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Digital Environmental Literacy for Sustainable Development: Integrating Artificial Intelligence, Electronic Engineering, and English Studies

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ABSTRACT

The escalating pace of environmental degradation, coupled with the equally rapid diffusion of digital technologies, has created an urgent need for a form of literacy that binds ecological awareness to technological fluency. This paper argues that digital environmental literacy (DEL) cannot be cultivated within a single discipline; rather, it emerges at the intersection of artificial intelligence (AI), electronic engineering, and English studies. Drawing on an integrative review of recent scholarship across these three fields, the paper develops a conceptual framework in which AI supplies the analytical and predictive tools for interpreting environmental data, electronic engineering supplies the sensing and communication infrastructure through which that data is captured, and English studies understood broadly as language pedagogy, discourse analysis, and ecolinguistics supplies the communicative competence needed to translate technical findings into public understanding and civic action. The paper reviews evidence from environmental education, AI-integrated engineering curricula, green and sustainable electronics, and eco-critical approaches to English language teaching, and it proposes a three-layer model technological, cognitive, and communicative for embedding DEL into higher-education curricula. Implications for curriculum designers, engineering educators, and language teachers are discussed, along with limitations and directions for future empirical research.

KEYWORDS: Digital environmental literacy, sustainable development, artificial intelligence, electronic engineering, English language teaching, ecolinguistics, interdisciplinary education

1. INTRODUCTION

The Environmental crises rarely announce themselves through a single discipline. Rising sea levels are, at once, a physical phenomenon, a data-engineering problem, and a matter of how societies talk about risk. Yet higher education continues to sort students into departments that treat these dimensions as separate concerns. Engineers are trained to build sensors; computer scientists are trained to model data; language teachers are trained to cultivate communicative competence. Rarely are the three brought into conversation with one another, even though the sustainability challenges of the twenty-first century demand exactly that kind of convergence.

Digital environmental literacy (DEL) is proposed here as the competency that sits at this convergence. It can be defined, provisionally, as the capacity to use digital tools to understand, monitor, and communicate environmental conditions in ways that support sustainable decision-making. This definition deliberately widens the scope of older, narrower notions of environmental literacy, which tended to emphasize ecological knowledge and pro-environmental attitudes without attending closely to the technological mediation of that knowledge in the current era [1]. It also widens conventional accounts of digital literacy, which have historically centered on information retrieval and media evaluation rather than on the specific technical pipeline sensing, computation, and communication through which environmental information travels from the physical world to the public sphere [2], [3].

This paper takes the position that three fields, each already the subject of a substantial and growing literature, need to be read together rather than separately if DEL is to be operationalized in curricula. Artificial intelligence contributes the analytical capacity to detect patterns in environmental data that would otherwise remain invisible to the human eye from anomaly detection in air-quality readings to predictive modeling of deforestation [4]. Electronic engineering, particularly through the Internet of Things (IoT) and green electronics, contributes the physical infrastructure of sensors, low-power circuits, and wireless networks that make continuous environmental observation possible in the first place [5], [6]. English studies, understood here to include English for Specific Purposes (ESP), applied linguistics, and ecolinguistics, contributes the communicative and rhetorical competencies through which technical findings are translated into narratives that can inform policy, mobilize communities, and shape public opinion [7].

The remainder of the paper proceeds as follows. Sections 1.1 through 1.4 review the relevant literature in each of the three domains and at their points of overlap. Section 2 describes the review methodology and develops a three-layer conceptual framework — technological, cognitive, and communicative — for integrating them. Section 3 translates the framework into a curriculum-mapping application and discusses its implications, tensions, and limitations. Section 4 concludes the paper.

Figure 1 previews the conceptual territory that this paper covers, depicting digital environmental literacy as the region of overlap among the three parent disciplines rather than as a property belonging to any one of them.

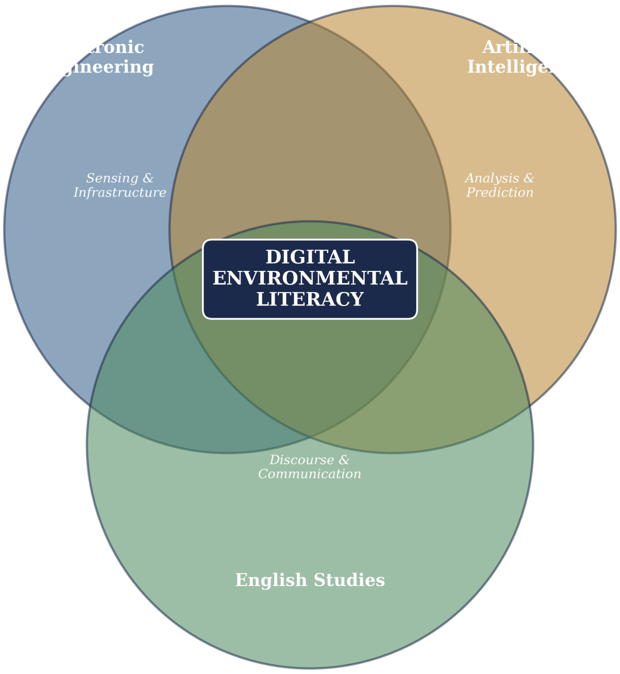

Figure 1. Convergence of three disciplinary domains in digital environmental literacy.

1.1 Environmental Literacy in the Digital Age

Environmental literacy has traditionally been conceptualized around four components: ecological knowledge, cognitive skills, attitudes, and behavior [1]. Recent scholarship, however, has increasingly recognized that digital tools reshape each of these components rather than simply supplementing them. A systematic review of digital tools used to foster sustainability awareness in classrooms found that virtual and augmented reality applications, along with climate-themed simulations, were associated with measurable increases in students' concern for planetary sustainability, particularly when the tools allowed learners to manipulate variables and observe consequences directly rather than reading about them [8]. Similarly, gamified applications introduced to primary-school children have been shown to raise both ecological awareness and digital literacy simultaneously, suggesting that the two competencies reinforce one another when taught together rather than in isolation [9].

Augmented reality in particular has drawn attention as a bridge between abstract environmental concepts and lived experience. Koparan [10] reported that secondary students exposed to augmented-reality texts about environmental issues demonstrated more favorable attitudes toward sustainable development than peers who engaged with conventional print materials, an effect the author attributed to the immersive quality of AR representations. Web 2.0-based digital games have produced comparable results, with Arslan and Karakuş [11] documenting improved retention of environmental content when instruction was delivered through interactive, game-based platforms rather than lecture formats. Taken together, this literature suggests that digital mediation does not merely deliver environmental content more efficiently; it changes how learners relate to that content cognitively and affectively.

At the level of teacher preparation, Pontes-Pedrajas and Varo-Martínez [12] demonstrated that concept-mapping tools embedded in digital environments helped pre-service science teachers organize environmental knowledge more coherently than paper-based mapping, a finding with direct relevance to how future educators will need to structure DEL curricula. More broadly, Acosta Castellanos and Queiruga-Dios [13] traced the historical shift from environmental education toward education for sustainable development in higher education, noting that this shift has been accompanied by a growing expectation that graduates, regardless of discipline, leave university with some digital competence for interpreting environmental data. Chaker [14], introducing a special issue on digital technologies for environmental education, argued that such technologies now function as infrastructural conditions for environmental citizenship rather than optional enrichments, directly tying digital fluency to the eco-citizenship goals embedded in the United Nations' Sustainable Development Goals [15].

1.2 Artificial Intelligence in Sustainability-Oriented Education

A parallel body of work has examined how artificial intelligence itself is reshaping education, both as a subject of instruction and as a pedagogical tool. Zawacki-Richter et al. [16], in a widely cited systematic review, found that AI applications in higher education cluster around four categories: profiling and prediction, assessment and evaluation, adaptive systems, and intelligent tutoring, but noted that pedagogical and ethical perspectives were comparatively underrepresented in the literature relative to computer-science perspectives. This imbalance is significant for DEL, because environmental applications of AI raise precisely the ethical questions data ownership, algorithmic bias in environmental risk models, energy costs of training large models that a purely technical treatment of AI risks overlooking [17], [18].

Within engineering education specifically, a comprehensive bibliometric review of generative AI applications found rapid growth in the use of AI tools for curriculum personalization and automated feedback, alongside persistent gaps in guidance on responsible and sustainable use [19]. Nakad et al. [20] reviewed methods for assessing how thoroughly sustainability content has been integrated into engineering curricula and concluded that most existing assessment instruments still treat sustainability as an add-on module rather than as a thread woven through core technical coursework, including AI and electronics courses. Kar et al. [4], reviewing the broader literature on AI and sustainability outside education specifically, catalogued applications ranging from precision agriculture to climate modeling, while cautioning that AI's own carbon footprint complicates any simple narrative in which artificial intelligence is treated as an unambiguous force for environmental good. This tension between AI as a diagnostic tool for sustainability and AI as a consumer of energy resources is a recurring theme that any DEL curriculum must address explicitly rather than gloss over.

1.3 Electronic Engineering, Green IoT, and Environmental Sensing

The physical layer of digital environmental literacy rests on developments in electronic engineering, particularly the Internet of Things. Francos et al. [21] conducted a systematic review of IoT applications in environmental monitoring and found extensive use of low-cost sensor networks for tracking air quality, water quality, and soil conditions, with the authors emphasizing that the scalability of these networks depends heavily on advances in low-power circuit design. Sisinni et al. [22] similarly documented how industrial IoT architectures are being adapted for environmental applications, though they noted persistent challenges in interoperability between sensor platforms developed by different manufacturers, a technical fragmentation problem with direct pedagogical implications for students who must learn to work across incompatible systems.

The concept of green IoT the effort to reduce the energy footprint of the sensing infrastructure itself has become central to this literature. Alsharif et al. [5] reviewed strategies for energy-efficient machine-to-machine communication and eco-sustainable wireless sensor networks, arguing that without such efficiency gains, the proliferation of environmental sensors risks becoming a net contributor to the very energy consumption it is meant to help reduce. Flexible and printed electronics have emerged as one promising avenue for addressing this tension: Scandurra et al. [6] reviewed materials and design approaches for flexible IoT devices, highlighting the importance of energy-harvesting techniques that allow sensors to operate with minimal or no battery replacement, thereby reducing electronic waste. Salam [23] situated these technical developments within a broader argument for community-oriented IoT design, contending that sustainable IoT deployment must be planned in dialogue with the communities whose environments are being monitored rather than imposed from outside. This community dimension is precisely where electronic engineering intersects with the communicative competencies developed in English studies, since community dialogue about sensor deployment, data ownership, and interpretation of results is fundamentally a language-mediated process.

1.4 English Studies, Ecolinguistics, and Environmental Communication

The third strand of the literature concerns the role of language education in cultivating environmental awareness. Ecolinguistics, as developed by Stibbe [7], examines how the stories embedded in everyday language metaphors of growth, framings of nature as resource, narratives of endless consumption shape environmental behavior at a scale that technical interventions alone cannot reach. This perspective has begun to filter into English language teaching (ELT) research. Hosseini et al. [24] examined an ecolinguistically informed task embedded within a computer-assisted language learning (CALL) environment and found that EFL learners exposed to the task showed measurable gains in ecological sustainability perspectives alongside their language development, suggesting that environmental content need not be treated as a distraction from language learning objectives but can instead reinforce them.

English for Specific Purposes (ESP) offers a particularly relevant frame for DEL, since its foundational premise is that language instruction should be designed around the genres, vocabulary, and communicative tasks that learners will actually need in their professional or academic domains [25], [26]. For students in engineering or environmental science programs, this implies a curriculum built around the genres of technical reporting, data visualization commentary, and public-facing science communication, rather than generic English instruction disconnected from their disciplinary futures. Wang et al. [27] extended this line of inquiry by examining chatbot-assisted language learning, finding that AI-driven conversational agents could provide learners with low-stakes practice in producing exactly these kinds of specialized, discipline-linked discourse, which points toward a natural convergence between the AI and English-studies strands of DEL.

Taken as a whole, the literature reviewed here supports three claims. First, environmental literacy is increasingly inseparable from digital literacy, to the point where treating them as distinct competencies risks producing incomplete curricula [8], [9]. Second, the AI and engineering literatures, while technically sophisticated, tend to underspecify the communicative and ethical dimensions of their own findings [4], [16]. Third, the language-education literature has begun to develop tools for exactly this communicative gap but has done so largely in isolation from the technical fields whose outputs most urgently need translating [7], [24]. This fragmentation motivates the integrative framework proposed in the next section.

Table 1 summarizes the studies reviewed above according to the disciplinary domain they occupy, their methodological approach, and their principal contribution to the argument developed in this paper.

Table 1. Summary of Reviewed Literature Across the Three Domains of Digital Environmental Literacy

Domain	**Source**	**Approach**	**Principal contribution**
Environmental & digital literacy	Hajj-Hassan et al. [8]	PRISMA systematic review	VR/AR and climate simulations raise sustainability awareness
Environmental & digital literacy	Ricoy & Sánchez-Martínez [9]	Quasi-experimental, primary schools	Gamification jointly builds ecological and digital literacy
Environmental & digital literacy	Koparan [10]	Experimental, secondary students	AR texts improve attitudes toward sustainable development
Environmental & digital literacy	Chaker [14]	Editorial synthesis	Frames digital technology as infrastructural to eco-citizenship
Artificial intelligence	Zawacki-Richter et al. [16]	Systematic review, higher education	AI applications cluster around prediction, assessment, tutoring; pedagogy under-represented
Artificial intelligence	Kar et al. [4]	Systematic literature review	Documents AI's sustainability applications and its own energy costs
Artificial intelligence	Bahroun et al. [19]	Bibliometric & content analysis	Rapid growth of generative AI in curricula, with governance gaps
Electronic engineering	Alsharif et al. [5]	Technical review	Energy-efficient strategies for green IoT sensor networks
Electronic engineering	Scandurra et al. [6]	Technical review	Flexible, energy-harvesting electronics reduce e-waste in IoT

Domain	Source	Approach	Principal contribution
Electronic engineering	Francos et al. [21]	Systematic literature review	Maps IoT sensor applications across environmental monitoring domains
English studies	Stibbe [7]	Theoretical / ecolinguistic analysis	Everyday language framings shape environmental behavior
English studies	Hosseini et al. [24]	Quasi-experimental, EFL learners	Ecolinguistically informed CALL tasks build language and sustainability outcomes together
English studies	Wang et al. [27]	Empirical, chatbot-assisted learning	AI conversational agents support discipline-specific discourse practice

2. METHODS

2.1 Literature Search and Selection

This paper adopts an integrative, conceptual-review methodology rather than an empirical one. Sources were identified through targeted searches of recent literature in environmental education, AI in higher education, green electronics and IoT, and English/applied-linguistics journals, with an emphasis on studies published within the last five years and on works that explicitly bridge two or more of the three domains. This approach follows the logic of conceptual synthesis common in interdisciplinary education research, where the goal is not to test a hypothesis statistically but to identify convergences and tensions across literatures that have developed largely independently of one another [13].

2.2 Conceptual Framework Development

Building on the literature reviewed above, this paper proposes that DEL be understood as composed of three interdependent layers, corresponding roughly to the three disciplines under discussion. Figure 2 renders this model schematically, showing the technological layer as the foundation on which the cognitive layer builds, with the communicative layer translating the output of both layers into forms usable outside the laboratory or engineering workshop, and a feedback channel returning community response back down to the technological layer to inform sensor redesign and new research questions.

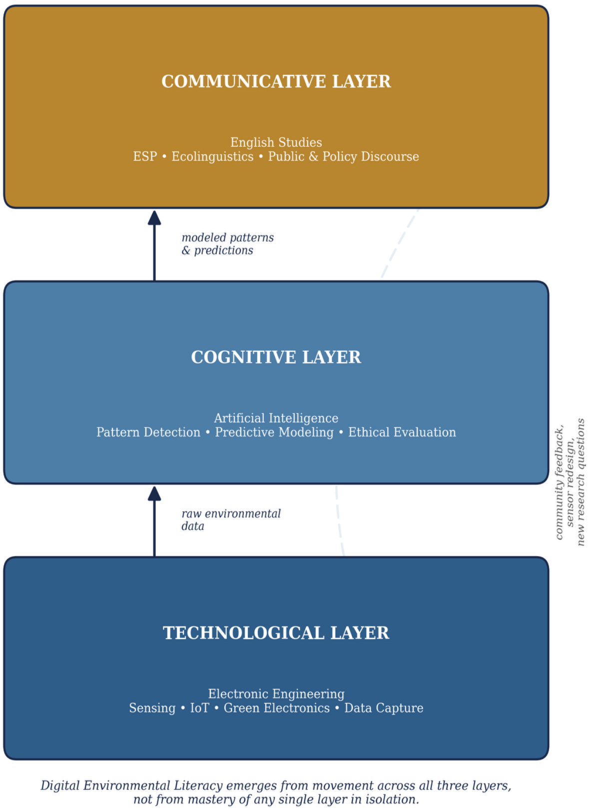

Figure 2. A three-layer model of digital environmental literacy, showing the upward flow of data and analysis and the downward feedback loop of community response.

The technological layer corresponds to electronic engineering and encompasses the sensing, transmission, and storage infrastructure through which environmental data is captured. Competence at this layer includes a working understanding of how sensor networks are designed, how energy constraints shape sensor deployment decisions, and how considerations of green electronics energy harvesting, low-power design, e-waste reduction bear on the sustainability of the monitoring infrastructure itself [5], [6]. A curriculum that develops this layer without the other two risks producing engineers who can build sensor networks but cannot interpret or communicate what those networks reveal.

The cognitive layer corresponds to artificial intelligence and encompasses the analytical processes through which raw environmental data is transformed into interpretable patterns, predictions, and risk assessments. Competence at this layer includes not only technical skills in data processing and model building but also critical awareness of the limitations of AI systems, including bias in training data, the opacity of some model outputs, and the energy costs of computation [4], [17]. A curriculum that develops this layer in isolation risks producing analysts who can generate sophisticated models without appreciating either the provenance of their sensor data or the rhetorical work required to make their findings actionable for non-specialist audiences.

The communicative layer corresponds to English studies and encompasses the discourse practices through which technical findings are rendered meaningful to policymakers, communities, and the general public. Competence at this layer draws on ESP approaches to genre and register [25], on ecolinguistic sensitivity to the framings embedded in environmental language [7], and on emerging AI-assisted language-learning tools that can provide learners with practice in producing discipline-specific discourse [27]. A curriculum that develops this layer in isolation, finally, risks producing communicators who are fluent in the rhetoric of sustainability but disconnected from the technical realities their communication is meant to represent.

The central claim of this framework is not that each layer should be taught by a different department in sequence, but that the three layers should be developed concurrently, through shared projects that require students to move across them. A student monitoring local air quality, for instance, would need to select and justify sensor placement (technological layer), apply a model to detect anomalous readings (cognitive layer), and draft a public-facing summary of the findings for a municipal council (communicative layer). It is in the movement between layers, rather than in any single layer, that digital environmental literacy is most plausibly built.

3. RESULTS AND DISCUSSION

3.1 Curriculum Mapping

Translating the three-layer framework into curriculum design suggests a project-based structure organized around real environmental problems local to the institution a nearby river, an urban heat island, a regional deforestation concern. Electronic engineering students would be responsible for the design and deployment of low-cost sensing hardware, ideally incorporating green-design principles such as energy harvesting [6]. Students with an AI or data-science orientation would be responsible for building interpretable models of the resulting data streams, with explicit instruction on the ethical and environmental costs of the computational choices they make [4]. Students in English or communication tracks would be responsible for producing the public-facing outputs reports, infographic-style summaries, oral presentations to community stakeholders drawing on ESP genre analysis and ecolinguistic awareness of framing effects [7], [25]. Assessment, in this model, would evaluate not only discipline-specific competence but also the coherence of the finished product across all three layers, which requires collaborative rubrics co-designed by faculty from engineering, computing, and language departments.

Table 2 operationalizes this proposal by mapping each layer of the conceptual framework onto illustrative learning outcomes, sample tasks, and assessment evidence that curriculum committees could adapt to their local context.

Table 2. Curriculum Mapping for a Project-Based Digital Environmental Literacy Course

Layer	Lead discipline	Illustrative learning outcome	Sample assessment evidence
Technological	Electronic engineering	Design and deploy a low-power environmental sensor node	Working sensor prototype with documented energy budget
Cognitive	Artificial intelligence / data science	Build and critique a predictive model of local environmental data	Model report including a stated limitations and bias section
Communicative	English studies (ESP / ecolinguistics)	Produce a public-facing report that avoids misleading framings of risk	Community report reviewed against an ecolinguistic framing checklist
Cross-layer	Joint / team-taught	Justify design choices across technical, analytical, and rhetorical dimensions	Oral defense before a panel drawn from all three departments

3.2 Discussion

Several tensions emerge from this integrative review that deserve explicit acknowledgment rather than resolution by fiat. The first concerns the energy paradox already noted in the AI and green-IoT literatures: the very technologies proposed here as tools for environmental monitoring and analysis carry their own environmental costs, from the electricity consumed by model training to the electronic waste generated by sensor hardware at end of life [4], [5]. A DEL curriculum that fails to make this paradox visible to students risks reproducing an uncritical techno-optimism that the ecolinguistics literature specifically warns against [7].

A second tension concerns institutional structure. Universities are organized around departments that hold budgets, hire faculty, and award degrees along disciplinary lines, and genuine cross-layer projects of the kind proposed in Section 3.1 require administrative arrangements joint appointments, shared course credit, team-taught modules that many institutions are not yet configured to support. The literature on sustainability integration in engineering curricula documents a comparable structural inertia, noting that sustainability content is more often added to existing courses than allowed to reshape how those courses are organized in the first place [20].

A third tension concerns equity of access. Much of the digital-tools literature reviewed in Section 1.1 draws on well-resourced classrooms with access to augmented reality, dedicated computing infrastructure, and reliable internet connectivity [8], [10]. Institutions in lower-resource settings, including many in the Global South, may find the technological layer of the proposed framework difficult to implement at the scale envisioned in this literature, even as they arguably stand to benefit most from low-cost, community-oriented IoT approaches of the kind Salam [23] describes. Curriculum designers adapting this framework should therefore treat the specific tools mentioned here as illustrative rather than prescriptive, and should prioritize low-cost, open-source alternatives where possible.

3.3 Limitations and Future Research

This paper is conceptual rather than empirical, and its three-layer framework has not yet been tested through classroom implementation or measured against learning outcomes. Future research should pursue quasi-experimental or mixed-methods studies that compare student outcomes in integrated DEL courses against outcomes in traditional, single-discipline courses covering the same content. Longitudinal studies would also be valuable for assessing whether the communicative competencies developed through this model persist into students' subsequent professional practice, an outcome that the ESP literature suggests may depend heavily on continued authentic use rather than one-time exposure [26]. Finally, further work is needed on the energy and equity tensions identified in Section 3.2, ideally through case studies of DEL implementation in resource-constrained settings, where the trade-offs between technological ambition and sustainable, accessible design are likely to be most visible and most instructive.

4. CONCLUSION

Digital environmental literacy, as this paper has argued, is not a single skill that can be taught within one department, nor a simple sum of digital literacy plus environmental literacy. It is better understood as a competency that lives in the connective tissue between artificial intelligence, electronic engineering, and English studies between the sensors that gather environmental data, the algorithms that make sense of it, and the language through which that sense is shared with the people who must act on it. The literature reviewed here shows real progress within each of these three fields taken separately, but comparatively little sustained attempt to bring them together in a single curricular vision. The three-layer framework proposed in this paper is offered as one such attempt: not a finished blueprint, but a starting point for the kind of interdisciplinary experimentation that the scale of contemporary environmental challenges seems increasingly to demand.

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