. In parallel, Education for Sustainable Development (ESD) requires pedagogical approaches that cultivate not only disciplinary knowledge but also systems thinking, anticipatory competence, ethical reasoning, and collaborative problem-solving skills (Marco, 2017; UNESCO, 2017a). AI applications such as adaptive learning systems, learning analytics, and intelligent simulations offer new opportunities to personalize learning, support competency-based assessment, and enhance sustainability-oriented decision-making (Luckin & Holmes, 2016; Holmes et al., 2019).

For countries like Vietnam, which are implementing national digital-transformation strategies, integrating AI with ESD presents both opportunities and challenges. Opportunities include scalable learning solutions and individualized pathways, while challenges relate to equity, pedagogical redesign, and institutional readiness. Vietnam's rapid industrialization, socio-economic goals, and commitments to global sustainability initiatives place significant expectations on its education system. The skills required for green and digital transitions such as technical expertise, problem-solving, and digital literacy, demand updates to curricula, teaching approaches, and assessment methods in vocational and higher education (Government of Vietnam, 2020; ILO, 2022; ILO Brief, 2024). In addition, demographic pressures and regional disparities in infrastructure highlight the need for context-specific strategies that address access, relevance, and workforce alignment.

While prior studies examine AI in education and ESD independently, limited research integrates these domains within emerging economies using a structured, operationalizable model. To address this gap, this study develops an AI-enabled ESD framework contextualized for Vietnam using a Design-Based Research (DBR) methodology. The framework integrates three enabling constructs of Digital Sustainability Competence (DSC), Ecological Value Orientation (EVO), and Institutional Adaptation Capacity (IAC) that collectively shape the implementation of AI-enabled ESD practices. Accordingly, this study proposes the following hypotheses:

***H*1:** Digital Sustainability Competence (DSC) positively affects AI-enabled ESD.
***H*2:** Ecological Value Orientation (EVO) positively affects AI-enabled ESD.
***H*3:** Institutional Adaptation Capacity (IAC) positively affects AI-enabled ESD.

1.1 Contribution

The study contributes to AI-enabled learning by enabling personalization, competency tracking, and simulation-based approaches, while offering a contextualized conceptual model, a 21-variable structure suitable for PLS-SEM validation, and design-oriented insights for curriculum, pedagogy, and institutional development.

2. Literature Review

To support the methodological development and conceptual model proposed in this study, the literature is organized into four streams such as (1) AI in education and pedagogy, (2) Education for sustainable development, (3) Digital transformation in Vietnam, and (4) Design-based research, that directly inform the modeling choices.

A. AI in Education and pedagogical affordances

Research on Artificial Intelligence in education has expanded rapidly. Recent reviews identify intelligent tutoring systems, learning analytics, automated feedback, virtual laboratories, and AI-supported assessment as primary application areas (Zawacki-Richter et al., 2019). Core pedagogical affordances include personalization, scalability, rapid feedback, and improved decision-making through data-driven insights. Scholars emphasize that AI tools must be aligned with instructional goals rather than treated as neutral technologies. Luckin et al. (2016) highlight the role of AI in augmenting teachers' capabilities and enabling more responsive learning experiences. Holmes et al. (2019) discuss the ethical and practical implications of AI adoption and call for human-centered implementation strategies.

B. Education for Sustainable Development Frameworks

The ESD literature identifies competencies spanning cognitive, socio-emotional, and behavioral domains (UNESCO, 2017a). National frameworks such as Germany's *Bildung für nachhaltige Entwicklung* (BNE) integrate ESD across institutional policies and curricula (BNE Portal, 2017); UNESCO, 2017b). Similarly, Japan's Society 5.0 envisions a people-centered integration of digital technologies to address societal challenges (H-UTokyo Lab, 2020). These frameworks emphasize values including intergenerational responsibility, precautionary thinking, and interdisciplinary problem-solving.

C. Digital transformation in Vietnam

Vietnam's National Digital Transformation Program (2020–2025) sets targets for developing a digital government, economy, and society, with education identified as a priority sector (Government of Vietnam, 2020; Vitic, 2024). Early assessments show progress in Learning Management System (LMS) adoption and remote-teaching capacity, accelerated by COVID-19. However, persistent rural–urban gaps highlight unequal infrastructure, limited digital resources, and uneven pedagogical integration, especially in vocational education (World Bank, 2023). These conditions create both momentum and constraints for implementing AI-enabled ESD initiatives.

D. Design-Based Research (DBR) and its relevance

Design-Based Research (DBR), also referred to Design Experiments or Design Research (Brown, 1992; Collins, 1992), is a flexible, iterative methodology widely used to develop and refine practical educational solutions while contributing to theoretical understanding. Wang & Hannafin (2005) describe DBR as "a research approach aimed at developing theories and practices through iterative design, implementation, analysis, and refinement in real-world settings." DBR emphasizes collaboration with practitioners, cyclical improvement, and the generation of actionable design principles. These attributes make DBR well-suited for integrating AI tools into ESD initiatives within authentic institutional environments.

DBR provides a methodological lens for co-designing and iteratively refining educational interventions in authentic contexts (Barab & Squire, 2004; Wang & Hannafin, 2005). DBR's strengths include its emphasis on collaboration with practitioners, cyclical refinement, and generating design principles that are both theoretically grounded and practically useful, attributes well-suited for integrating AI into ESD.

E. Summary

The literature converges on three foundational areas that guide the development of the conceptual model:

(1) AI in Education, emphasizing pedagogical affordances such as personalization, rapid feedback, and data-driven insights when implemented through human-centered, pedagogically aligned design;
(2) Education for Sustainable Development, which outlines the competencies necessary for sustainability-oriented learning across cognitive, socio-emotional, and behavioral dimensions; and
(3) Vietnam's digital transformation, which provides the contextual conditions, highlighting advancements in digital infrastructure alongside persistent disparities in access and pedagogical integration, particularly in vocational institutions.

Complementing these foundations, Design-Based Research is identified as an appropriate methodological orientation, offering an iterative, collaborative approach for developing and refining AI-enhanced ESD interventions in real educational settings.

3. Methodology

This study applies a Design-Based Research approach, implemented across four iterative phases:

(1) problem analysis and stakeholder needs assessment;
(2) co-design and prototyping of an AI-enabled ESD framework;
(3) pilot implementation in selected vocational and higher education institutions; and
(4) evaluation and iterative refinement of the framework.

Figure 1 illustrates the DBR cycle in which design and theoretical insights are progressively refined through repeated iterations.

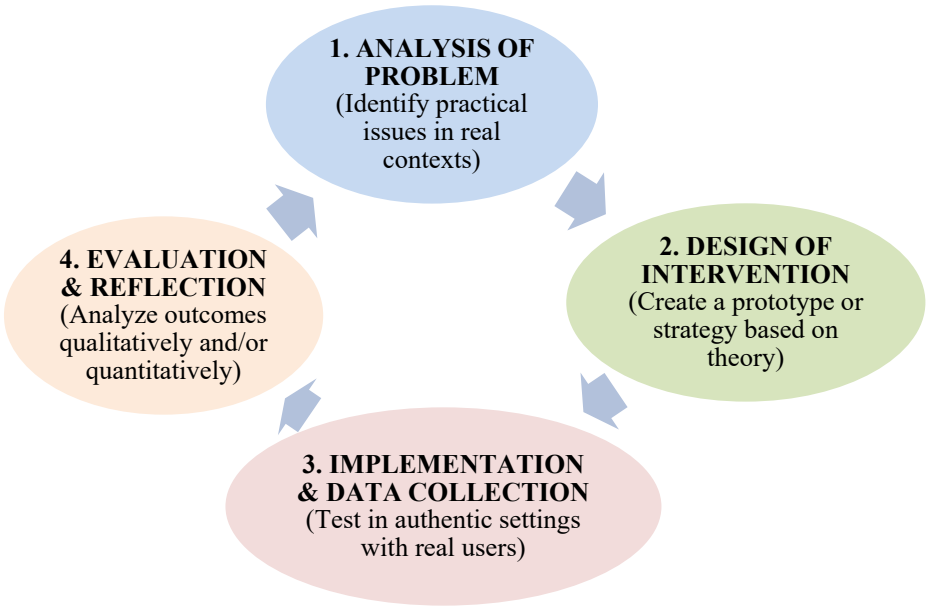

Figure 1. A typical design-based research cycle (*source: own processing*)

Data were triangulated from three major sources: national and institutional policy documents, a synthesis of relevant literature, and semi-structured interviews with 20 stakeholders (educators, program managers, and industry partners) representing urban, peri-urban, and rural contexts across three provinces. The methodological details for each phase are presented below.

3.1 Phase 1: Problem Analysis and Document Review

The first phase involved a systematic review of national and institutional policy documents, including Vietnam's National Digital Transformation Program (2020–2025), institutional ESD strategies, and relevant evaluative reports from government agencies and international organizations. This analysis identified structural constraints, equity challenges, varying levels of digital readiness, and existing pedagogical practices related to AI and ESD integration. The document review provided a baseline understanding of contextual conditions that informed subsequent phases.

A. Semi-Structured Interviews with 20 Stakeholders

To complement the document review, semi-structured interviews were conducted with 20 lecturers, program managers, vocational administrators, and industry partners.

B. Sampling Strategy

Purposive sampling targeted individuals with experience in curriculum development, digital teaching tools, AI-supported modules, or sustainability-oriented industry practices.

C. Interview Protocol Development

The protocol covered five themes: (1) digital and AI adoption; (2) sustainability competencies and curriculum alignment; (3) faculty readiness; (4) institutional governance; and (5) industry expectations.
Interviews were conducted in Vietnamese or English based on participant preference. Each session lasted 45–70 minutes, was audio-recorded with participant consent, and subsequently transcribed.

D. Data Analysis

A thematic analysis following Braun and Clarke's six-step method was used to generate themes that informed Phase 2 co-design activities (Braun & Clarke, 2006).

3.2 Phase 2: Co-Design Workshops and Prototype Development

Two co-design workshops involving educators, instructional designers, sustainability experts, and industry partners were conducted to refine framework components. Outputs included prototype LMS modules, draft simulations, and preliminary analytics dashboards.

3.3 Phase 3: Pilot Implementation

The prototype was piloted in two vocational colleges with contrasting digital-readiness profiles. The pilot included deploying LMS-based micro-modules, integrating AI-driven simulations, using analytics dashboards, and providing faculty coaching. Observation notes, usage logs, and learner performance data were collected.

3.4 Phase 4: Evaluation and Iterative Refinement

A mixed-methods evaluation used pre/post competency assessments, usage metrics, student focus groups, and faculty reflection logs. Insights informed revisions to the framework, particularly around faculty training and data-governance requirements.

Ethical Considerations

The research clearance was obtained by following research policy of the Vietnamese-German University. Participants were informed of confidentiality protections and voluntary participation. All data were anonymized and stored following institutional data-protection policies, with extra attention given to ethical use of AI-based analytics.

4. Conceptual Framework and Hypotheses Development

Figure 2 presents the proposed conceptual framework for AI-enabled ESD that may be adopted within Vietnam's vocational and higher education sectors. The framework is structured around three core constructs of Digital Sustainability Competence (DSC), Ecological Value Orientation (EVO), and Institutional Adaptation Capacity (IAC) which together represent the learner, value-driven, and institutional dimensions that shape the integration of AI into sustainability-oriented education (AI-enabled ESD), the outcome construct. These constructs align with three enabling layers of pedagogy, technology affordances, and external drivers (e.g., policy, industry, community), providing both conceptual clarity and practical measurability within diverse institutional contexts.

4.1 AI-enabled ESD

Based on these above layers, seven AI-enabled ESD operational variables are proposed. They are consistent with a framework designed to support modular curriculum interventions, faculty development pathways, and institutional governance adjustments aligned with ESD goals.

(1) AI-supported modular curriculum integration: Use of AI tools to deliver modular, competency-based ESD content (UNESCO, 201a; Holmes et al., 2019).
(2) AI-enhanced learner-centered pedagogy: The extent to which AI supports personalization, inquiry-based learning, and adaptive scaffolding (Luckin et al., 2016; Zawacki-Richter et al., 2019).
(3) AI-driven simulations & virtual labs: Application of AI-based scenario modeling for environmental and socio-economic sustainability issues (de Jong et al., 2013; Xu & Ouyang, 2022).
(4) Learning analytics for ESD competency tracking: Use of AI dashboards to monitor learner progress on ESD competencies (Ifenthaler & Yau, 2020).
(5) AI tools supporting equity & accessibility: Ability of AI to reduce rural–urban divides, language barriers, and resource constraints (Government of Vietnam, 2020; World Bank, 2023b; Akgün & Krajcik, 2024).
(6) Policy and governance alignment for AI-ESD: Degree of institutional alignment with national digital transformation and ESD strategies, including governance, quality assurance, and planning mechanisms (H-UTokyo Lab, 2020; Vitic, 2024; Li et al., 2025).
(7) Industry/community engagement via AI: Use of AI tools to link learners with industry partners and community sustainability initiatives (Sterling, S., 2014).

4.2 Digital Sustainability Competence (DSC)

DSC refers to learners' technological and analytical capabilities to use digital and AI tools responsibly and effectively for sustainability problem-solving. As a multidimensional construct, it comprises five dimensions: AI literacy, data-ethics understanding, proficiency in simulations and virtual labs, digital collaboration skills, and competency in sustainability-oriented data analysis (UNESCO, 2017a, 2017b; Holmes et al., 2019; Zawacki-Richter et al., 2019). Together, these dimensions capture the skills and dispositions required for learners to leverage advanced digital technologies in support of informed, ethical, and sustainability-oriented decision-making. Hypothesis 1 was derived from these findings.

4.3 Ecological Value Orientation (EVO)

EVO captures the attitudes and value commitments that motivate learners' engagement with ecological issues. Four dimensions define this construct as a motivational and value-driven construct: environmental stewardship, systems thinking, pro-sustainability decision-making, and participation in community initiatives. Together, these variables represent the dispositions and mindset that underpin sustained engagement with environmental issues and support meaningful contributions to sustainability-oriented learning and practice (Luckin et al., 2016; UNESCO, 2017a, 2017b). As a result, the second hypothesis is established.

4.4 Institutional Adaptation Capacity (IAC)

IAC represents the structural and pedagogical readiness of educational institutions to adopt, implement, and sustain AI-enhanced ESD practices. As an organizational-level construct, it includes digital infrastructure, faculty development for AI-ESD, supportive governance structures, cross-sector partnerships, and alignment with national policies on digital transformation & sustainability (Cabinet Office, Government of Japan, 2016; UNESCO, 2017b; Holmes et al., 2019; Zawacki-Richter et al., 2019; Government of Vietnam, 2020; World Bank, 2023) Collectively, these indicators capture the institutional conditions necessary to enable effective and enduring AI-enabled ESD initiatives. Hence, the hypothesis 3 is developed.

4.5 AI-enabled ESD Framework

The full *4*-construct, *21*-variable model with hypothesized relationships shown in Figure 2. Together, these components provide a structured basis for designing, evaluating, and scaling AI-enabled ESD interventions within Vietnam's vocational and higher education systems.

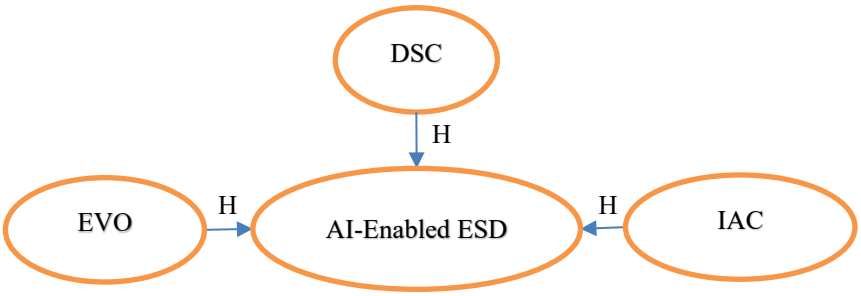

Figure 2. AI-enabled ESD conceptual framework for Vietnam (*source: own processing*)

5. Constructs and Variables

Following the presentation of the framework, Table 1, and Table 2 detail the hypotheses, constructs, and associated variables of the research model. In total, 21 variables are systematically organized across the model's constructs, and the hypothesized relationships specify the expected mechanisms through which AI-enabled learning processes advance sustainability competencies and support institutional adaptation in Vietnam's education system.

The articulation of these constructs and pathways ensures coherence with the proposed AI-enabled ESD framework and establishes a clear foundation for empirical testing in further study.

Table 1. Related hypotheses of the model (*source: own processing*)

Hypotheses	
H1	DSC directly affects AI-Enabled ESD.
H2	EVO positively affects AI-Enabled ESD.
H3	IAC positively affects AI-Enabled ESD.

Table 2. Summarizes the constructs, observable variables, and suggested data sources for evaluation (*source: own processing*)

Constructs		Key Variables (Observable/Measurable)	Data Sources
1. AI-enhanced ESD practices.	Pedagogical Integration	1. AI-supported modular curriculum integration	National and institutional documents.
		2. AI-enhanced learner-centered pedagogy.	
	Technological Affordance	3. AI-driven simulations & virtual labs.	
		4. Learning analytics for ESD competency.	
		5. AI tools supporting equity & accessibility.	
	External drivers	6. Policy & governance alignment for AI-ESD.	
		7. Industry/community engagement via AI.	
2. Digital Sustainability Competence (DSC).		8. AI literacy. 9. Data ethics. 10. Ability to use simulations & virtual labs. 11. Competency in digital collaboration. 12. Problem-solving with sustainability data.	Pre/post assessments; learning analytics; project rubric scores; digital portfolios.
3. Ecological Value Orientation (EVO).		13. Environmental knowledge. 14. Systems thinking performance. 15. Pro-sustainability intentions. 16. Participation in community sustainability projects.	Surveys; reflective journals; community project deliverables; peer assessment.
4. Institutional Adaptation Capacity (IAC).		17. Infrastructure uptime. 18. Percentage of faculty trained in AI pedagogy. 19. Governance documents integrating ESD. 20. Partnerships with industry/community. 21. Policy alignment.	Institutional audits; faculty training logs; MOUs; policy documents; uptime metrics.

6. Findings and Stakeholder Insights

The triangulated analysis from stakeholder interviews and document review revealed four major themes shaping the adoption of AI-enabled ESD in Vietnam.

A. Infrastructure and equity

Access to digital infrastructure remains uneven across institutions. Rural vocational colleges reported limited bandwidth, insufficient devices, and inconsistent access to digital learning platforms, creating disparities in learners' ability to engage with AI-enhanced materials.

B. Faculty readiness

Although instructors demonstrated strong subject-matter expertise, most lacked structured preparation in AI-supported pedagogy, digital assessment methods, and the facilitation of competency-based learning. This gap constrained effective integration of AI tools into instructional practice.

C. Curricular alignment

Current curricula emphasize technical skills but rarely incorporate explicit sustainability competency mapping. Stakeholders indicated that ESD outcomes are often implicit rather than systematically embedded, limiting opportunities for interdisciplinary learning and applied sustainability problem-solving.

D. Data governance and ethics

Concerns emerged regarding learner privacy, data security, and the risk of bias in analytics tools when safeguards are insufficient. Institutions generally lacked standardized governance procedures for managing AI-generated data.

Industry partners expressed strong interest in applied project collaboration and emphasized the need for clearer sustainability-related competency taxonomies that correspond to workplace expectations in emerging green and digital sectors.

These findings informed iterative refinements to the conceptual framework, including the incorporation of a dedicated capacity-building dimension for faculty development and the integration of data-governance checkpoints across analytics workflows. These adjustments strengthened the alignment between stakeholder needs and the operationalization of the AI-enabled ESD model.

7. Discussion

Stakeholder insights provide practical support for the proposed conceptual framework and its three hypothesized relationships. First, disparities in digital readiness, especially in rural vocational colleges, confirm that Digital Sustainability Competence (DSC) is foundational for meaningful AI-enabled ESD. Participants noted that without skills in AI literacy, data ethics, simulation tools, and digital collaboration, learners and instructors cannot fully benefit from AI-supported sustainability learning. This directly reinforces ***H1***, highlighting DSC as a prerequisite for enabling AI-driven pedagogical innovation. Second, variations in ecological awareness among faculty and administrators demonstrate the role of Ecological Value Orientation (EVO) in motivating the adoption of sustainability-focused learning tasks. Programs with strong environmental commitments were more proactive in using AI for scenario modeling, virtual experiments, and community-oriented sustainability projects. This supports ***H2***, emphasizing that value-driven engagement shapes how AI tools are integrated into ESD. Third, institutional constraints like limited infrastructure, unclear governance structures, and insufficient professional development, underscore the importance of Institutional Adaptation Capacity (IAC). Institutions with better digital systems, leadership support, and policy alignment were substantially more capable of piloting AI-based ESD innovations. These findings validate ***H3***, confirming IAC as a critical enabler of sustained AI-ESD integration. Taken together, the findings suggest that strengthening DSC, EVO, and IAC will be essential for operationalizing AI-enabled ESD in Vietnam's vocational and academic sectors. Curriculum designers should embed competency mapping; educators should adopt learner-centered, simulation-enhanced pedagogies; and institutional leaders should prioritize infrastructure, governance, and partnerships that support responsible AI use.

8. Conclusion

This study introduces a conceptual framework for integrating Artificial Intelligence into Education for Sustainable Development within Vietnam's vocational and academic sectors. By organizing 21 variables across the outcome

construct of AI-enable ESD and three enabling constructs of Digital Sustainability Competence, Ecological Value Orientation, and Institutional Adaptation Capacity, the framework provides a structured basis for designing AI-supported curricula, faculty development programs, and institutional policies aligned with national digital transformation goals.

The framework highlights how AI can enhance personalization, competency tracking, and simulation-based learning while also emphasizing the importance of values, governance, and equity. Implementation will require sustained collaboration among educators, policymakers, and industry partners to ensure ethical, context-aware, and scalable adoption.

Future empirical validation, including PLS-SEM analysis using tools like SmartPLS, will be essential to assess the robustness of the model and guide its refinement. As Vietnam advances its digital and sustainability agendas, the proposed framework offers a strategic foundation for leveraging AI to strengthen competency-based, future-ready education.

9. Limitations & Future research

This study is conceptual and exploratory, drawing on literature synthesis and stakeholder interviews; the proposed model lacks empirical testing and validation across institutional contexts, while equity implications remain insufficiently examined.
Future research should empirically validate the model using PLS-SEM and address AI ethics, data privacy, and algorithmic bias in AI-enabled education systems.

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Biography

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