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Ethical Integration of AI and STEAM Pedagogies in Higher Education: A Sustainable Learning Model for Society 5.0

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Abstract

In the face of environmental degradation, social inequality, and technological change—acknowledged as defining challenges of the 21st century—Higher Education Institutions (HEIs) lead educational innovation, integrate sustainability as a transformative axis, and act as key actors in global responses. This study develops and validates a conceptual model that advances the goals of Society 5.0 through the integration of sustainability-oriented STEAM education and AI ethics as strategic drivers of a human-centered, socially inclusive, and technologically relevant learning ecosystem. The model rests on multidisciplinary and project-based learning and active engagement with society and industry. Its validation followed a Design Science Research approach supported by expert interviews, the Sustainable Classroom implementation, and international benchmarking with higher education cases from Indonesia, the United Kingdom, Australia, Uruguay, and the European Union. The combination of the constant comparison method of grounded theory with abductive reasoning ensured theoretical coherence and practical consistency. Triangulation across interviews, classroom implementation, and international cases reinforced robustness, while theoretical saturation, cross-validation, and reflexive safeguards strengthened credibility, controlled bias, and secured data management. Findings confirm that the ethical integration of advanced technologies strengthens citizenship, ecological literacy, and institutional innovation, and establishes a replicable and scalable framework that reorients higher education toward sustainability, ethics, and digital equity, positioning it as a cornerstone of education for Society 5.0 and as a global benchmark for achieving the Sustainable Development Goals.

Keywords: ethical artificial intelligence; multidisciplinary learning; project-based learning; Society 5.0; STEAM; sustainable higher education

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1. Introduction

Higher Education Institutions (HEIs) today face fundamental challenges related to access, quality, and—most importantly—their responsibility to educate individuals capable of responding ethically to a world shaped by climate change, social inequality, and the accelerated advancement of technology. In this context, HEIs must assume a central role in preparing individuals capable of addressing the interconnected crises of environmental degradation, social inequality, and technological change to social demands. To achieve this

mission, HEIs redesigned educational models based on ethical and sustainability principles. Sterling [1] emphasizes that education systems shift from transmissive to transformative approaches to respond substantively to the challenges of sustainability. In this context, rethinking educational goals, it is no longer sufficient to train technically competent professionals, because it is essential to cultivate individuals with ecological awareness, a sense of justice, and a commitment to the common good [2,3]. Therefore, educational models must focus on the development of human capabilities that encourage collaboration, creativity, and active commitment in the transformation of their environments [4].

Global commitments, in line with UNESCO recommendations, emphasize that the integration of knowledge, values, and attitudes for ethical and responsible action through initiatives such as Education for Sustainable Development (ESD) is the way to implement actions within the framework of the 2030 Agenda. However, generally, the educational innovations to follow technocratic models centered on efficiency and digitalization and often detached from a broader vision of sustainability and collective well-being [5]. Addressing this gap requires recognizing that educational change is a complex process influenced by structural, cultural, and pedagogical factors. As Morin Notes, such complexity demands that reforms incorporate cognitive, emotional, and institutional dimensions [6], alongside ethical and contextual conditions that enable transformative learning. While some scholars and researchers advocate digital integration as a driver of modernization, others warn that this stance perpetuates inequalities and neglects ecological imperatives [7]. For this reason, there is still a growing consensus in many HEIs to adopt fragmented strategies focused on digital optimization, lacking a systemic ethical or ecological basis. Accentuating this trend, sustainability is operated as a dimension of educational practice with curricula that reinforce teaching-learning dynamics that do not link changes in the use of technology with ethics, innovation with justice, or digital transformation with social responsibility [6,7]. In this context, Society 5.0 emerges—introduced in Japan as a humanistic paradigm of technological development—which places artificial intelligence, automation, and connectivity as instruments to promote human development and the common good [8] and, therefore, sustainability as the axis of the transformation of educational models.

Recent advances in three-dimensional AI and morphological segmentation demonstrate the potential of human-centered technological design. Xing et al. [9] developed the Hand Surface Segmentation Network (HSSN), integrating 3D graph-based deep learning with laser point cloud data to process complex geometries and varying densities using multi-scale edge convolution, geometric enhancement, and normal vectors. In the built-environment domain, Xing et al. [10] established a rehabilitation model for aging populations, combining 3D computer vision and deep learning algorithms to enhance human–computer interaction with a user-centered approach. These developments illustrate that intelligent systems applicable to healthcare and education, when guided by sustainability principles, are essential components of resilient, ethical, and context-sensitive techno-pedagogical environments. This vision integrates technology, innovation, justice, and human development to reorient educational models toward social and ecological transformation.

In technology-focused higher education contexts, particularly in countries of the Global South, institutional narratives of sustainability coexist with pedagogical practices that normalize the lack of coherent integration of emerging technologies—such as AI—in the construction of the common good as a guiding axis for the transformative potential of HEIs [11,12]. Implementing sustainable educational models entails reconceptualizing learning environments as dynamic systems where sustainability and STEAM (Science, Technology, Engineering, Arts, and Mathematics) pedagogies are integrated as overarching

principles, shaped by organizational structures, available infrastructure, cultural diversity, levels of technological maturity, and relational factors.

This study examines the integration of ethical and sustainability principles into higher education within the context of AI and STEAM, focusing on identifying and addressing systemic challenges.

2. Theoretical Foundation

Sustainability through education constitutes an urgent priority in the face of ecological degradation, social fragmentation, and global inequality. Advancing ESD in higher education demands overcoming the structural resistance of fragmented or technocratic models that resist ethical and systemic transformation. Critical perspectives critique content-centered approaches [4] and promote flexible curricular frameworks, recognizing diversity, and fostering institutional support for innovation [5,13]. These changes strengthen sustainability as more than ecological balance; they position it as the creation of inclusive and adaptive learning ecosystems capable of addressing complex challenges [14]. UNESCO emphasizes that ESD entails a profound redefinition of educational purposes, pedagogical practices, and institutional structures to achieve intergenerational justice and ethical coexistence [15]. Achieving this vision calls for confronting disciplinary rigidity, accelerating digital transformation with equity, and counteracting economic logics that prioritize competitiveness over collective well-being. An educational model aligned with these principles integrates sustainability, ethics, cultural diversity, and social justice as guiding principles, placing the development of critical and committed citizens at the center of academic action [4].

Building on this vision, the recognition of education as a common good in the 2030 Agenda and UNESCO frameworks promotes inclusive, ethical, and sustainable teaching approaches [5,16]. This global vision enables the integration of interdisciplinary initiatives that connect science, technology, citizenship, and humanistic values. In this scenario, STEAM education operates as both a pedagogical strategy and a cultural project, linking technical competencies with critical thinking, socio-emotional development, and environmental responsibility [16]. In parallel, the concept of Society 5.0—originating in Japan—positions digitalization, automation, and artificial intelligence as drivers of human flourishing [8]. Unlike the productivity-oriented logic of Industry 4.0, Society 5.0 advances intelligent systems and equitable access to technology as tools to address complex social challenges. Grounded in sustainability principles, this vision redefines educational institutions, the role of teachers, and the learning process [13,15]. Education in this framework develops citizens capable of acting creatively, ethically, and critically in a rapidly changing world [17], thus forming the foundation for the theoretical axes of the proposed model.

In this context, education extends beyond its traditional function as preparation for the workplace and serves as a comprehensive, inclusive, and transformative space for learning. Gimeno Sacristán highlights that the educational experience integrates ethical, cultural, and political dimensions [18,19]. Society 5.0 introduces both a technological challenge and an opportunity to reconnect knowledge with social justice and human development. Addressing the gap between educational goals and actual practices involves revising curricula, transforming institutional culture, and redefining pedagogical principles. This approach integrates cognitive, ethical, civic, and competencies for sustainability into real-world contexts, enabling transformative educational experiences [20] that align with the principles and operational pillars of the proposed model.

Transforming higher education demands the intentional design of theoretical, methodological, and institutional frameworks that form individuals capable of critically interpreting and responding to emerging social and technological scenarios. HEIs link technical

knowledge with democratic, supportive, and sustainable values through the shared action of educators, policymakers, and researchers. The proposed model integrates the STEAM approach with an ethical and humanistic perspective to strengthen civic capacities. Its foundation draws on theoretical contributions that position innovation as a public good [14], define sustainability as a transversal principle [20], and frame human development as the expansion of fundamental freedoms [4,21], all guided by an ethic of cordial reason committed to social justice [22].

The challenges of Society 5.0 extend beyond the technical sphere to encompass political and pedagogical dimensions. This study examines the profile of individuals that higher education prepares, and the organization of knowledge required to promote ethical innovation, critical citizenship, and institutional transformation. It formulates the central question: How can a higher education model integrate STEAM, AI ethics, and sustainability to align with the aspirations of Society 5.0? The research proposes and validates a conceptual model grounded in these principles, with the premise that their integration enhances students' ethical and civic competencies, and that institutional implementation fosters transformative, socially relevant learning practices. The model builds on an interdisciplinary framework: Sen and Nussbaum's capabilities approach frames human development as the expansion of freedoms [4,14]; Cortina's ethics of cordial reason emphasizes the common good [7]; and Romer's theory of endogenous growth positions innovation as a collective resource for social progress [23]. In this perspective, technological development operates as an ethically grounded, collaborative process that advances sustainability and civic agency [24].

These ideas are further reinforced by systemic perspectives on educational change advanced by Michael Fullan and Peter Senge [24,25], along with the theories of distributed learning and connectivism developed by José Salinas and George Siemens [26,27]. The STEAM perspective, as conceptualized by Jing Liu Yakman, Edgar Morin, and P Burnard, L Colucci-Gray, C Cooke [6,20,28], operates as an integrative model that addresses the complexity of contemporary knowledge in an ethical, creative, and sustainable way. Together, these theoretical contributions converge into five axes that articulate a sustainable and human-centred educational model, aligning higher education with the ethical and transformative aspirations of Society 5.0.

2.1. Society 5.0 and Education as a Common Good

Society 5.0 establishes a normative and cultural framework that places technological progress at the service of human flourishing, ecological balance, and intergenerational responsibility. By centering people in the development process, it defines an ethic that challenges higher education to address automation, inequality, and the climate crisis. From this vision, HEIs assume the principles of equity, sustainability, and social justice to integrate technological and disciplinary expertise. They create spaces for axiological reflection and the collaborative construction of sustainable futures. As Cortina [7], Sen [4], and Nordhaus [29] observe, every technological choice entails political, moral, and environmental consequences. Higher education must therefore transcend the instrumental adoption of tools, cultivating value-based reasoning, civic, and critical capacities that guide innovation toward the common good and ecological responsibility.

Building on this ethical horizon, the proposed model moves beyond economic growth and isolated skill acquisition to expand fundamental freedoms [4,14]. From a humanistic standpoint, it develops reflective, value-driven, and socially committed graduates capable of advancing justice and sustainability. To prioritize dignity, agency, and human flourishing, higher education integrates ethical reflection, critical thinking, autonomy, and empathy—competencies essential for addressing interconnected challenges such as exclusion, climate change, and automation. This perspective positions HEIs as drivers for developing the

capabilities required for responsible and transformative action, which aligns with the goals of ESD [5].

Within this framework, sustainability operates as a unifying principle connecting intergenerational justice, ecological integrity, and social equity. Evaluating technological development through environmental and normative lenses establishes the basis for civic and ecological education that integrates systemic thinking and integrity-driven engagement. Anchored in project-based learning, this perspective enables students to design sustainable solutions rooted in real-world needs and fosters socio-emotional and leadership skills essential for civic participation. It also drives the institutional transformation of higher education toward sustainable cultures of practice.

2.2. Higher Education and Pedagogy in Society 5.0

HEIs have been linked to andragogical approaches that emphasize autonomous and self-directed learners (Knowles, 1984, cited in Lees, A. [30]). This distinction, however, proves insufficient in contexts marked by profound inequality, rapid digitalization, and algorithmic control. In both the Global South and the Global North, structural, technological, and cultural conditions challenge the assumption of a fully autonomous learner with complete curricular agency. The term pedagogy in this research is defined as moving beyond the infantilization of students, recognizing that formative processes remain shaped by power relations, institutional structures, and technological asymmetries [31,32]. From this reasoning, this study assumes that a situated critical pedagogy addresses the complexity of contemporary learners within the framework of Society 5.0.

Drawing on this pedagogical stance, rethinking the teaching of disciplines traditionally considered neutral, such as mathematics or physics, affirms their technical value while acknowledging that every educational practice reflects curricular, technological, and human choices with ethical implications [6,33]. This perspective promotes critical and dialogic pedagogical reflection on the purpose and audience of teaching in a historical period defined by unprecedented socio-environmental challenges [34,35].

Historically, education has evolved in response to the demands of society. In the context of Society 5.0, this evolution transforms both the role of teaching and its relationship with the various actors in the educational process [36]. This transformation calls for incorporating multiple voices in the design of learning solutions [37,38], harmonizing STEAM knowledge with principles of responsibility, sustainability, and social awareness, while maintaining academic rigor. Ultimately, it requires expanding the scope of pedagogy to address the implicit assumptions that have limited its transformative potential.

2.3. STEAM Approach and Interdisciplinarity

Science, technology, engineering, the arts, and mathematics are gaining pedagogical relevance, known as STEAM [20,39], within a transformative framework of 21st-century education. Unlike traditional STEM, which prioritizes technical and scientific skills, STEAM incorporates the arts and humanities as a foundation for the development of competencies: creativity, ethical reflection, and socio-emotional competencies from the human-centered vision of Society 5.0 [6,28]. It facilitates a conscious and inclusive pedagogy capable of addressing complex global challenges, from climate change to digital inequality, through interdisciplinary and contextually relevant learning [35].

Beyond serving as a pedagogical strategy, STEAM operates as a comprehensive educational model that integrates technical, creative, ethical, social, and sustainability dimensions. Its interdisciplinary nature allows it to address the multifactorial challenges of Society 5.0 through complex and holistic knowledge. Rather than reinforcing disci-

plinary silos, STEAM promotes meaningful learning experiences grounded in real-world problem-solving, collaborative engagement, and sustainability-oriented projects.

Several scholars, including Morin [6], Yakman [20], Burnard, Colucci-Gray, Cooke [28], and Beers [40], emphasize STEAM's capacity to promote ethically responsible decision-making, strengthen twenty-first-century skills, and create inclusive learning environments that connect academia, industry, and the community. Within the proposed model, STEAM links technological development with civic responsibility, enabling students to imagine solutions, evaluate consequences, and intervene ethically in real contexts. This alignment reinforces the pillars of multidisciplinary and project-based learning while directly advancing the goals of ESD.

2.4. Ethics of Artificial Intelligence and Educational Innovation

Given the diversity of sociocultural and organizational contexts, levels of technical maturity and teaching competencies are some of the determining factors in the integration of emerging technologies to improve personalization, optimize learning processes, and enable innovative pedagogical designs in higher education. This condition creates unprecedented opportunities and complex ethical challenges. However, it also raises concerns over surveillance, algorithmic accountability, bias, dehumanization, erosion of student and teacher agency, and digital or environmental exclusion [5,21]. Policymakers and decision-makers in Higher Education Institutions addressing these challenges require a human-centered AI approach to educational innovation, based on sustainability and explicit ethical guidelines (OECD, 2023, cited in [41]), as well as equity, inclusion, and sustainability, in line with the principles of ESD.

Addressing these concerns requires grounding technological adoption in ethical theories and principles. Cortina's [7] ethics of cordial reason combines critical rationality with empathy, orienting technological decision-making toward the common good through social inclusion and ecological responsibility. This principle guides the design, implementation, and evaluation of AI applications that protect human dignity—especially for vulnerable populations—while promoting equitable and sustainable digital infrastructures in higher education. In this sense, Floridi [21] points out that information ethics reinforces the defense of transparency, explainability, and accountability in algorithmic governance, thus promoting environmental and social sustainability through responsible data practices. By this proposal, Boddington [42] emphasizes that there are reasons to safeguard autonomy and equity in machine learning contexts as essential to prevent the deepening of digital divides and mitigate the ecological footprint of technological infrastructures [43].

Educational innovation acquires meaning when technological adoption is coupled with profound pedagogical transformation rooted in collaboration, ethics, sustainability, and shared purpose for Fullan [24]. This axis supports the model's operational pillars of project-based learning and social engagement, ensuring that advanced technologies contribute to justice, critical thinking, and inclusive, sustainability-oriented education. Transitioning toward a Society 5.0 and higher education ecosystem demands more than adopting new tools; it calls for a structural redefinition of teaching and learning aligned with SDG 4 (Quality Education) and the UNESCO AI in Education guidelines.

The integration of coherent pedagogical frameworks with emerging technologies, immersive environments, and digital platforms, when carried out with criteria of sustainability and inclusion, favors the democratization of access to knowledge, the promotion of inclusive participation, and the promotion of lifelong learning [26,27]. However, without intentional design, these same technologies run the risk of reinforcing hierarchical structures, perpetuating exclusion, and generating unsustainable environmental impacts. A meaningful and sustainable digital transformation requires aligning technological systems

with learner-centered participatory methodologies that respond to social and ecological needs [26,27]. Consequently, complexity, as a paradigm, provides the cognitive scaffolding to transcend the compartmentalization of knowledge, allowing for more integrated and contextually relevant learning [6].

Within this horizon, the proposed model, innovation is not conceived merely as a pathway to efficiency, but as a space for critical reflection, ethical transformation, and reimagining the purpose of education, considering ethical innovation in EdTech, social responsibility, and sustainability imperatives. Empirical validation through expert interviews and the Sustainable Classroom case demonstrates the model's capacity to guide responsible and transformative digitalization.

2.5. Human Capabilities and Sustainability

Human capabilities are understood as the expansion of substantial freedoms and opportunities to live a life we value [4,14]. Therefore, education is not the acquisition of knowledge, but rather a process that strengthens students' autonomy, dignity, and capacity to act responsibly in social, economic, and ecological spheres. From this perspective, HEIs are moving toward human-centered development, placing equity, inclusion, and environmental stewardship at the heart of their mission.

This perspective resonates with the Sustainable Development Goals, particularly SDG 4 (Quality Education) and SDG 10 (Reduced Inequalities). The premise of human capabilities expands the traditional scope of higher education to include sustainability competencies such as ethical reasoning, systems thinking, and collaborative problem-solving [6,43,44]. Competencies integrate into the graduates' performance in building solutions to complex global challenges, such as climate change, social inequality, and technological disruption, while fostering resilience and adaptability in rapidly evolving contexts.

Considering the construction of Society 5.0, the sustainability dimension is institutionalized from a capabilities approach in the teaching and learning processes. This vision of higher education encompasses both technical training and critical, ethical, and creative engagement in solving contemporary problems. This integration is based on multidisciplinary learning and project-based learning for sustainability that generates a tangible social and ecological impact. By fostering collaboration between academia, industry, and the community, HEIs can co-create solutions that capitalize on collective capabilities and participation, accelerating the transition toward a more equitable and sustainable society.

Ultimately, embedding the human capabilities approach into the educational model aligns institutional strategies with Education for Sustainable Development (ESD) principles, reinforces ethical AI governance in education, and enhances the potential for globally transferable frameworks that respond to the demands of the twenty-first century. This alignment not only strengthens the moral and civic purpose of higher education but also positions HEIs as key agents in shaping inclusive, sustainable, and future-ready societies.

2.6. Proposed Conceptual Model

The proposed conceptual model draws directly from the five theoretical axes outlined above—education as a common good, the STEAM pedagogies for sustainability, ethical AI governance in education, sustainability and the human capabilities approach, and educational innovation—each serving as a foundation for the operationalization of its core components. The axis of education as a common good provides the normative and ethical basis for academic–industry–community collaboration, positioning Higher Education Institutions as spaces for public deliberation, democratic formation, and the co-construction of sustainable futures. Within STEAM, science and technology foster inquiry, engineering and mathematics drive problem-solving, and the arts cultivate creativity, ethical reflec-

tion, and socio-emotional learning. The axis on AI ethics and educational innovation ensures that the digital transformation in HEIs adheres to the principles of transparency, inclusion, and equity [44] and implies developing mechanisms for critically supervising technology-mediated learning environments. The dimension of human capability development and sustainability provides the pedagogical foundation that prepares autonomous, empathetic, and civically engaged learners committed to ecological responsibility and social transformation.

Figure 1 synthesizes the model's five theoretical foundations with three interrelated operational pillars: multidisciplinary learning, project-based learning for sustainability, and industry–society engagement. This configuration places people at the center of educational transformation and demonstrates how conceptual principles translate into actionable strategies grounded in ethics, informed by technology, and responsive to society.

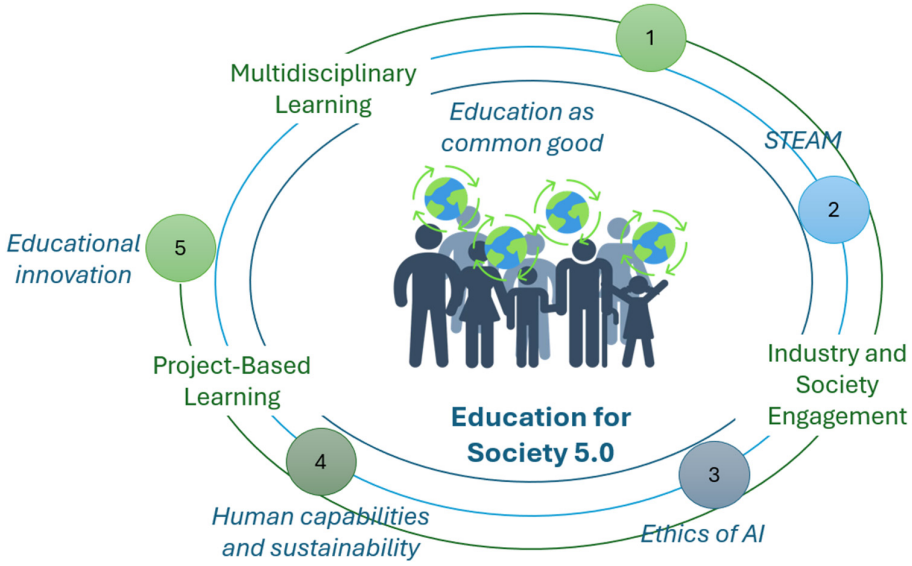

Figure 1. Educational model for Society 5.0. Note: Educational model for Society 5.0 integrating five theoretical axes—education as a common good, STEAM, AI ethics, sustainability and human capabilities, and educational innovation—with three operational pillars: multidisciplinary learning, project-based learning, and industry–society engagement. The model presents radial and hierarchical relationships from the center ("Education for Society 5.0") outward, highlighting the centrality of people as the core of educational transformation.

Multidisciplinary learning integrates scientific, technological, artistic, and social knowledge to develop a systemic understanding of contemporary challenges. Teaching transcends disciplinary boundaries by linking research with real-world problem-solving from multiple perspectives. STEAM acts here as a catalyst for technical, creative, and ethical competencies [6,26,28].

Project-based learning promotes the contextualization of knowledge, which, in line with the principles of sustainability and social transformation [6,25,45], involves students in the co-creation of solutions by combining disciplinary expertise with transversal skills such as communication, empathy, and critical thinking. In the context of industry and society, participation connects HEIs with productive sectors, civil society, and public bodies. Curricular relevance and situated learning are conditions for the implementation of collaborative actions with a measurable social and ecological impact. This means including, as Romer [23] emphasizes, innovation as a social value when knowledge and resources are shared between sectors.

The collaboration among these pillars forms the internal logic of the model. Multidisciplinary learning provides the epistemological and ethical basis for addressing complex socio-technical challenges; project-based learning operationalizes this foundation through real-world interventions with ethical grounding; and industry–society engagement acts as a feedback loop, ensuring contextual relevance, enhancing disciplinary integration, and incorporating situated knowledge through co-creation. This dynamic interaction fosters an educational ecosystem where technology, society, and human development operate in symbiosis, fulfilling the central vision of Society 5.0 in higher education.

Compared to existing frameworks such as the Technology Acceptance Model, the Theory of Planned Behavior, the Substitution, Augmentation, Modification, and Redefinition model, and the Technological Pedagogical Content Knowledge framework—which primarily address technology adoption and task redesign—the proposed model integrates ethics, sustainability, and social responsibility as central drivers of sustainable higher education transformation [45–48]. It directly aligns Sustainable Development Goals (SDG 4: Quality Education, SDG 9: Industry, Innovation and Infrastructure, SDG 17: Partnerships for the Goals) and with UNESCO's Education for Sustainable Development (ESD) roadmap, ensuring its global relevance.

This study advances the premise that a higher education model for Society 5.0 must integrate multidisciplinary learning, project-based methodologies, and active engagement with society and industry through STEAM pedagogies, ethical AI governance, and sustainability principles [40]. It sustains the hypothesis that such integration fosters critical, ethical, and socially responsible citizenship in HEIs [44]. By grounding theoretical foundations in operational strategies applicable to diverse institutional contexts, and by positioning educational innovation and digital transformation as cross-cutting enablers, the model offers a holistic, replicable, and globally transferable framework for the sustainable transformation of higher education in the twenty-first century [42,49–52].

3. Materials and Methods

Guided by an interpretivist lens, this research acknowledges the active role of the researcher in the co-construction of meaning. A qualitative, exploratory, and theory-building design was adopted to address the central research question: How can an ethical, sustainable, and human-centered educational model be structured in higher education to foster citizenship in the context of Society 5.0? Grounded in interpretivism, the study emphasizes researcher reflexivity and the analysis of contextually embedded educational practices. These philosophical foundations shape the methodological strategy, which unfolds in two complementary phases: (1) expert interviews, and (2) a case study of the Sustainable Classroom. Data analysis followed the constant comparative method of grounded theory [53], supported by an abductive reasoning process that enabled the iterative refinement of theoretical categories and the emergence of a context-sensitive conceptual model [54,55].

3.1. Research Design

The study adopted the Design Science Research (DSR) approach for its capacity to integrate the design and validation of innovative solutions to complex problems coherently and systematically. This approach is particularly suited to structuring an ethical, sustainable, and human-centered educational model in the context of Society 5.0, as it combines the rigorous identification of needs with the construction and evaluation of conceptual artifacts applicable to educational practice. The methodological process unfolded in six interconnected phases that ensured consistency between problem definition, model design, empirical validation, and critical feedback. The process began with problem identification,

which defines the limitations of current educational models in integrating ethical and sustainability principles into higher education.

The next phase focused on designing the strategic model, grounded in five theoretical axes—education as a common good, the STEAM approach, artificial intelligence ethics, sustainability and human capabilities, and educational innovation—and three operational pillars—multidisciplinary learning, project-based learning, and industry–society engagement. Expert validation provided specialized judgments on the model's relevance, coherence, and applicability. The research team followed this with the demonstration phase, implementing the model in the Sustainable Classroom as a real-world scenario to assess initial feasibility. The preliminary evaluation synthesized findings from the validation and demonstration phases, guiding conceptual and operational refinements. Finally, the dissemination phase systematized the results and presented them for discussion within the academic and professional community. Figure 2 illustrates the relationship between the DSR phases, and the techniques applied in each, reinforcing the traceability and robustness of the process.

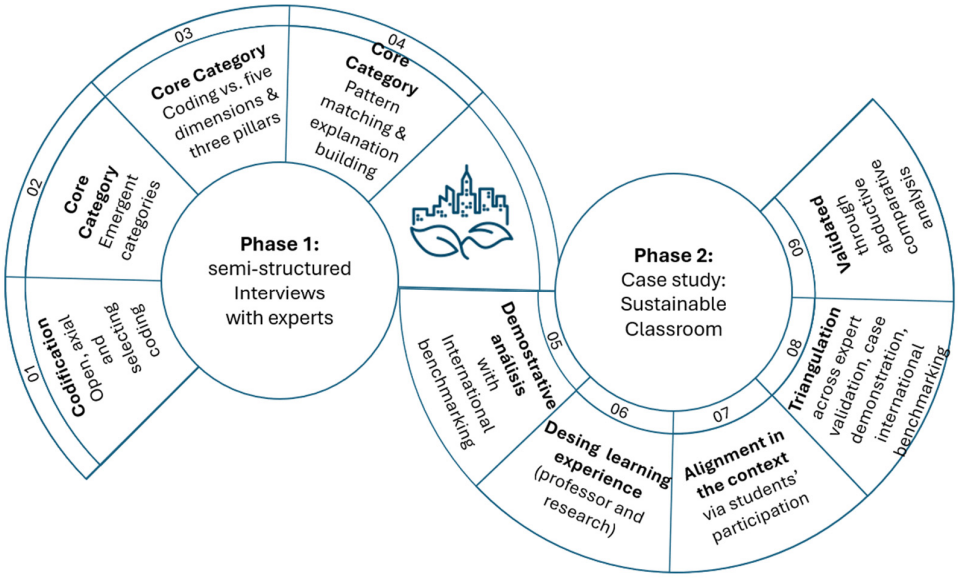

Figure 2. Methodological synthesis: integration of phases. Note: The figure shows the methodological link between expert interviews and case analysis, emphasizing model development through abductive comparison.

3.2. Data Collection

The data collection process comprised two complementary phases: expert interviews and a case study of the Sustainable Classroom. Both phases formed an integral part of the DSR framework, serving as the core mechanisms for the model's validation and demonstration. This phase also incorporated a comparative review of four international cases that explicitly integrate AI, STEAM, ethics, and sustainability in higher education. The cases were selected according to three criteria: recency (2024–2025), documented governance or curricular mechanisms, and explicit alignment with at least two of the model's five dimensions. The corpus included examples from Indonesia, the United Kingdom and Australia, Uruguay, and the European Union, based on peer-reviewed publications and institutional policy documents. This comparative perspective provided a benchmark for assessing the model's portability across diverse socio-institutional contexts.

3.2.1. Expert Interviews

As part of the validation stage within the DSR framework, the first phase explored expert perspectives on the ethical, pedagogical, and institutional principles underpinning the proposed educational model for Society 5.0. The research team conducted five semi-structured interviews with purposefully selected specialists in educational innovation, AI ethics, curriculum design, and academic leadership, each with proven experience in at least one of the model's five theoretical axes. Fieldwork took place between July 2024. All participants provided informed consent, and data anonymization during processing ensured confidentiality and protected personal information.

Table 1 presents the academic background, areas of expertise, and institutional affiliation of the five participants, all of whom are Mexican nationals. The selection process ensured disciplinary relevance to the study's focus on AI ethics, STEAM education, sustainability, and higher education. Each expert is identified through a coded label (E1–E5) to preserve anonymity while enabling consistent reference throughout the analysis.

Table 1. Profiles of interviewed experts.

ID	Academic Background	Area of Expertise	Institutional Affiliation	Theoretical Axes Contributed
E1	PhD in Electrical Engineering, MSc in Electrical Engineering, BSc in Communications and Electronics	AI, Robotics, Computational Models, Ethics in Technology	National Research Institute (Engineering/Computer Science Focus)	Innovation in education; STEAM
E2	MSc in Energy Engineering, BSc in Mechanical and Electrical Engineering	Energy efficiency, energy systems, industrial cogeneration, sustainability metrics, regulatory frameworks, and ISO 50001 systems	National Energy Efficiency Commission (Public Sector)	AI Ethics; Sustainability
E3	M.D in Pediatrics, MSc in Health Sciences Education, PhD in Medical Education Sciences	Higher education innovation, medical education, curriculum design, learning assessment, and ethics in health education	National Autonomous University of Mexico (UNAM)–CEIDE	Common good in education; STEAM; Sustainability
E4	Master's Degree in Education and Bachelor's in Pedagogy	Curriculum design, educational innovation, pedagogical evaluation, integral and institutional formation	Instituto Politécnico Nacional (IPN)–Escuela Superior de Cómputo (ESCOM)	Sustainability; Human Capabilities
E5	Ph.D. in Mathematics; MSc in Mathematics, BSc in Physical Mathematics	Strategic educational planning, mathematics, and higher education reform	Public university specializing in technology	AI Ethics; Human Capabilities

Note: The table summarizes the academic background, areas of expertise, and institutional affiliation of the five experts interviewed. The selection ensured disciplinary relevance to the study's focus on AI ethics, STEAM education, sustainability, and higher education. All interviewed experts are Mexican nationals. Identifiers (E1–E5) preserve anonymity while enabling reference in the analysis.

The interview protocol was designed to align with the study's objectives on the ethical integration of AI, the implementation of sustainability-oriented STEAM pedagogies, and the institutional conditions required for transformative change in higher education. As presented in Appendix A, the guide comprised three thematic blocks: ethics of AI in higher education, sustainability-oriented STEAM approaches, and institutional enablers

and barriers to educational innovation. Each block contained open-ended questions to elicit in-depth, experience-based reflections on challenges, strategies, and enabling conditions for ethical and sustainable transformation in the context of digitalization and Society 5.0. A final reflective question invited participants to share additional insights beyond the predefined thematic areas.

Experts were recruited through purposive sampling of professional networks and institutional invitations. Inclusion criteria required demonstrated experience in higher education and expertise in at least one disciplinary field related to the model's theoretical axes. Individuals without experience in the design, implementation, or evaluation of higher education models, or without relevant contributions to sustainability, ethics, or educational innovation, were excluded. The research team conducted five face-to-face interviews, each lasting approximately 45 min. With participants' consent, all sessions were audio-recorded and transcribed verbatim. The interview guide underwent pilot testing with two non-participant experts to refine clarity and sequencing. Member checking involved sharing concise analytical summaries for factual verification.

3.2.2. Case Study: The Sustainable Classroom

As part of the demonstration stage in the DSR process, the second phase examined the extent to which the Sustainable Classroom embodied the principles and operational pillars of the proposed model. The analysis combined a document review of the project's design records, implementation timeline, and pedagogical objectives with direct observation during the setup and early operational stages. It focused on the integration of sustainability-oriented STEAM practices, the ethical use of educational technologies—including AI-based resources—and the promotion of collaborative, multidisciplinary problem-solving. The case represents a learning experience intentionally designed to operationalize the model's principles. The aim was to capture the qualitative dimensions of this experience and assess its potential to foster citizenship within the framework of Society 5.0.

3.2.3. International Benchmarking

The third source of evidence consisted of a comparative corpus of four international cases that integrate AI, STEAM, ethics, and sustainability in higher education. This sub-phase aimed to identify implications and scope conditions for the proposed model. Selection criteria required recency (2024–2025), documented governance or curricular mechanisms, and explicit alignment with at least two of the model's five dimensions. The corpus included Indonesia, focusing on AI–STEAM curricular reforms and project-based learning; the United Kingdom and Australia, addressing governance responses to algorithmic risks and institutional autonomy; Uruguay, implementing a national policy that institutionalizes STEAM for equity and inclusion; and the European Union, emphasizing human-centered AI principles, quality assurance standards, and funding programs. Data sources comprised peer-reviewed publications and institutional policy or quality assurance documents. This comparative perspective served as secondary evidence to benchmark the model's portability across diverse socio-institutional contexts.

3.3. Data Analysis

The analysis employed the constant comparative method of grounded theory as the central strategy [55]. The research team advanced through open coding to identify discrete concepts, axial coding to link categories by conditions, actions or interactions, and consequences, and selective coding to integrate core categories aligned with the model's five theoretical axes. ATLAS.ti facilitated code management, thematic network construction, and full traceability of analytical decisions [56,57]. The reasoning process followed an abductive approach, alternating between empirical material and theoretical

propositions to refine model components, examine competing explanations, and consolidate emerging insights.

For the expert interviews, a line-by-line analysis generated categories and subcategories connected to the five theoretical axes—education as a common good, STEAM approach, AI ethics, sustainability and human capabilities, and educational innovation—as well as to the three operational pillars: multidisciplinary learning, project-based learning, and industry–society engagement. Cross-case comparisons revealed points of convergence, divergence, and context-specific nuances. Preliminary saturation was considered achieved when the final interview failed to contribute substantively new codes to the major categories, although a broader sample remains necessary to confirm saturation.

In the case study analysis, the focus remained on conceptual and operational alignment with the model rather than on functional outcomes. The research team mapped design principles, implementation processes, and early operational practices to the five axes and three pillars, using a correspondence matrix to consolidate evidence from documents and observations. This mapping provided initial validation of the model's feasibility and coherence, positioning the Sustainable Classroom as a living laboratory for future evaluation using defined indicators.

Triangulation across expert validation through interviews, demonstration in the Sustainable Classroom, and international benchmarking of secondary cases reinforced the study's internal coherence and supported analytical generalization [58]. Within the DSR framework, the international review functioned as an observational evaluation that extended the model's validation beyond the local context. This comparative perspective informed the agenda for future research on functional outcomes, governance indicators, and longitudinal processes of institutional change, ensuring the model's adaptability to diverse educational environments.

While the conceptual model for Society 5.0 was defined in Figure 1, Figure 2 illustrates the methodological pathway that led to its empirical grounding. This analytical structure provided the empirical foundation for the model's development and served as the basis for its preliminary validation, as described in detail in the discussion section. The inductive phase identified emerging categories derived from expert interviews. In contrast, the abductive phase guided their reinterpretation and informed the design of a learning experience in the Sustainable Classroom [58], grounded in the proposed conceptual model. The demonstration of the preliminary validation confirmed internal coherence and alignment between theoretical principles and educational practice, achieved through the iterative integration of empirical data.

3.4. Criteria of Rigor and Ethical Considerations

To ensure the study's credibility and interpretive validity, the qualitative rigor criteria applied included triangulation, theoretical saturation, and cross-validation [59,60], which enhanced analytical credibility and strengthened the potential for transferability in the context of Society 5.0. The evaluation criteria—clarity, ethical alignment, sustainability orientation, and institutional adaptability—were derived directly from the model's objectives. A subsequent DSR cycle will expand the evaluation to include student-level outcomes (participation, competencies, assessment) and longitudinal institutional indicators (policy integration, quality assurance, and scaling).

Given the research team's institutional proximity to the demonstration context, reflexive memos were developed during coding, and analytical decision logs were maintained to mitigate loyalty bias. An anonymized codebook contained de-identified excerpts, and ATLAS.ti facilitated data management and coding. The study did not develop any custom

codes. No generative AI tools (ChatGPT, OpenAI, GPT-4) were used for content generation or analysis, ensuring full compliance with ethical research standards.

3.5. Validation Metrics and Data Sources

The validation of the theoretical model drew on three qualitative metrics. The theoretical coherence primarily involves coherence in determining how every component aligns with the five axes outlined in the Theoretical Foundation. In the validation, empirical alignment considered the degree of correspondence between those components and the categories that emerged from open, axial, and selective coding of expert interviews. As for practical applicability, this was established through the model's implementation in a real educational setting, using the Sustainable Classroom learning experience as the primary reference. For each of these metrics, the information is obtained from distinct and complementary sources. In the case of theoretical coherence and empirical alignment, the analysis relied on the systematic coding of interviews, and the results a. The data were subsequently tabulated to calculate the frequency and percentage of each category, which allowed an estimation of their relative weight.

Additionally, the relationships among categories were represented in visual diagrams to convey the underlying structure of the model and the conceptual links binding its components. This validation has led the authors to revisit the evidence for practical application, which was derived from operational indicators and results compiled during the Sustainable Classroom case study). Moreover, the international reference cases outlined offered a comparative perspective that situates the proposed model within broader global debates on education and sustainability. Taken together, the application of these metrics—supported by multiple data sources—demonstrates that the model rests on a solid theoretical foundation, is consistent with empirical evidence, and can adapt to varied educational contexts committed to innovation, ethics, and sustainable development.

4. Results

During the qualitative analysis, three interrelated dimensions that support the responsible integration of AI in higher education were described: ethical-pedagogical transformation, sustainable technological integration, and institutional adaptability. These dimensions were established through rigorous monitoring of the process of constantly comparing the grounded theory (open, axial, and selective coding) of the collected data with the expert interviews. The presentation of the results was structured in five progressively sequential stages. The first, coding, reveals that ethics, pedagogy, and technology converge in higher education practices; while in the second stage, validation metrics and thematic rooting establish the empirical robustness and coherence of the emerging categories. The third stage, with structural alignment matrix, consolidates the correspondence between the theoretical axes and the experts' perspectives, reinforcing the conceptual soundness of the model; fourth, a comparison of experiences situates the model within the global landscape. Furthermore, a fifth Sustainable Classroom case study demonstrates the model's viability and transformative capacity in practice. Together, the stages converge on five theoretical axes: education as a common good, STEAM as an integrative paradigm, AI ethics and technological governance, human capabilities and sustainability, and educational innovation, suggesting that the model has a replicable and scalable contribution to advancing Society 5.0.

4.1. Findings from Expert Interviews

The analysis of expert interviews opened the study's empirical exploration: open, axial, and selective coding to show how ethics, pedagogy, and technology intersect in higher edu-

cation. The experts' voices highlighted institutional opportunities, tensions, and barriers, which together revealed the foundations of the conceptual model. This section presents the emerging categories and illustrates their significance through representative excerpts.

4.1.1. Open Coding

Open coding provided detailed insight into how experts perceive the intersection of ethics, sustainability, and technology, revealing emerging tensions in institutional settings. These findings address the study's objectives by showing how ethical, technological, and didactic aspects are integrated in AI integration. Guided by the conceptual framework, the coding process created categories that reflect both normative objectives and practical issues. The categorization summarized in Table 2 reflects how educators conceptualize the intersection of ethics, sustainability, and technology in higher education, offering insight into the structural and cultural changes necessary for a sustainable and ethically grounded digital transformation.

Table 2. Emergent categories and subcategories from open coding.

Research Objective	Category	Subcategory	References	Coverage	Representative Quote
Explore AI applications	Technological-sustainability integration	Responsible AI use	[12]	3	It is essential to educate about the risks and benefits of AI, to foster critical thinking...
Explore AI applications	Technological-sustainability integration	Integration of sustainability in learning	[22]	2	combining advanced technology with essential human values and aligning with global commitments such as the 2030 Agenda
Explore AI applications	Technological-sustainability integration	Reflective design and human impact	[14]	1	Technology does not transform on its own; it is the ethics with which we integrate it that determines whether it becomes a tool for inclusion or exclusion
Understand teacher's role	Ethical-pedagogical transformation	Redefinition of the teacher's role	[20]	3	The teacher will be, more than ever, a reflective professional, a designer of learning experiences, and an ethical educator.
Understand teacher's role	Ethical-pedagogical transformation	Student agency and capability development	[49]	1	not only technical skills, but also socioemotional competencies, critical thinking, creativity, and ethical commitment.

Note: These categories emerged through open coding of interview transcripts using ATLAS.ti. Subcategories were identified through recurrent semantic fields and interpretive analysis.

This phase exposed the tension between instrumental and humanistic approaches to AI in education. Participants emphasized the need to align technological adoption with ethical values and educational goals. These insights informed the axial coding stage, where relationships among categories led to broader interpretive themes that support the theoretical foundations of the proposed educational model for Society 5.0.

Overall, expert perspectives converged on three key challenges: ethical mediation in AI use, a redefinition of the educator's role, and institutional adaptability—providing a solid empirical foundation for understanding educational transformation in the AI era, particularly regarding the integration of sustainability, civic responsibility, and human development in higher education.

4.1.2. Axial Coding

Building upon the emergent categories from the open coding phase, this section presents the results of axial coding, which aimed to establish connections among categories and uncover higher-order themes. These axes provide an empirical bridge to the theoretical model, particularly in aligning technology with sustainability and civic formation (see Table 3).

Table 3. Axial coding.

Research Objective	Axial Category	Dimension	Interpretive Description
Analyze the types of interaction between educators and AI	Technological discernment for sustainability	AI use with reflection; sustainability as transversal competence	The adoption of emerging technologies must be guided by critical reflection and oriented towards ecological and social responsibility.
Understand perceptions of impact on the teacher's role	Ethical-pedagogical agency	Teacher as ethical mediator; student autonomy; values in education	Educators are repositioned as ethical facilitators who nurture students' autonomy, critical reasoning, and social sensitivity.
Identify barriers and needs for ethical integration	Institutional innovation for transformation	Governance flexibility, intersectoral collaboration, leadership for change	Institutional adaptability is crucial for supporting innovation, reducing resistance, and fostering a culture of ethical and sustainable transformation.

Note. These axes represent the underlying structure for the construction of the conceptual model.

The results in Table 3 show, first, that the emerging category technological discernment for sustainability indicates that the integration of AI in HEIs requires critical reflection and positions sustainability as a transversal competence that transcends instrumental uses of technology. The "ethical-pedagogical agency" as an emerging category, in the second place, suggests that the educator is an ethical mediator who cultivates student autonomy, critical reasoning, and socio-emotional development, thus safeguarding the humanistic dimension of education. In the third category, "institutional innovation for transformation" emphasizes that flexible governance, cross-sector collaboration, and transformational leadership are key strategies to overcome structural resistance and promote a culture of ethical and sustainable change. Together, these categories contribute to the ethical integration of AI from a transformative, multidimensional approach—technological, pedagogical, and institutional—that aligns with sustainability principles and the goals of Society 5.0. The intersection of these categories reveals recurring patterns in educators' responses, expanding the theoretical depth of the study and consolidating the foundations of the conceptual model.

4.1.3. Selective Coding

Table 4 presents the key theoretical concepts that emerged from the selective coding phase. This stage allowed for the integration of insights from open and axial coding into a coherent conceptual framework that supports the proposed educational model for Society 5.0. Through analytical abstraction, these were condensed into three fundamental dimensions: normative (ethical orientation and social justice), pedagogical (teacher roles and student agency), and institutional (governance and adaptability), which define the fundamental requirements for the responsible and sustainable integration of AI in higher education.

Table 4. Selective coding.

Research Objective	Core Theoretical Category	Analytical Memo
Contribute to the formulation of an ethical-sustainable educational model	Education as an ethical-technical agency for sustainability	This category conceptualizes education as a dual force ethical and technological capable of shaping sustainable development. It highlights the educator's role in guiding AI use through values-based criteria and fostering student capabilities that align with ecological, social, and civic imperatives.
Understand shifts in educational roles and relationships	Reconfiguration of educational roles and relational dynamics	This construction underscores a paradigmatic shift from traditional hierarchies toward co-construction of knowledge, ethical facilitation, and learner autonomy. It repositions the teacher as a critical and empathetic agent within AI-mediated learning environments.
Identify the necessary institutional conditions	Institutional readiness for transformative learning	This category encapsulates the structural, cultural, and governance conditions required for sustained educational innovation. It emphasizes the need for adaptive leadership, inclusive policies, and collaborative ecosystems that enable ethical experimentation and systemic change.

Note. The selective coding phase integrated previous coding outcomes into theoretically robust categories.

Selective coding consolidated the analysis into three core constructs: ethical–technical agency, pedagogical reconfiguration, and institutional readiness. These categories establish the normative, pedagogical, and structural foundations required for the ethical integration of AI, thereby consolidating the conceptual model for Society 5.0.

4.1.4. Code Association Mapping

Validation metrics confirmed the frequency and coverage of the categories. Thematic rooting placed them within the model's axes, ensuring its robustness and empirical coherence. Figure 3 presents the associative network generated in ATLAS.ti, (version 23.2.1) which links the subcategories derived from expert interviews with the five core axes of the proposed conceptual model for higher education in Society 5.0: (1) Teacher role reconfigured as ethical mentor, (2) Institutional conditions for innovation, (3) Ethical governance of AI, (4) STEAM as an integrative vision, and (5) Multimodal and personalized learning.

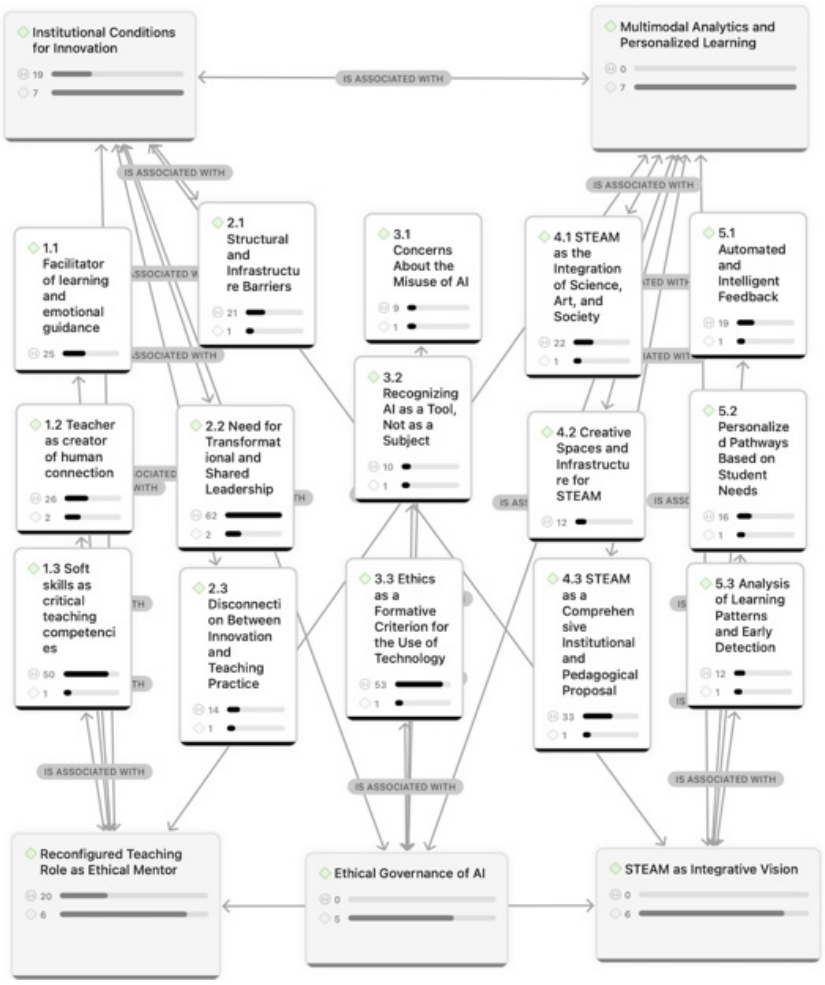

Figure 3. Network of Categories and Theoretical Axes Derived from Expert Interviews. Note. Legend dashed = associated; solid = aggregated; dotted = high-level link.

Together, they demonstrate structural interdependence, reinforcing systemic validity for guiding higher education in Society 5.0. This dynamic associative network helps us understand how classroom practices are transformed by highlighting the connections. The map illustrates how ethical orientation, pedagogical transformation, and institutional adaptability operate as mutually reinforcing dynamics. This articulation underscores the systemic complexity of higher education, where governance, values, and teaching practice must be addressed within an integrated framework, rather than in isolation.

The interconnections identified in the map align with international debates on AI and sustainability in education, increasing its credibility, transferability, and potential impact. The associative network mapped in ATLAS.ti links subcategories with the five central axes of the conceptual model; this mapping shows how ethical orientation, pedagogical transformation, and institutional adaptability interact as mutually reinforcing dynamics, underscoring the systemic complexity of higher education. Validation metrics confirmed the frequency and coverage of the categories.

The visualization demonstrates the transferability of the model, as the interconnections identified reflect challenges and opportunities currently debated at the international level in the fields of AI and sustainability in education. The mapping integrates the categories into a coherent structure, serving as a bridge between the coding phases and the validation analyses presented in Section 4.2.

4.2. Thematic Rooting Matrix

The validation with metrics confirms that the model's core categories achieved a high frequency of citations and broad coverage among the experts interviewed. For example, the Need for Transformational and Shared Leadership (n = 62, coverage = 2) and Ethics as a Formative Criterion for the Use of Technology (n = 53, coverage = 1) demonstrate their alignment with the model's theoretical axes.

Categories with lower frequencies, such as Structural Barriers and Infrastructure (n = 8, coverage = 1), enrich the model by highlighting the contextual constraints that shape the learning process. This combination of frequently cited and less frequently cited categories reinforces the model's reliability and applicability in diverse higher education contexts. Thematic centrality was illustrated by visualizing highly connected nodes, such as 2.2 (Need for Transformational and Shared Leadership) and 3.3 (Ethics as a Formative Criterion for the Use of Technology), which provides conceptual coherence between the empirical data and the model's structural relationships.

The network structure also revealed vertical and horizontal associations, demonstrating that institutional, pedagogical, and ethical components reinforce each other. Categories such as STEAM (Integration of Science, Art, and Society) and Creative Spaces and Infrastructure connected pedagogical innovation with broader sociotechnical goals, thus aligning the framework with the principles of Society 5.0.

This relational configuration confirms that the categories derived from the expert interviews consistently support the model's theoretical architecture. The multiple links identified between the nodes reinforce thematic coherence, while the distribution of categories across domains highlights the framework's adaptability to diverse higher education contexts.

Table 5 summarizes the thematic categories resulting from the expert interviews by grouping the coded data. The summary highlights that the empirical evidence aligns with the five core axes that support higher education for Society 5.0.

The interpretive axes of axial coding confirm that educators perceive AI as a technological tool that catalyzes ethical, pedagogical, institutional, and sustainability transformation, which reinforces the fundamental structure of the proposed model and highlights the transition toward ethically grounded and sustainability-oriented higher education in the era of Society 5.0.

Figure 4 shows the frequency of subcategories derived from expert interviews, highlighting the emphasis on human connection in teaching, the need for cross-disciplinary leadership, and the ethical integration of technology. Validation metrics confirmed that the model's core categories feature a high frequency of citations and broad participant coverage, indicating strong thematic relevance and consensus among experts. Categories such as the Need for Transformational and Shared Leadership (n = 62, coverage = 2) and Ethics as a Formative Criterion for Technology Use (n = 53, coverage = 1) recurrence and alignment with the model's theoretical axes. Less frequent categories, such as Structural and Infrastructural Barriers (n = 8, coverage = 1), also contribute to the model by revealing contextual constraints on the learning process. Taken together, the combination of frequency and coverage confirms that the proposed framework is based on empirically validated perspectives that reinforce its reliability and applicability in diverse higher education contexts.

Table 5. Thematic synthesis of categories.

Thematic Category	Grouped Codes	Interpretive Synthesis
Ethical and sustainable citizenship formation	Centrality of human values; Critical education for Society 5.0	The educational model must prepare citizens who are ethically grounded, socially committed, and capable of addressing contemporary challenges through a sustainability lens.
Reconfiguration of the teaching role in AI environments	Redefinition of teaching role; Affective limits of AI; AI as content source	The teacher evolves into a learning designer and ethical mediator, fostering student agency and safeguarding the human dimensions of education in technologically mediated contexts.
Institutional conditions for educational innovation	Lack of institutional strategy; Need for pedagogical transformation	Structural transformation in governance, resource allocation, and curriculum design is essential to embed ethical innovation in educational systems.
Technology, ethics, and algorithmic justice	Critical AI literacy; Human oversight	Principles of justice, transparency, and critical awareness must govern AI. Educators must prepare students to navigate ethical dilemmas and systemic biases inherent in algorithmic systems.
STEAM education as a civilizational vision	STEAM as an integrative framework: Interdisciplinarity	STEAM education transcends technical instruction by integrating science, art, ethics, and social engagement, serving as the epistemological backbone of education for Society 5.0.

Note. This synthesis table reinforces that ethical and sustainable education in the AI era requires integrated, interdisciplinary, and justice-oriented pedagogical approaches.

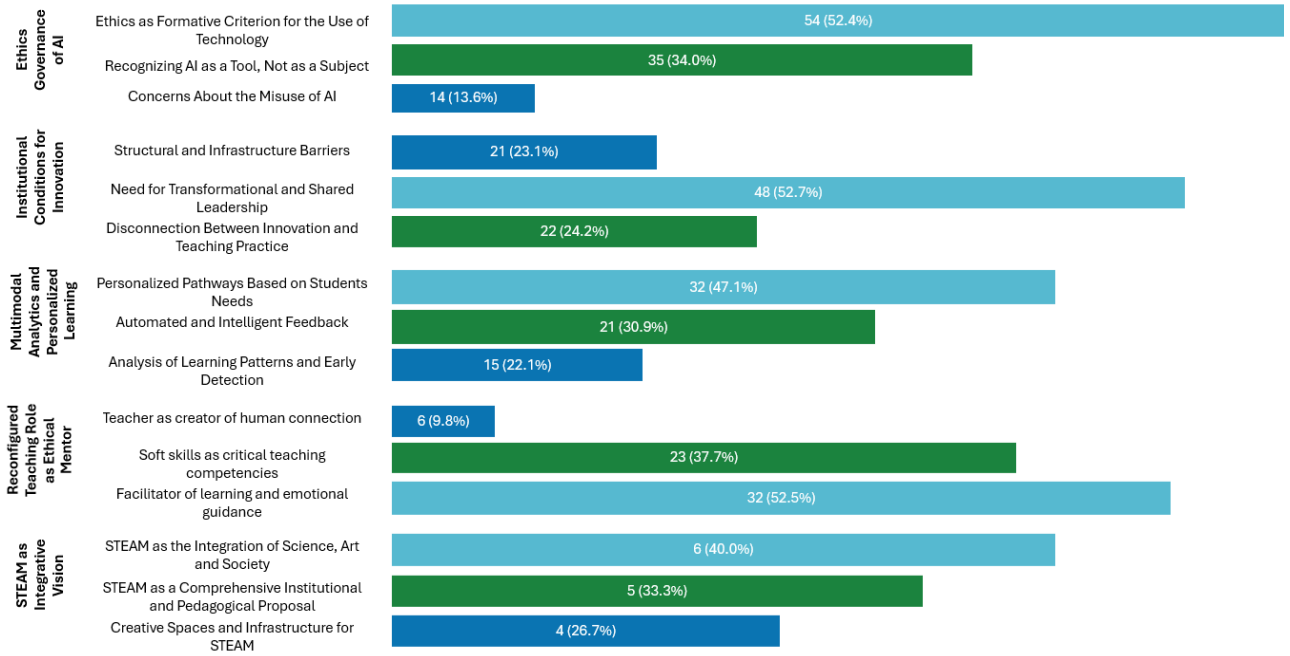

Figure 4. Thematic Rooting Matrix of Categories and Subcategories. Note. This visual representation consolidates the analytical dimensions emerging from the expert interviews.

Visualization highlights the human connection in teaching, the need for interdisciplinary leadership, and the ethical integration of technology; in other words, this reinforces the coherence of the model. The associative network was consolidated into three categories: ethical orientation, pedagogical transformation, and institutional adaptability. Therefore, the high frequency, broad coverage, and strong interconnections suggest that experts perceive AI as a tool for rethinking educational values, governance structures, and pedagogical priorities that integrate ethics and sustainability. This confirms empirical relevance and coherence with the five core axes of the model.

4.3. Synoptic Overview of the Analytical Process

This section provides a synoptic account of the analytical process to ensure methodological transparency and reinforce the theoretical robustness of the proposed model. Table 6 provides an overview of the analytical process employed in this study model, ensuring coherence between data collection, interpretation, and theory building. It demonstrates the iterative nature of the grounded theory approach. The synthesis outlines how each phase of grounded theory—open, axial, and selective coding—contributed to the model's construction, demonstrating a logical progression from empirical data to conceptual abstraction.

Table 6. Synoptic overview of the analytical process.

Analysis Stages	Description	Analytical Memo
Open Coding	Identification of significant segments regarding perceptions, tensions, and conditions for ethical AI integration in higher education. Codes included: "the teacher becomes a learning designer," "AI lacks empathy," "the challenge is cultural and institutional."	AI is perceived as a complementary tool that requires ethical mediation. Institutional barriers and the need to redefine educational purpose are recurrent themes.
Axial Coding	Grouping codes into five thematic categories: (1) Ethical and sustainable citizenship formation, (2) Reconfiguration of the teaching role, (3) Institutional conditions, (4) Technology ethics, (5) STEAM as a civilizational vision.	These categories reflect the articulation of key dimensions within the conceptual model. The central issue is not the technology itself, but the ethical direction of its integration.
Constant Comparison	Juxtaposition of expert discourses across emergent categories. Notable themes include the risk of dehumanization without ethical mediation and institutional inertia as a barrier to change.	This stage allowed the refinement of categories and the construction of a structural matrix linking expert voices with the conceptual dimensions of the model.
Theoretical Saturation	Achieved by the fifth interview, where consistent patterns such as ethics, human capabilities, institutional flexibility, and sustainability repeatedly emerged.	Theoretical saturation confirmed the robustness and coherence of the categories, supporting the internal validity of the educational model for Society 5.0.

Note. This table synthesizes the core analytical stages that led to the construction of the conceptual model.

4.3.1. Structural Alignment of Data and Model

Building on the validation of frequency, coverage, and associative links presented in the previous sections, this stage examines the structural coherence between the empirical findings and the axes of the proposed conceptual model. The objective is to demonstrate that the categories derived from the expert interviews converge with the theoretical foundations of the model, supporting the conceptual proposals' consistency with the lived

experiences and reflective practices of educators. Aligning the data and the model reinforces systemic coherence and highlights its relevance in guiding the transformation of higher education in the era of Society 5.0.

4.3.2. Structural Matrix: Interviews and Conceptual Model Axes

This section presents a structural matrix that aligns the axes of the conceptual model with categories derived from expert interviews, thereby reinforcing the coherence between theoretical constructs and empirical insights. Table 7 displays the structural matrix linking expert interview responses to the axes of the conceptual model. Through this triangulation process, the model is validated by showing how its core propositions are grounded in the real-world perspectives of practitioners and scholars working at the intersection of education, technology, and ethics.

Table 7. Structural matrix: interviews and conceptual model axes.

Conceptual Model Axis	Emergent Interview Category	Representative Expert Voice
Education as a common good	Ethical and sustainable citizenship formation	E1: "Education must focus on what makes us human: thinking, caring, collaborating."
STEAM approach	Education as an integrative vision of knowledge	E3: "STEAM lets us connect the technical with the human and the artistic."
Ethics of AI and technological governance	Algorithmic justice and human oversight	E2: "AI needs an ethical compass—without it, it merely reproduces inequalities."
Human capabilities and sustainability	Learning with social and ecological value	E5: "Learning also means learning to live in community and to care for the environment."
Educational innovation and institutional change	Reconfiguration of teaching roles and institutional resistance	E4: "The challenge is not only pedagogical; it's institutional—some structures don't allow innovation."

Note. This matrix links the model's guiding principles with expert perspectives, underscoring its practical relevance and applicability in higher education focused on AI, sustainability, and civic values.

The convergence observed in this matrix reinforces the conceptual soundness and empirical relevance of the proposed model, illustrating how the principles of Society 5.0 can be translated into both reflective educational practices and institutional change. It further demonstrates that the model is not only theoretically grounded but also aligned with the practical concerns and aspirations of educators and policymakers committed to advancing the future of higher education.

4.4. Benchmarking Internacional

This section presents an international benchmarking exercise to position the proposed model within global debates on the ethics of AI, sustainability, and higher education. The analysis underscores convergences and opportunities for contextual adaptation, strengthening the model's credibility and transferability in line with the principles of Society 5.0.

In the 21st century, HEIs integrate AI into core academic and administrative processes, generating international experiences that offer solid empirical evidence of systemic transformation. This section examines four selected cases that exemplify the implementation of ethical, sustainable, and technologically integrated strategies in higher education.

In Indonesia, national policy aligns HEIs with digital literacy competencies and ethical as well as sustainability imperatives through the integration of AI–STEAM frame-

works [61–63]. Implementation occurs via curriculum reforms that position interdisciplinary project-based learning as a core pedagogical strategy. This approach has strengthened students' ability to address complex scientific, technological, and socio-environmental problems, linking technological proficiency with values-based learning outcomes. The Indonesian experience offers a replicable model for embedding sustainability and ethical governance within digital education ecosystems [64].

In the United Kingdom and Australia, HEIs face governance challenges arising from the increasing algorithmization of educational processes. Algorithmic risks, the opacity of automated decision-making systems, and the potential erosion of academic autonomy [65] have prompted the development of regulatory and enforceable frameworks. These initiatives aim to safeguard transparency, mitigate systemic bias, and protect institutional independence, forming the basis for policies and ethical governance mechanisms in AI adoption strategies for higher education.

In Uruguay, HEIs integrate STEAM principles into their curricula as a strategic policy axis to promote equity, sustainability, and social inclusion [66]. This integration is supported by a governance architecture that deploys regulatory frameworks aligned with national public policies, legislative provisions, and curricular standards. Participatory mechanisms ensure that the development of technological and scientific competencies remains consistent with social and environmental responsibility. The Uruguayan approach demonstrates how a Global South nation can institutionalize STEAM to operationalize education as a common good.

In the European Union, AI integration in higher education follows ethical principles anchored in human-centered design methodologies and inclusive participation strategies [65]. Implementation relies on normative guidelines, regulatory frameworks, quality assurance standards, and funding programs that sustain technological innovation, ethical governance, and stakeholder participation. These initiatives serve as international benchmarks, demonstrating the integration of the model's five dimensions—education as a common good, STEAM, AI ethics, human capabilities and sustainability, and educational innovation—across diverse socio-institutional contexts. They also show that the model's operational pillars—multidisciplinary learning, industry–society collaboration, and project-based learning—act as structural enablers adaptable to local priorities while maintaining ethical integrity and sustainability orientation.

Taken together, these international cases demonstrate that the proposed model resonates with global efforts to integrate ethics, sustainability, and technological innovation into HEIs. Therefore, and consequently, convergences highlight their conceptual robustness and practical transferability; the contextual differences also reveal opportunities for adaptation in line with local governance structures, cultural traditions, and policy frameworks. This benchmarking confirms the model's relevance as both a theoretically grounded and internationally adaptable framework for guiding higher education in the era of Society 5.0. The following section presents the Sustainable Classroom as a case study that empirically demonstrates the applicability of the proposed model in higher education.

4.5. Case Analysis: Demonstration Through the Sustainable Classroom

This section introduces the Sustainable Classroom as a case study designed to demonstrate the applicability of the proposed conceptual model in a real higher education environment. The implementation at the Interdisciplinary Professional Unit for Energy and Mobility (UPIEM) of the Instituto Politécnico Nacional, the Sustainable Classroom, represented one of the opportunities for its relevance in integrating AI ethical governance, sustainability principles, and institutional innovation. The case provides empirical validation of the model, and also illustrates that evidence for articulating the five axes and

three operational pillars can be coherently embedded in educational practices that combine technological infrastructure, ethical reasoning, and sustainability-driven learning.

The Sustainable Classroom is not conceived as a conventional classroom, but rather as a living laboratory co-designed by students, faculty, and institutional stakeholders. It is a prototype for forward-thinking learning environments where clean energy systems, AI applications, Internet of Things (IoT) technologies, and sustainability practices converge to promote interdisciplinary higher education. The technical infrastructure, which includes an autonomous microgrid with lithium-ion battery storage, a photovoltaic system, and IoT-based monitoring and control systems, was deliberately integrated as an educational platform [58], rather than installed as equipment. By interacting with these systems, students engage in scientific inquiry, engineering design, technological operation, ethical reflection, and creative problem-solving. The setup thus demonstrates that technological infrastructure is an interdisciplinary pedagogical resource; in this setting, the Sustainable Classroom is a concrete example of why STEAM approaches are indispensable for addressing the complexity of sustainable and ethically guided HEIs.

From a pedagogical standpoint, the Sustainable Classroom fosters active and experiential learning within a real-world, sustainability-driven context. Students engage in the installation, monitoring, and optimization of clean energy and digital systems, thereby developing both technical competencies and civic capacities rooted in democratic participation, ethical reasoning, and environmental stewardship. Ethical deliberation is intentionally embedded in classroom activities, particularly in domains such as energy justice, algorithmic fairness, and ecological responsibility. These practices directly reflect and operationalize the five theoretical axes and three operational pillars of the proposed conceptual model, reinforcing its educational relevance and transformative intent.

The analysis of this case involved documentary evidence—including technical reports, academic presentations, and photographic records—with the empirical categories identified during Phase 1. This triangulation enabled a systematic and context-sensitive comparison, enhancing the credibility and applicability of the conceptual model in real higher education environments. The process confirmed that the Sustainable Classroom operationalizes the model's theoretical principles, particularly in fostering sustainability, ethics, and innovation. The synthesis of this validation process is presented in Table 8, which illustrates the correspondence between the theoretical axes, operational pillars, and the empirical evidence derived from the Sustainable Classroom case study.

Table 8. Validation matrix: alignment of the sustainable classroom with the conceptual model.

Conceptual Model Axis	Sustainable Classroom Practices
Education as a common good	Participatory design, shared responsibility, and ethics-driven curriculum focused on collective well-being.
STEAM approach	Integration of science, engineering, ethics, design, and community engagement in learning activities.
Ethics of AI and technological governance	Development of AI prototypes with ethical guidelines, sensor usage protocols, and data privacy workshops.
Human capabilities and sustainable development	Emphasis on collaboration, ecological awareness, empathy, and practical engagement in sustainability projects.
Educational innovation and institutional change	Off-grid technology infrastructure, cross-disciplinary teaching teams, and openness to experimentation.

Note. The Sustainable Classroom exemplifies how the proposed conceptual model can be implemented in practice, serving as a pedagogical and technological prototype for ethical and sustainable education in higher education.

The demonstration process conducted through the Sustainable Classroom confirmed the model's feasibility, sustainability orientation, and relevance to higher education. The alignment between observed practices and theoretical assumptions affirms its empirical consistency and potential for replication. This demonstration followed an inductive–constructivist logic, complemented by abductive reasoning: while induction enabled the emergence of categories from expert interviews, abduction allowed for their reinterpretation considering real-world data from the case study.

Beyond its internal coherence, the model advances scholarly debate by consolidating previously fragmented perspectives on sustainability, ethics, and technological innovation into a unified framework (Table 8). It addresses pedagogical practices, institutional governance, policy design, and industry engagement, thereby bridging micro-, meso-, and macro-level dimensions of higher education. This integrative scope distinguishes the model from prior approaches that examined sustainability, AI ethics, and STEAM pedagogy in isolation, and positions it as a robust foundation for advancing educational innovation within the global vision of Society 5.0.

5. Discussion

Section 5 examines the implications of the proposed model on three levels. First, it addresses the integration of sustainability, ethics, and technological innovation into HEI practices. Second, it analyzes the policy frameworks that foster the conditions for systemic change in higher education. Finally, it presents the contribution of industry partnerships to align academic initiatives with the demands of society and the labor market, thus reinforcing the transition to Society 5.0.

The central category—education as an ethical-technical agency for sustainability—redefines education in the digital age beyond instrumental training. It demands the cultivation of critical thinking, ethical decision-making, and civic responsibility. Drawing on Sen and Nussbaum's capabilities approach [4,14], this vision reframes the role of the teacher, shifting from being a transmitter of content to an ethical mediator, interdisciplinary designer, and manager of responsible technological integration [11]. The implementation of this model requires institutional transformation, ongoing professional development, and governance oriented toward ethics and sustainability. The case of the Sustainable Classroom demonstrates its viability and illustrates the convergence of sustainability, ethics, and STEAM disciplines in participatory and socially engaged learning [27]. On this basis, the debate unfolds along five thematic axes that connect empirical findings with international policy frameworks and the normative vision of Society 5.0 [7].

5.1. Education as a Common Good in the Age of AI

Participants and case evidence converged on the view that education must be reclaimed as a space for ethical formation, collective deliberation, and democratic participation. Instead of reducing AI to a mechanism of technocratic optimization, the findings underscore the imperative to orient its application toward social justice, care, and planetary well-being. This perspective aligns with UNESCO's conception of education as a common good and reinforces the ethical imperatives established in the 2030 Agenda for Sustainable Development [1].

This axis echoes Gimeno Sacristán's call to uphold education as an emancipatory practice and a cultural–political project, one that resists its reduction to market logics or instrumental automation [16,17]. Within this framework, AI should be integrated not as a neutral or merely functional instrument but as a catalyst for civic awareness, ethical reflection, and democratic engagement. Such a perspective strengthens the role of education in shaping citizens who are socially and environmentally responsible.

5.2. Ethical Mediation and the Reconfiguration of the Teaching Role

The redefinition of the teaching role emerged as a central concern in both expert interviews and the Sustainable Classroom case. Participants emphasized the transition from transmissive pedagogy to facilitation, ethical mediation, and the design of interdisciplinary learning experiences with real-world relevance. The case study illustrated this shift, as teachers co-designed value-driven projects that promoted sustainability and acted as mentors in civic learning and ethical inquiry.

This perspective aligns with recent research on teacher agency in technological contexts [18,19] and highlights the relevance of emotional intelligence, moral reasoning, and pedagogical judgment in AI-mediated environments. Within Society 5.0, teachers function not as operators of technological tools but as ethical and epistemological mediators who guide learning through deliberation, sustainability awareness, and democratic participation. Evidence indicates that teacher agency in AI-mediated learning supports self-regulation and critical reflection [60]. Teacher agency remains essential to ensure that automation and innovation serve educational purposes grounded in justice, inclusion, and the common good.

5.3. Institutional Innovation and Contextual Adaptability

A recurring challenge in HEIs is institutional inertia, which constrains ethical and sustainable innovation. Therefore, rigid administrative policies, compartmentalized structures, and weak strategic alignment often obstruct transformative initiatives. From a perspective, the Sustainable Classroom demonstrates that meaningful change becomes possible when institutions implement inclusive governance, support pedagogical experimentation, and strengthen collaboration between academia, industry, and the community.

This case illustrates how institutional adaptability can operate as a catalyst for embedding sustainability, ethical reflection, and interdisciplinary learning—the foundational pillars of the proposed educational model for Society 5.0. These insights resonate with Fullan's theory of systemic change [22], which conceptualizes institutions as dynamic learning ecosystems capable of continuous renewal. Within this perspective, governance models should encourage innovation processes grounded in ethical principles, contextual responsiveness, and cross-sector partnerships. Instead of relying on reforms imposed from above, transformation arises from institutional cultures that prioritize participation, reflection, and sustainability, which represent essential values of the proposed model for Society 5.0.

5.4. Governance of Technology and Algorithmic Justice

The ethical governance of AI emerged as a central concern in both the expert interviews and case study analysis. Participants highlighted the need for transparency, critical digital literacy, and participatory oversight in the implementation of AI tools in educational contexts. Beyond legal and technical safeguards, the study emphasizes that governance must also be pedagogical and epistemic—shaping how knowledge is produced, mediated, and assessed. This calls for reframing AI integration not merely as a matter of regulatory compliance, but as an opportunity to foster democratic practices, ethical reflection, and shared responsibility in educational decision-making. As Farrell [62] indicates, beyond technical performance, algorithmic education must embed ethical and cultural reflection, especially when targeting disadvantaged or sensitive populations.

This perspective aligns with the ethical principles articulated by Floridi et al. [21] and expands them by highlighting the hidden curricula and value systems embedded in technological choices. The integration of AI into education is never neutral; it reproduces power relations, shapes curricular priorities, and promotes specific social imaginaries.

Accordingly, educational institutions must establish robust mechanisms for algorithmic accountability, curricular justice, and inclusive deliberation to ensure that AI deployment aligns with democratic, ethical, and sustainability-oriented educational aims. Design justice further insists on recognizing the lived experiences and agency of marginalized communities, countering the biases frequently embedded in data-driven systems [63].

5.5. STEAM as a Civilizational Framework

One of the model's contributions is its reimagining of STEAM from a civic perspective. Rather than being viewed as a set of technical tools for innovation, STEAM is recast as an integrative framework that reconstructs the relationship between knowledge, ethics, creativity, and collective well-being. It fosters the convergence of scientific inquiry, artistic expression, and civic engagement, positioning education as a cultural project oriented toward sustainability, justice, and democratic participation.

This perspective aligns with Yakman's [20] vision of STEAM as a transdisciplinary paradigm that integrates epistemological and ethical dimensions in learning. It also echoes Morin's [6] call for "complex thought" capable of addressing systemic crises by interlinking disciplines, values, and lived experience. In this view, STEAM education becomes a platform to cultivate planetary awareness and social responsibility in response to the challenges of Society 5.0.

The Sustainable Classroom exemplifies this civilizational vision through its emphasis on transdisciplinary design, environmental responsibility, and collective problem-solving as foundational principles of its pedagogical approach. Furthermore, it aligns with recent work on posthuman and relational pedagogies that dismantle disciplinary silos and foster interconnected, multispecies, and planetary forms of learning [3].

In this context, STEAM operates not merely as a teaching method but as a catalyst for shaping futures that prioritize social justice and ecological sustainability alongside technological advancement. Through the integration of multiple ways of knowing and strong ethical foundations, it enables learners to respond critically and creatively to the complex challenges of the 21st century.

5.6. Aligning Emergent Categories with the Theoretical Model

The proposed conceptual model has been empirically validated through its implementation in the Sustainable Classroom, offering concrete evidence of its institutional viability. While the conceptual triangle was originally introduced in the theoretical framework, its validation relies on the consistency between empirical findings and the model's operational logic. To support this coherence, Table 9 maps the core categories derived from the grounded theory analysis to the three pillars of the model: multidisciplinary learning, project-based learning, and community engagement. This correspondence demonstrates that the model is not only conceptually grounded but also empirically supported.

These results not only provided conceptual scaffolding for the model but also enabled its empirical validation. The implementation of the Sustainable Classroom as a real-world learning environment served as a testing ground for assessing the coherence, feasibility, and contextual relevance of the proposed framework. This alignment between theoretical constructs and observed practices reinforces the model's robustness and opens pathways for its strategic and context-sensitive implementation—issues that are further explored in the following discussion.

Table 9. Mapping of emergent categories to model pillars.

Emerging Category (Analysis)	Operational Pillar (Model)	Rationale
Ethical-pedagogical transformation	Multidisciplinary learning	Emphasizes values, civic engagement, and critical thinking across disciplines.
Technological-sustainability integration	Project-based learning	Promotes applied problem-solving and technological innovation in learning.
Institutional adaptability and collaboration	Community engagement	Encourages co-responsibility and relevance through external collaboration.

5.7. International Experiences for Ethical and Sustainable Higher Education in Society 5.0: Implications and Future Research

The comparative analysis of the four international cases reveals both convergences and divergences in the integration of ethics, sustainability, and innovation in higher education. Across contexts, institutions converge on the principle of framing education as a common good but diverge in their mechanisms of implementation. Uruguay stands out for its high degree of institutionalization through national policies, legislation, and curriculum standards. The European Union achieves moderate integration via regional frameworks and institutional guidelines, while Indonesia, the United Kingdom, and Australia embed the principle more indirectly through curriculum design strategies that emphasize access and equity.

International experiences also demonstrate how STEAM has become a central curricular axis for fostering interdisciplinary, project-based learning. In Indonesia and Uruguay, STEAM serves to strengthen collaborative knowledge production, while in the European Union, it is integrated with AI ethics, forming a synergistic framework that connects technical skills with normative reflection. In the United Kingdom and Australia, STEAM principles operate within broader educational reforms, advancing critical thinking and digital literacy as key competencies for democratic and sustainable education.

The Ethics of AI dimension is most developed in the United Kingdom, Australia, and the European Union, where institutions have implemented governance frameworks, transparency protocols, and risk mitigation measures. By contrast, Indonesia and Uruguay address this dimension more implicitly through ethics modules embedded in technology-oriented curricula, fostering values-based competencies alongside technical skills.

The Human Capabilities and Sustainability dimension is most prominent in Indonesia and Uruguay, where curricula incorporate ecological literacy, socio-emotional learning, and adaptive problem-solving to strengthen long-term societal resilience. Institutions in the European Union, the United Kingdom, and Australia emphasize this dimension through governance policies and digital ethics standards that embed environmental and social responsibility into organizational practices and technology adoption strategies.

The Educational Innovation dimension emerges across all contexts, although with distinct priorities and governance capacities. In Indonesia, it is expressed through community-based projects that integrate local knowledge with STEAM methodologies. In Uruguay, it is institutionalized via national policy frameworks that embed innovative pedagogies. In the European Union, pilot programs on ethical AI integration provide a basis for large-scale adoption, while in the United Kingdom and Australia, governance reforms incorporate innovation into institutional decision-making processes. Collectively, these approaches highlight the adaptability of innovation strategies to diverse higher education systems while preserving alignment with the model's ethical and sustainability dimensions.

Table 10 summarizes the comparative findings across the model's five dimensions. While the relative emphasis varies by context, the evidence demonstrates that the full integration of all dimensions and operational pillars is essential to achieving sustainable and ethically grounded systemic transformation in higher education.

Table 10. Alignment of the model's five dimensions with comparative findings from selected international cases.

Model Dimension	Indonesia	Uruguay	European Union	United Kingdom–Australia
Education as a Common Good	Indirectly addressed through inclusive curriculum strategies aimed at expanding access and equity, without an explicit legal framework.	Highly institutionalized within national policies, supported by legislation and curriculum standards.	Moderately embedded through regional policy instruments and institutional guidelines.	Indirectly addressed through inclusive curriculum design strategies.
STEAM Integration	Central curricular axis reinforced by interdisciplinary projects and project-based learning (PBL).	Strategic policy axis with cross-cutting integration at all educational levels.	Complemented by advanced AI ethics training.	Peripheral presence, influencing critical thinking and digital literacy initiatives.
Ethics of AI	Embedded transversally in technology programs through dedicated ethics modules.	Addressed in technology curricula with a focus on social responsibility.	Highly operationalized through regulatory frameworks and transparency protocols.	Highly operationalized through governance mechanisms, transparency measures, and algorithmic risk mitigation.
Human Capabilities and Sustainability	Explicit emphasis on ecological literacy, socio-emotional learning, and adaptive problem-solving.	Inclusion of sustainability and socio-emotional competencies in the national curriculum.	Addressed through institutional governance frameworks and digital ethics standards.	Primarily approached via institutional policies and ethical standards for technology adoption.
Educational Innovation	Community-based projects integrating local knowledge with STEAM methodologies.	National policy frameworks institutionalizing innovative pedagogies.	Pilot programs for ethical AI integration, informing large-scale adoption.	Governance reforms aimed at embedding innovation within institutional processes.

Note: This table synthesizes the comparative findings from four international cases analyzed in this study, mapping them onto the model's five dimensions.

The results shown in Figures 3 and 4 confirm the structural robustness and internal coherence of the proposed model. The centrality of the categories Need for Transformational and Shared Leadership (2.2) and Ethics as a Formative Criterion for the Use of Technology (3.3) reveals their transversal influence in fostering innovation for sustainability and ethical governance in higher education. The relational density illustrated in Figure 4 highlights both vertical and horizontal associative dynamics, linking institutional enablers, pedagogical innovation, and the ethical use of AI. This structural consistency aligns with comparative evidence from the international cases examined in Section 5.6. The experiences of Indonesia, Uruguay, the European Union, the United Kingdom, and Australia confirm that the model's five dimensions—education as a common good, STEAM integration, AI ethics, human capabilities and sustainability, and educational innovation—are adaptable to

diverse socio-institutional contexts while maintaining congruence with ethical imperatives and sustainability goals.

Furthermore, the analysis of empirical evidence and case studies identified a recurring sequence of three adoption stages—exploration, piloting, and scaling—that ensures consistency between the theoretical foundations of the model and its practical implementation (see Table 11). This sequence holds across contexts in both the Global North and the Global South.

Table 11. Sequential implementation phases of the conceptual model for the ethical and sustainable integration of AI and STEAM pedagogies in higher education.

Phase	Objective	Key Actions	Stakeholders	Expected Outputs
Stage 1—Exploratory (Awareness & Diagnosis)	Establish institutional awareness and assess baseline capacities.	- Conduct faculty workshops on the model's five dimensions. - Audit infrastructure and competencies. - Map regulatory and socio-cultural conditions.	University leadership, faculty, IT, and governance units	Baseline report on technological, pedagogical, and governance readiness
Stage 2—Pilot (Controlled Implementation)	Test model components in selected programs.	- Develop interdisciplinary STEAM projects. - Implement ethical AI case studies. - Evaluate outcomes using mixed-method approaches.	Pilot program coordinators, faculty, students, and evaluation teams.	Evidence-based adjustments to curricula and governance practices
Stage 3—Scaling (Institutional Integration)	Consolidate model integration across policies and curricula.	- Embed AI ethics and sustainability principles in all programs and policies. - Formalize governance mechanisms. - Establish continuous monitoring and quality assurance.	All academic units, policy boards, and QA offices.	Institutional policy alignment, system-wide integration, and monitoring indicators

Note. This table summarizes the three sequential phases of the validated conceptual model, outlining objectives, actions, stakeholders, and outputs as a replicable roadmap for ethically grounded, sustainability-oriented transformation in Higher Education Institutions aligned with Society 5.0.

The cross-national comparison indicates that, in Uruguay, priority is placed on policy coherence, teacher capacity development, and iterative evaluation to achieve effective institutionalization. In contrast, the European Union demonstrates stronger regulatory frameworks, concrete multi-stakeholder participation, and sustained financial investment to secure long-term outcomes. Together, these cases reinforce the conceptual validity and transferability of the model, underscoring its relevance for guiding systemic transformations in higher education globally.

5.8. Strategic Guidelines for Implementation

Building on the comparative validation of the four international cases presented in Section 5.6, the proposed strategic guidelines translate the model's five theoretical dimen-

sions into actionable, context-sensitive recommendations for higher education leaders, faculty, and policymakers. Structured across three sequential stages—exploratory, pilot, and scaling—and organized into three strategic axes, these guidelines provide a replicable roadmap for aligning institutional policies, curricula, and governance mechanisms with the human-centered, sustainability-oriented vision of Society 5.0. Derived from the comparative validation of international case studies and grounded in the model's theoretical foundations, Table 12 details the strategic guidelines, which focus on (i) Ethical–Technical Transformation and Human-Centred Education, (ii) Collaborative and Transdisciplinary Institutional Innovation, and (iii) Smart Learning Environments and Ethical Technology Integration.

Table 12. Strategic guidelines for ethical and sustainable higher education within the framework of Society 5.0.

Strategic Axis	Tactical Actions
1. Ethical–Technical Transformation and Human-Centered Education	- Design learning environments that integrate ethics, sustainability, and technological innovation as core components. - Transform classrooms into "living laboratories" (e.g., Sustainable Classroom) to apply STEAM-based, project-oriented pedagogies to real-world challenges. - Train educators to act as ethical mediators and facilitators of values-based learning. - Integrate critical thinking, ethical reasoning, and sustainability literacy across curricula. - Install infrastructure that models sustainable practices, including renewable energy systems, water reuse mechanisms, and digital monitoring tools.
2. Collaborative and Transdisciplinary Institutional Innovation	- Build adaptive governance structures that promote ethically grounded experimentation. - Forge partnerships between academia, government, industry, and civil society. - Engage societal stakeholders directly in curriculum co-design to ensure contextual relevance. - Establish cross-sector alliances and secure sustainable funding to scale innovative initiatives.
3. Smart Learning Environments and Ethical Technology Integration	- Deploy AI, IoT, and advanced digital tools through challenge-based learning approaches. - Promote responsible digital citizenship and strengthen critical digital literacy among students and faculty. - Apply technology strategically to enhance accessibility, equity, and energy efficiency in learning environments. - Establish prototyping laboratories to develop innovations that deliver social value and support sustainability goals.

Note. These guidelines are derived from the empirical validation of the model through international benchmarking and align with its five theoretical dimensions.

They operationalize the model's principles and pillars into context-sensitive guidelines that provide higher education leaders, educators, and policymakers with targeted actions adaptable to diverse socio-institutional contexts. At the same time, they ensure alignment with the human-centered, sustainability-oriented vision of Society 5.0. Informed by empirical evidence and international benchmarking, these strategic recommendations offer higher education systems a structured pathway toward ethically grounded and sustainability-driven transformation.

6. Conclusions and Recommendations

This research developed and validated a conceptual model for the ethical and sustainable integration of AI in higher education, aligned with the human-centered principles of Society 5.0. Based on qualitative analysis using the constant comparative method and abductive reasoning, the study identified three interrelated pillars: ethical and pedagogical reconfiguration, integration of technology and sustainability, and institutional adaptability. Based on expert interviews and a case study of the Sustainable Classroom, the model illustrates how the alignment of pedagogical practices, institutional culture, and ethical governance of technology can drive educational transformation based on civic responsibility and sustainability. By offering a robust and replicable theoretical framework, the model advances global educational priorities and reinforces the role of higher education in fostering just, inclusive, and sustainable societies in the digital age. To support its implementation and ongoing theoretical refinement, the following strategic recommendations are proposed:

1. Advance Interdisciplinary Research on AI and Sustainability in Education: Promote longitudinal, comparative, and participatory action research that explores the intersection of AI, ethics, and sustainability across diverse educational settings. This research agenda should assess the long-term impact of ethical AI integration on learning outcomes, equity, and institutional transformation.
2. Apply and Adapt the Model Across Diverse Educational Contexts: Extend the model's application beyond engineering education and Global North settings. Pilot its implementation in vocational training, non-formal education, and higher education institutions in the Global South, incorporating cultural, economic, and infrastructural specificities.
3. Promote Governance Frameworks for Ethical AI Integration: Establish institutional policies that guarantee transparency, accountability, and ethical deliberation in AI deployment. These frameworks should include digital literacy programs, risk assessment mechanisms, and participatory governance involving faculty and students.
4. Cultivate Institutional Cultures that Support Ethical Innovation: Redesign governance structures to encourage interdisciplinary collaboration, shared leadership, and institutional experimentation. Mission statements should explicitly align with sustainability, inclusion, and digital ethics as guiding principles.
5. Embed Ethics and Sustainability into Curricula and Teacher Education: Reform academic programs to position ethics, sustainability, and critical digital literacy as foundational competencies. Teacher education must prepare educators to serve as ethical mediators and facilitators of value-driven, project-based learning. This agenda advances Sustainable Development Goals, particularly SDG 4 (Quality Education) and SDG 16 (Peace, Justice, and Strong Institutions).
6. Scale Living Laboratories and Educational Prototypes: Replicate and adapt initiatives such as the Sustainable Classroom to create innovative ecosystems at the intersection of ethics, technology, and sustainability. These living laboratories should inform institutional strategies, guide infrastructure investments, and inspire curricular redesign.
7. Balance Model Dimensions for Context-Sensitive Implementation: Ensure that institutional strategies integrate the five dimensions of the model—education as a common good, STEAM, AI ethics, human capabilities and sustainability, and educational innovation. Effective implementation depends on each context's regulations, institutional capacity, and sociocultural priorities. Yet, successful cases demonstrate that strengthening interdisciplinarity, ethical governance, and socio-ecological competencies enables alignment with the human-centered vision of Society 5.0.

Together, these strategic directions reinforce the ethical dimension of digital transformation in higher education and position institutions as societal catalysts—capable of shaping just, inclusive, and sustainable futures through value-driven innovation. Education for Society 5.0 emerges not only as a technological requirement but also as a civic and ecological imperative.

This study presents a theoretically grounded and empirically validated educational model that integrates AI ethics, STEAM pedagogies, sustainability, and human capabilities, fully aligned with the human–technology–society symbiosis central to Society 5.0. Validation through expert perspectives ensured conceptual consistency and practical applicability; however, the scope was limited by the purposive selection of five specialists recognized for their expertise in AI ethics, STEAM education, sustainability, and innovation in higher education. This targeted composition enhanced analytical depth while constraining diversity of perspectives and comparative breadth.

Future research should expand the participant base to include a wider range of disciplines, geographic regions—particularly from the Global South—and professional sectors beyond academia. Such an expansion will strengthen comparative analyses, broaden theoretical and practical insights, and increase the model's adaptability across diverse socio-institutional realities. This broader scope consolidates its relevance as a globally applicable reference for promoting ethical, sustainable, and innovation-oriented higher education within the framework of Society 5.0.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
ESD	Education for Sustainable Development

ICT	Information and Communication Technologies
STEAM	Science, Technology, Engineering, Arts, and Mathematics
UNESCO	United Nations Educational, Scientific and Cultural Organization
HEIs	Higher Education Institutions
OECD	Organization for Economic Co-operation and Development
UPIEM	Unidad Profesional Interdisciplinaria de Energía y Movilidad

Appendix A

Purpose: To explore expert perspectives on the challenges, opportunities, and institutional conditions necessary for the ethical integration of Artificial Intelligence (AI), STEAM pedagogies, and sustainability principles into higher education models, within the context of digital transformation and the Society 5.0 vision.

Block 1: Ethics of Artificial Intelligence in Higher Education

Linked Objective: Explore the challenges associated with the ethical teaching of AI and its integration into educational settings.

1. How would you describe the current state of ethics education in artificial intelligence at your institution or academic environment?
2. What do you consider to be the main challenges in incorporating an ethical perspective into the use and development of AI in higher education?
3. Which approaches or strategies do you find most effective for addressing the ethical dimension of AI in university education?
4. Based on your professional experience, have you observed tensions between technological innovation and ethical reflection?

Block 2: STEAM Approaches Oriented Toward Sustainability

Linked Objective: Investigate the potential of STEAM pedagogies to promote sustainable and transformative competencies.

5. What value do you see in STEAM approaches as tools to address current social and environmental challenges?
6. What elements do you consider essential for a STEAM pedagogy to be genuinely aligned with sustainability?
7. Have you encountered successful educational experiences that coherently integrate science, technology, arts, and sustainability? What lessons would you highlight from those cases?

Block 3: Institutional Conditions for Educational Transformation

Linked Objective: Identify institutional barriers and enablers for the implementation of ethical and sustainable educational models in the context of technological transformation.

8. From your perspective, what institutional conditions are necessary to transition toward more ethical, sustainable, and human-centered educational models?
9. What role do institutional policies, regulatory frameworks, or academic leadership play in these processes?
10. What forms of resistance have you identified within the educational system regarding such transformations?

Interview Closure:

11. Would you like to add any reflections, experiences, or recommendations that have not yet been addressed and that you consider relevant for this study?

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