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Responsive Digital Pedagogy and the Social Sustainability of Digital Education: A Relational and Ecological Framework

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Abstract

Digital transformation has intensified questions about the sustainability of educational systems, yet sustainable digital education is often discussed in terms of technological capacity, access, efficiency and scalability. This conceptual article develops a distinct conceptualisation of responsive digital pedagogy (RDP) for the social sustainability of digital education. Drawing on scholarship on social sustainability, digital education, relational pedagogy, student agency and sociotechnical educational infrastructures, and informed by peer-reviewed research on responsive and democratic pedagogies, the article distinguishes sustainable educational provision from sustainable educational experience. It proposes four interconnected dimensions: relational sustainability, concerning recognition and pedagogical response; temporal sustainability, concerning attention and differentiated rhythms; participatory sustainability, concerning agency, plurality and meaningful influence; and infrastructural sustainability, concerning the technological and institutional conditions that organise educational possibility. These dimensions are examined through tensions between efficiency and attention, visibility and meaningful participation, scalability and relational density, and predictability and pedagogical openness. Socially sustainable digital education is therefore defined as the capacity of a digitally mediated educational ecology to maintain over time the relational, temporal, participatory and infrastructural conditions through which meaningful educational participation remains possible. The framework is presented as an analytical proposition for further empirical refinement rather than as a validated measurement model.

Keywords: responsive digital pedagogy; social sustainability; digital education; pedagogical ecologies; student agency; relational pedagogy; higher education

1. Introduction: The Overlooked Social Sustainability of Digital Education

Digital transformation has become inseparable from contemporary debates on educational sustainability. Online and hybrid provision, platform-based learning environments, data-intensive infrastructures and, increasingly, generative artificial intelligence are reshaping how education is organised, accessed and experienced. These developments have expanded possibilities for flexibility, participation and access while also intensifying questions concerning educational quality, equity, institutional capacity and the social consequences of technologically mediated learning.

At the same time, social sustainability remains comparatively underdeveloped as a concept in educational research. A recent systematic review of 98 studies found that only 38 provided an explicit definition of social sustainability, with existing conceptualisations distributed across concerns such as equity and belonging, diversity, quality of life and basic

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needs [1]. This conceptual ambiguity is significant because educational sustainability may refer to very different objects: education's contribution to sustainable societies, the organisational continuity of educational institutions, or the capacity of educational environments themselves to sustain socially and pedagogically meaningful forms of learning.

A parallel gap is visible in scholarship on digital transformation. Research on the relationship between digital technologies and sustainability has devoted considerably greater attention to economic and environmental dimensions than to their social consequences. Szalkowski and Johansen's [2] systematic review, for example, concludes that the societal implications of digital technologies remain comparatively under-researched despite increasing attention to questions of inclusion, inequality, health and working conditions. More recent work similarly calls for approaches to digital transformation that take social sustainability into account rather than treating digitalisation primarily as a technical or organisational process.

Within educational technology research, sustainability is also beginning to be framed more broadly. Daniela [3], for instance, distinguishes pedagogical, technological and socio-ethical sustainability in technology-enhanced learning, arguing that digital integration raises questions not only of technical durability but also of equity, cognitive wellbeing and pedagogical quality. Such work marks an important shift away from understandings of sustainability centred exclusively on infrastructure or technological continuity.

However, a further conceptual problem remains insufficiently developed: how the pedagogical conditions of digitally mediated education themselves become socially sustainable. A learning environment may be technologically reliable, institutionally viable and scalable while still weakening the conditions through which learners can become meaningfully present, exercise agency, receive recognition, encounter difference and participate in shared processes of knowledge construction. Persistent access does not necessarily produce presence; interaction does not necessarily constitute participation; visibility does not necessarily entail recognition; and technological connectivity does not in itself generate pedagogical relationships. These oppositions are not presented as new in themselves; they build on long-established distinctions in the presence, participation and community-of-inquiry studies. Their contribution here lies in being drawn together within a single sustainability-oriented, ecological framework—developed in Sections 3–6—that connects them to four interdependent dimensions and to explicit implications for pedagogical and institutional design, rather than treating them as isolated observations.

The proposed novelty is therefore a conditional, longitudinal diagnostic claim: a digital arrangement is not socially sustainable simply because it permits valued interactions at one moment; it must retain demonstrable capacity to renew pedagogical recognition, plural time and consequential learner influence when enrolment, technologies, labour or governance arrangements change. The framework links organisational pressures to specific mechanisms of erosion, feasible forms of repair and evidence that could contradict its expectations. This claim goes beyond re-labelling access/presence distinctions while remaining a theoretical proposition awaiting empirical testing.

This article addresses this problem by developing a distinct conceptualisation of responsive digital pedagogy (RDP) for socially sustainable digital education. RDP refers here not simply to teacher availability, rapid feedback or technological adaptation but to the capacity of educational environments to interpret and respond to learners, differences and emerging situations while sustaining the relational, temporal, technological and institutional conditions through which meaningful participation becomes possible.

The argument draws together scholarship on social sustainability, digital education, relational and responsive pedagogy, student agency and sociotechnical approaches to educational infrastructures. As a conceptual article, it develops its contribution through

an integrative synthesis of these studies rather than through the presentation of a new empirical study.

Conceptual Approach

This article is an integrative theoretical synthesis and conceptual model-building exercise, not a systematic or scoping review. Its purpose is to organise and critically relate established constructs, rather than estimate prevalence, pool effects or claim exhaustive retrieval. The source corpus was assembled purposively across five fields: social sustainability in education, digital education, relational pedagogy, learner agency and sociotechnical studies of educational infrastructures. The synthesis began from the literature previously engaged with in the author's research, including AECED-related work, and was complemented by targeted, topic-oriented searches for recent reviews and research contributions. These exploratory searches were guided by conceptual relevance rather than a predefined search-and-screening protocol. Foundational theoretical work was retained when needed to specify conceptual boundaries. Source relevance, conceptual explanatory value and coverage of both pedagogical experience and institutional conditions informed selection. A reproducible database search, fixed date window, screening count and formal inclusion/exclusion log were not recorded; consequently, none is claimed retrospectively. This is a methodological limitation, and the traceability table identifies conceptual anchors rather than a systematic-review selection pathway.

This conceptual development is also informed by a strand of peer-reviewed research conducted within the Horizon Europe project AECED—Transforming Education for Democracy through Aesthetic and Embodied Learning, Responsive Pedagogies and Democracy-as-Becoming. Within this programme, published studies have examined teachers' professional learning for democratic practice through aesthetic and embodied pedagogies [4], democracy-as-becoming across aesthetic, embodied and digital pedagogical ecologies [5], democratic risk and professional agency [6], and institutional conditions for democratic innovation [7]. The present article does not reproduce those frameworks; it extends this research trajectory into a distinct conceptual problem: the social sustainability of digitally mediated education.

Use of generative AI during manuscript preparation: OpenAI ChatGPT was used to assist with drafting and revising explanatory passages, organising conceptual comparisons and tables, and preparing responses to peer review. These outputs were critically reviewed and edited by the author. The conceptual synthesis and selection of the supporting literature remain the author's responsibility; AI-generated content is not treated as empirical evidence or independent validation of the framework.

Three gaps therefore converge. First, although social sustainability is increasingly discussed in educational research, its pedagogical meaning remains conceptually fragmented. Second, the social consequences of digital transformation remain less developed than its economic and environmental dimensions. Third, emerging work on pedagogical and socio-ethical sustainability has not yet provided an integrated framework for examining how digitally mediated educational environments sustain recognition, attention, agency, differentiated temporalities and meaningful participation.

Table 1 traces each dimension and tension to its principal source constructs and representative citations to make explicit how the synthesis in the Conceptual Approach Section informed the four-dimensional structure proposed below.

Table 1. Mapping of the four proposed dimensions and four tensions to their principal source constructs and representative citations.

Dimension/Tension	Key Source Constructs	Representative Citations
Relational sustainability	Relational pedagogy (care, culture, community); social and teaching presence; voice, recognition and epistemic justice	Campbell & Coker [8]; Noddings [9]; Tronto [10]; Garrison, Anderson & Archer [11]; Couldry [12]; Fraser [13]; Fricker [14]
Temporal sustainability	Social acceleration and resonance; the ecology of attention; digital temporality as a domain of agency	Rosa [15]; Citton [16]; Stenalt [17]
Participatory sustainability	Digital student agency as relational, cultural and technological; ecological approaches to agency	Stenalt [17]; Priestley, Biesta & Robinson [18]
Infrastructural sustainability	The platform society; critical data studies; datafication of universities; postdigital critique	van Dijck, Poell & de Waal [19]; Williamson [20]; Komljenovic, Sellar & Birch [21]; Knox [22]
Efficiency/attention	Digital distraction and attentional conditions	Martin et al. [23]
Visibility/participation	Behavioural bias in learning-analytics measures of engagement	Bergdahl et al. [24]
Scalability/relational density	Social sustainability and transformation in higher education	Wolff & Ehrström [25]
Predictability/openness	Democratic risk and professional agency under institutional constraint (AECED)	[6]

The analytic derivation followed three explicit conceptual decisions. First, recurring constructs were grouped by the primary object at stake: recognition and pedagogical uptake (relational), experienced time and opportunities for reconsideration (temporal), consequential learner influence (participatory), and the institutional–technical arrangements that make these practices viable (infrastructural). Second, a category was retained only when it raised a distinct diagnostic question and could plausibly erode or be regenerated under changing conditions. Third, the four tensions were treated as cross-cutting organisational pressures, not as the source of four parallel dimensions. Four dimensions are proposed as the most parsimonious configuration meeting these criteria, not as a deductively necessary or empirically exhaustive number. Overlaps are expected but must be identified rather than concealed.

To address this intersection, the article proposes four interconnected dimensions of socially sustainable digital education: relational sustainability, concerned with recognition and pedagogical response; temporal sustainability, concerned with attention and differentiated rhythms; participatory sustainability, concerned with agency, plurality and meaningful influence; and infrastructural sustainability, concerned with the sociotechnical and institutional arrangements through which participation, visibility and authority are organised.

Together, these dimensions shift the sustainability question from whether digital educational systems can simply continue to operate towards a different question:

What must digital education be capable of sustaining for it to remain educationally meaningful?

Importantly, the four dimensions proposed in this framework are not intended to represent the only possible dimensions of the social sustainability of digital education, nor do they constitute an exhaustive or definitive taxonomy. Rather, they offer a theoretically

grounded and analytically coherent configuration of interdependent conditions identified as particularly relevant to the research problem addressed in this article. Other dimensions may emerge from different educational contexts, theoretical perspectives, or future empirical investigations. The framework therefore remains open to critical refinement, extension, and potential reformulation.

2. Sustainable Education Beyond Technological Continuity

Sustainability in education increasingly encompasses social as well as environmental and economic concerns, including equity, participation, belonging and institutional resilience. Yet social sustainability remains conceptually heterogeneous in educational research [1,26]. This matters because sustainability may refer to education's contribution to sustainable societies, the continuity of institutions, the durability of technologies, or the capacity of educational environments to sustain meaningful forms of teaching and learning.

The distinction becomes particularly important in digital education. Digital technologies have expanded access and flexibility, but their social implications remain less developed than their technological, economic or environmental dimensions. Szalkowski and Johansen [2] identify social sustainability as a comparatively under-examined dimension of digital transformation, while Okur et al. [27] show that decisions about educational technologies in European universities involve social and organisational considerations as well as technical ones. Daniela [3] similarly argues for pedagogical and socio-ethical sustainability alongside technological sustainability.

These developments support a distinction between technological continuity and educational sustainability. Technological continuity concerns the maintenance of platforms, connectivity, access and provision. Such conditions are indispensable, particularly where digital infrastructures make participation possible for learners otherwise excluded by geography, time or circumstance. However, continuity alone does not indicate what kind of educational experience an infrastructure supports.

Educational sustainability, as understood here, concerns whether digitally mediated environments can maintain the conditions through which learners and educators participate, interpret, exercise judgement and construct knowledge with others. Technology and pedagogy are not treated as opposing domains; the issue is whether gains in efficiency, visibility or scale also preserve the pedagogical conditions required by the educational model.

This distinction is also useful because the social dimension of sustainability can otherwise remain too broad to guide pedagogical analysis. Equity, inclusion and wellbeing are indispensable concerns, but a digital learning environment may formally address them while still organising participation through temporal, technological or institutional conditions that undermine meaningful educational involvement. The focus adopted here is therefore on the sustainability of the conditions through which those wider social commitments become pedagogically enactable.

A system may become more efficient while narrowing opportunities for interpretation; provision may expand while relational resources for meaningful mediation become constrained; and participation may become increasingly measurable without becoming more meaningful. These tensions are especially important because digital environments increasingly organise educational activity through datafication, automation and platform-mediated interaction.

What becomes visible as engagement is partly determined by the categories through which systems represent activity. Behavioural traces can support intervention, but they privilege forms of participation that are readily observable. A learner's contribution may be pedagogically significant even when it is infrequent, delayed or weakly represented by

conventional indicators. The sustainability question therefore concerns not only whether participation occurs but also which forms of participation educational systems can recognise.

Time raises a related issue. Online education is often valued for flexibility, but asynchronous provision can coexist with dense deadlines, continuous notifications and expectations of rapid response. A socially sustainable environment must therefore be capable of accommodating different rhythms of participation and reflection rather than treating immediacy as an implicit standard of engagement.

No single rhythm is proposed as ideal for digital education. Synchronous interaction, rapid feedback and structured deadlines may be important in many contexts, while social sustainability requires enough temporal plurality for different educational purposes and learner trajectories to coexist without making speed an unspoken criterion of engagement or legitimacy.

Scale introduces a further tension. Digital infrastructures can support larger populations, but the relevant pedagogical issue is whether the forms of interaction, recognition and professional judgement required by the intended educational experience remain viable as provision expands. Scalability is therefore not inherently problematic; it becomes a sustainability issue when expansion systematically weakens the pedagogical capacities on which the educational model depends.

This pedagogical reading of sustainability also connects to the broader policy framing of Education for Sustainable Development. The 2030 Agenda's Sustainable Development Goal 4 commits to inclusive and equitable quality education (SDG 4), with targets that include equal access to education and training (target 4.1), equal access to affordable and quality technical, vocational and higher education (target 4.3), and the knowledge and skills needed to promote sustainable development (target 4.7); UNESCO's associated Education for Sustainable Development frameworks likewise treat education's own capacity to sustain meaningful participation, not only its contribution to other sustainability goals, as part of this agenda. The present framework contributes to this agenda at the level of pedagogical conditions: a digital education system that expands access while eroding recognition, agency or relational density addresses SDG 4's quantitative targets without necessarily advancing the qualitative and equity-oriented commitments that target 4.7 and the ESD agenda also require. Earlier work on social sustainability in higher education likewise cautions against reducing sustainability to institutional continuity or environmental performance [25]. The present argument extends this concern to digitally mediated education by distinguishing sustainable educational provision from sustainable educational experience. Institutions must be able to continue offering education, but the qualities that make that provision educational must also remain possible over time.

This distinction reframes the problem. The issue is not simply whether a digital model can be maintained, technically supported or expanded but what it can sustain as conditions change. Responsive digital pedagogy, developed in the following section, addresses the question posed above by connecting technological organisation with the relational, temporal and participatory conditions of social sustainability.

3. Responsive Digital Pedagogy: From Responsiveness to Pedagogical Ecologies

Responsive digital pedagogy (RDP) is developed here as a framework for conceptualising digitally mediated education beyond models centred primarily on transmission, interaction management or technological efficiency. Its premise is that educational quality depends not only on what technologies enable but also on whether environments are organised so that learners can participate meaningfully, exercise agency, become recognisable to others and contribute to shared knowledge construction.

The expression responsive digital pedagogy has also recently been used in higher education to describe a technology-enabled academic-integrity intervention [28]. The framework developed here uses the expression in a distinct conceptual sense: RDP refers to the relational and ecological conditions through which pedagogical responsiveness can remain educationally meaningful and socially sustainable.

This argument resonates with relational approaches to pedagogy, which understand teaching and learning as constituted through relationships of attention, recognition, care and response rather than as the implementation of technique alone. In online higher education, Campbell and Coker [8] identify community, culture and care as central to relational pedagogy. Related AECED research on teachers' professional learning shows that learning for democratic practice is shaped by relational and institutional conditions and by situated forms of participation [4].

Responsiveness, in this article, therefore, means more than availability or rapid reaction. It concerns the capacity to interpret educational situations and respond to difference, uncertainty and emerging needs. Teaching remains intentional and epistemically demanding, but it cannot be reduced to predefined procedures. The educator retains responsibility for curricular coherence and intellectual challenge while exercising judgement about how those aims can become educationally possible in a particular situation.

Responsiveness should not be confused with accommodation. RDP does not allow learner preference to displace knowledge, standards or pedagogical responsibility. Intellectual challenge is nevertheless encountered through concrete conditions of participation, timing, communication and recognition, and responsiveness concerns how those conditions are interpreted in relation to educational purposes.

This emphasis places professional judgement at the centre of RDP. Judgement is required precisely because educational situations cannot be fully specified in advance: the same visible behaviour may have different meanings, and the same pedagogical intervention may have different consequences across contexts. Responsiveness therefore involves interpreting situations in relation to educational purposes rather than merely reacting to learner behaviour.

Digital environments make this issue especially visible because participation is mediated through interfaces, traces, temporal arrangements and institutional expectations. Research on digital student agency shows that agency is not an individual capacity exercised independently of technology; it emerges through relational, cultural, technological and temporal conditions [17]. Opportunities for participation are therefore shaped by the environments through which learners act.

This premise moves responsiveness beyond the interpersonal level. Platforms, curriculum structures, institutional routines, data infrastructures and workload arrangements do not simply surround pedagogical interaction; they help organise it. Critical and postdigital scholarship similarly cautions against treating technologies as neutral delivery tools, emphasising the sociotechnical conditions through which educational possibilities are configured [19,20,22].

The notion of pedagogical ecologies brings these conditions together. An ecological perspective considers relational, temporal, technological and institutional dimensions as mutually constitutive. It shifts attention from whether an individual educator is responsive to whether the broader educational environment enables responsiveness. A teacher may value reflection while a platform privileges rapid interaction or seek plural participation while institutional routines make only particular forms of activity legible.

This ecological perspective also helps explain why apparently minor design decisions may have significant pedagogical consequences. The organisation of asynchronous spaces, the visibility of prior contributions, the timing of activities or the availability of multiple

modes of expression can change who is able to participate and how participation becomes recognisable. Responsiveness is therefore partly a matter of reading and adjusting the ecology in which teaching occurs.

Pedagogical ecologies also direct attention to the distribution of authority. Platforms and institutional procedures may appear neutral while privileging particular ways of speaking, contributing or demonstrating engagement. Ecological responsiveness therefore includes scrutiny of how educational arrangements make some forms of participation easier to recognise than others and how these arrangements can be revised without assuming that every difference can or should be technologically resolved.

RDP consequently extends responsiveness from an interpersonal disposition to an ecological capacity. Two analytically related forms can be distinguished. Relational responsiveness concerns the capacity to attend to, interpret and respond to participants and emerging educational situations. Ecological responsiveness concerns the capacity to identify and, where possible, reshape the temporal, technological and institutional conditions through which participation, recognition, authority and agency are organised.

Neither dimension is sufficient alone. Relational responsiveness without ecological responsiveness risks individualising responsibility, as though attentive teaching could compensate indefinitely for structural constraints; ecological responsiveness without relational responsiveness risks reducing pedagogy to system design detached from interpretation, encounter and professional judgement.

RDP therefore operates neither exclusively as a theory of teacher behaviour nor as a theory of educational technology. It concerns the relation between pedagogical interpretation and the conditions that enable such interpretation to have consequences, including institutional situations in which educators may recognise a need for response but lack the temporal, curricular or technological room to act on that judgement.

RDP also differs from technological adaptation. Adaptive systems may modify content, pacing or pathways based on learner data, but adaptation and responsiveness are not equivalent. Prediction and optimisation can support learning, yet pedagogical responsiveness also requires interpretation, especially when participation is ambiguous, delayed or difficult to quantify. A technically adaptive system may still respond poorly to forms of learner presence that fall outside the categories it can detect.

This difference becomes increasingly consequential in AI-mediated education. Automated systems can respond quickly and at scale, but speed and personalisation do not by themselves establish pedagogical responsiveness. The latter depends on whether responses remain connected to educational purposes, learner agency and the possibility of interpretation by human participants.

Presence raises a related problem. Observable indicators such as access, frequency or completion can provide useful information without being equivalent to pedagogical presence. A learner may participate infrequently but substantively, require extended observation before contributing, or become visible through different modes of expression. Educational environments therefore need interpretative room to recognise such differences as pedagogically meaningful.

Listening is therefore implicit in RDP, not as a separate communicative technique but as the interpretative condition through which participation can become consequential. In digital environments, listening may involve attending to delayed contributions, recognising fewer dominant modes of expression and allowing one participant's contribution to alter the direction of shared inquiry. It is inseparable from the temporal and infrastructural organisation of the learning environment.

Responsive digital pedagogy can therefore be defined as an approach to digitally mediated education that understands pedagogical responsiveness as the situated capacity

to interpret and respond to learners and emerging educational situations while critically attending to, and where possible reorganising, the relational, temporal, technological and institutional conditions through which meaningful participation becomes possible.

This definition requires a non-circular criterion for what makes a response pedagogically consequential, as opposed to mere feedback, acknowledgement or automated adaptation. Three conditions distinguish it: the response is connected to an identifiable educational purpose rather than being procedural; it involves situated interpretive judgement under uncertainty rather than the application of a predefined rule; and it leaves a traceable effect on subsequent pedagogical action, whether through what the educator does next or through how shared inquiry develops. A reply that satisfies none of these conditions—an automated acknowledgement, a scheduled grade release—falls outside what this article treats as a pedagogical response, even where it is prompt and personalised.

RDP is thus neither a fixed teaching method nor a synonym for personalised learning, rapid feedback or intensive interaction. It is a conceptual lens for examining how educational environments organise possibilities of participation, recognition, agency and response. Its relevance to social sustainability lies precisely in asking whether those conditions can remain viable under conditions of scale, automation, standardisation and technological change.

4. Tensions in the Social Sustainability of Digital Education

RDP becomes particularly relevant where organisational and technological demands come into tension with pedagogical conditions. These tensions are not simple oppositions between desirable and undesirable practices. Efficiency, visibility, scalability and predictability can all support educational provision; the question is when and how they begin to constrain attention, recognition, relational quality or professional judgement. Four tensions are especially significant.

4.1. Efficiency and Attention

Efficiency can improve accessibility, consistency and institutional capacity, but it becomes pedagogically problematic when speed and continuous activity operate as implicit indicators of quality. Research on digital distraction shows that attention is shaped by technological, instructional and contextual conditions rather than by individual disposition alone [23].

From a social-sustainability perspective, attention is a resource that educational environments must help preserve. Reflection, reconsideration and delayed contribution may require temporal spaces that are not immediately productive or visible. Efficiency becomes unsustainable when it removes the conditions needed for attention, interpretation and response.

4.2. Visibility and Meaningful Participation

Digital environments make educational activity highly observable, but observable activity is not equivalent to meaningful engagement. Bergdahl et al. [24] found that 95% of reviewed higher-education learning-analytics studies measured engagement through behavioural activity, while cognitive, emotional and social dimensions were much less represented.

The distinction matters because institutional dashboards can gradually turn available indicators into implicit definitions of engagement. When this occurs, what is easy to count may acquire disproportionate influence over pedagogical decisions. RDP therefore treats analytics as one source of evidence within a broader interpretative process rather than as a complete representation of participation.

Such data can support pedagogical judgement but should not substitute for it. A student may be highly visible while contributing little to shared inquiry, whereas less

frequent or delayed participation may be educationally substantial. Social sustainability therefore requires recognising that significant participation may be poorly represented by behavioural traces.

4.3. Scalability and Relational Density

Digital education can widen access at scale, but expansion raises the question of whether necessary forms of mediation and recognition remain viable. Relational density refers here to the extent to which interaction enables substantive response and mutual influence rather than simply increasing contact.

Large-scale education is not inherently unsustainable, nor does relational quality require intensive individual interaction in every context. The issue is whether the mechanisms used to achieve scale systematically erode the forms of relationship required by the educational aims of the programme. Scalability is therefore a pedagogical as well as an organisational question.

The relevant threshold will vary by educational purpose. A course organised around independent study may require different forms of relational support from one organised around dialogue, collaborative inquiry or professional formation. Social sustainability therefore asks whether the relational resources of a model remain proportionate to what that model claims educationally to achieve.

4.4. Predictability and Pedagogical Openness

Educational systems require planning, explicit expectations and assessment criteria, but education cannot be entirely predetermined. Learners introduce unexpected interpretations, difficulties and questions, and teaching therefore involves uncertainty and professional judgement. AECED research on democratic risk shows how educators negotiate precisely this tension between openness, exposure and professional agency [6].

Predictive analytics and automated systems make the issue more visible because their categories are necessarily selective. RDP therefore distinguishes structure from closure: structure provides orientation, whereas closure reduces the space for responding to what was not anticipated. Social sustainability requires enough pedagogical openness for educators and learners to act when educational situations exceed predefined categories.

4.5. Holding the Tensions Together

These tensions are not binaries. Efficiency can preserve resources, visibility can support intervention, scale can widen access and predictability can support fairness. Problems arise when these organisational values become proxies for educational quality and displace the conditions through which learning becomes meaningful.

The tensions can be summarised as shown in Table 2:

Table 2. Summary of the four tensions in the social sustainability of digital education.

Organisational Demand	Potential Pedagogical Risk	Sustainability Question
Efficiency	Acceleration and fragmented attention	Are there sufficient temporal conditions for reflection and response?
Visibility	Engagement reduced to observable behaviour	What forms of participation remain difficult to detect or interpret?
Scalability	Weakening of relational mediation	What forms of feedback, recognition and interaction remain viable as provision expands?
Predictability	Reduced space for judgement and emergence	Can educators and learners respond meaningfully to what was not anticipated?

The table summarises these tensions and leads to the central framework: the four dimensions of relational, temporal, participatory and infrastructural sustainability. The tensions and the dimensions are not parallel, one-to-one taxonomies: the tensions name the organisational pressures under which sustainability is tested, while the dimensions name what is pedagogically at stake under those pressures. Some correspondences are direct—efficiency pressures attention most directly within temporal sustainability, and scalability pressures relational density most directly within relational sustainability—while others cut across more than one dimension: visibility affects both what counts as recognition (relational sustainability) and what counts as legitimate agency (participatory sustainability), and predictability bears primarily on infrastructural and institutional conditions, which is why it is treated below as an enabling rather than a co-equal concern.

5. Four Dimensions of Socially Sustainable Digital Education

The preceding sections have argued that the sustainability of digital education cannot be reduced to technological continuity, institutional viability or scale. If socially sustainable digital education concerns the capacity to maintain the conditions through which education remains meaningful over time, then those conditions need to be specified more precisely.

This section proposes four interconnected dimensions: **relational sustainability, temporal sustainability, participatory sustainability and infrastructural sustainability**. They are analytically distinguishable but pedagogically interdependent. They should not be understood as a hierarchy, a sequence or a measurement scale. Rather, they identify four sets of conditions through which digitally mediated education can sustain recognition, attention, agency and meaningful participation.

The framework responds to a limitation in existing sustainability debates. Recent work has begun to connect online higher education with relationality, social sustainability and socio-ethical dimensions of technology use, but these concerns tend to remain distributed across separate studies. Campbell and Coker's [8] review of relational pedagogy in online higher education, for example, identifies culture, community and care as closely connected dimensions of relational online practice and explicitly links them to wider sustainability agendas. Research on digital student agency similarly shows that agency is produced through relational, cultural, technological and temporal dynamics rather than residing solely in individual learners [17]. Critical work on digitalised higher education, meanwhile, demonstrates that platforms, data infrastructures and institutional arrangements increasingly shape educational interactions and organisational possibilities.

The four dimensions proposed here bring these strands together to answer the question posed in Section 1: what must digitally mediated educational environments be capable of sustaining if they are to remain pedagogically meaningful?

5.1. Relational Sustainability: Recognition and Pedagogical Response

Relational sustainability concerns the capacity of an educational environment to sustain relationships through which participants can become recognisable to one another, contribute meaningfully and receive pedagogically consequential responses.

Relational pedagogy provides an important foundation for this dimension. Recent research in online higher education has shown that relationships of care, community and cultural recognition are not peripheral to online learning but contribute to the quality of educational experience. Campbell and Coker's review of 34 studies, for example, identifies these dimensions as mutually constitutive elements of relational online education. These concerns extend a longstanding tradition of relational and care-based thinking in education [9,10] and resonate with earlier accounts of social and teaching presence in text-based online learning communities [11].

The argument developed here extends this concern by focusing specifically on recognition and response. The opportunity to contribute is not sufficient if contributions remain pedagogically inconsequential. Participation becomes relationally meaningful when learners can reasonably expect that their ideas, questions or difficulties may be noticed, interpreted and responded to. This emphasis also draws on wider accounts of voice, recognition and epistemic justice [12–14].

Relational sustainability therefore involves more than interpersonal warmth or frequent communication. It concerns whether the educational environment supports forms of relation in which difference can become intelligible.

This is particularly important online, where participation may occur asynchronously, through different modalities and with varying degrees of visibility. Some learners may contribute frequently and immediately; others may require more time, rely on written or multimodal expression, or participate less visibly. A relationally sustainable environment does not require uniform participation but must remain capable of recognising educational significance across different forms of presence.

Recognition should not, however, be confused with affirmation. Pedagogical response may involve challenge, correction or disagreement. Relational sustainability is compatible with intellectual demand because its concern is not that all contributions be validated but that participants can enter a pedagogical relation in which their contributions are treated as interpretable and consequential. Relational sustainability erodes, for example, when expanding enrolment or caseloads reduces the time available for pedagogically consequential response, turning recognition into a scarce, rationed resource; it is regenerated through institutional choices—staffing ratios, structured response windows, peer- and community-based forms of response—that keep recognition proportionate to the number of participants rather than treating it as a fixed individual capacity.

Relational sustainability can therefore be expressed as a question:

Does the educational environment sustain the conditions through which participants can become recognised and receive meaningful pedagogical responses?

5.2. Temporal Sustainability: Attention and Differentiated Rhythms

Temporal sustainability concerns the capacity of educational environments to sustain learning across different rhythms without reducing educational time to immediacy, continuous production or rapid response. This concern resonates with critiques of social acceleration and the erosion of resonant relationships to time [15] and with accounts of attention as an ecological, unevenly distributed resource shaped by digital environments [16].

The temporal organisation of digital learning is often discussed in terms of flexibility, synchrony and scheduling. Yet time is also constitutive of participation and agency. Stenalt's framework of digital student agency explicitly identifies **digital temporality** as one of the domains through which agency is shaped in digital contexts, alongside digital sociality, self-representation and data use.

This is important because flexibility does not automatically produce temporal diversity. An asynchronous course may technically permit participation at different moments while simultaneously imposing dense deadlines, rapid feedback cycles or expectations of continuous visibility.

Temporal sustainability therefore concerns whether learners and educators have sufficient time to interpret, reconsider and respond.

It may involve:

- asynchronous opportunities for participation;
- delayed rather than immediate response;
- time for revision and reflection;

- opportunities to revisit earlier contributions;
- rhythms that alternate interaction and consolidation.

The point is not to idealise slowness. Effective online higher education depends on multiple factors, including clear structure, high-quality interaction, assessment diversity, teacher support and adequate institutional infrastructure. A recent meta-review of 47 reviews and meta-analyses confirms precisely this combination of course-, student-, teacher- and institution-level conditions [29].

Complementing this review-level synthesis, Li and Yu [30] analysed questionnaire data from 1478 Chinese university students studying English in blended environments using structural-equation modelling. Learner attitude, self-identity and course design were prominent correlates of learning outcomes, with teacher guidance also implicated. These factor-level findings underscore that learning conditions are multidimensional; they neither directly measure differentiated temporal experience nor validate the four RDP dimensions. This distinction between contributing evidence and framework validation is deliberate.

Temporal sustainability instead argues against treating a single temporal pattern as pedagogically normative.

Some educational purposes require immediacy.

Others require interruption.

Some learners benefit from rapid interaction.

Others may need time before their participation becomes substantive.

The sustainability issue is whether the educational environment can accommodate these differences without treating delayed participation as automatically inferior. Temporal sustainability erodes when deadlines, notification systems or performance metrics implicitly reward immediacy, compressing the room available for reflection and delayed participation; it is regenerated through curricular design that legitimates asynchronous and delayed contribution—grading criteria that do not penalise delayed but substantive participation, or assessment structures that build in revision cycles.

Temporal sustainability therefore asks:

Can learning unfold through more than one legitimate rhythm while preserving opportunities for attention, interpretation and response?

5.3. Participatory Sustainability: Agency, Plurality and Influence

Participatory sustainability concerns whether educational environments can sustain participation as an exercise of agency rather than merely as observable activity.

This distinction is particularly important in digital education because opportunities for interaction do not necessarily imply opportunities for agency. Learners may respond to prompts, complete tasks and participate frequently while exercising limited influence over how knowledge is explored or how shared educational activity develops.

Research on digital agency provides a strong basis for moving beyond this individualised understanding of participation. Stenalt [17] argues that student agency in digital contexts emerges through the interplay of relational, cultural and technological dynamics. More broadly, ecological approaches to agency similarly emphasise the interaction between individual capacities and structural conditions [18].

From this perspective, participatory sustainability concerns the conditions under which learners can act meaningfully within educational environments.

This includes opportunities to:

- make choices that matter educationally;
- contribute to knowledge construction;
- respond to and influence others' interpretations;
- use different modes of expression;

- shape shared inquiry through decisions and contributions that matter educationally.

Participatory sustainability does not require the elimination of teacher authority or curricular structure. It concerns whether learners can exercise meaningful agency within a coherent and intellectually demanding educational framework.

The question is instead whether participation can have educational consequences.

A learning environment may offer extensive opportunities for expression while remaining highly predetermined. Conversely, structured pedagogical environments can support substantial agency when learners are able to interpret, question, create and influence shared inquiry within those structures.

Plurality is therefore central. Participation should not require all learners to become visible through the same communicative or expressive forms. Participatory sustainability erodes when interaction is organised so that learners can respond but not influence—for example, discussion structures that require posting without any mechanism for prior contributions to shape subsequent activity; it is regenerated through design that makes influence structurally possible, such as visible uptake of learner contributions, optional modes of participation, and opportunities to shape the direction of shared inquiry.

Participatory sustainability asks:

Can learners exercise meaningful agency and influence shared educational activity rather than merely demonstrate participation?

5.4. Infrastructural Sustainability: The Conditions That Organise Educational Possibility

Infrastructural sustainability concerns the technological, organisational and institutional conditions through which relational, temporal and participatory sustainability become possible.

This dimension is necessary because the educational experience is not organised exclusively through teacher–student relationships. Learning management systems, communication platforms, assessment technologies, analytics, institutional policies and commercial infrastructures all participate in shaping educational activity.

Critical research on the digitalisation of higher education increasingly demonstrates this infrastructural role. Platform architectures establish rules, interfaces and forms of intermediation that shape human interactions and institutional possibilities rather than functioning as neutral delivery systems [19,21].

This ecological reading also resonates with AECED research on democracy-as-becoming, which analyses educational experience through aesthetic, embodied and digital pedagogical ecologies rather than through isolated teaching techniques [5]. In the present article, that ecological orientation is extended towards a sustainability question: whether technological and institutional arrangements can continue to support meaningful forms of relation, temporality and participation as conditions change.

Komljenovic, Sellar and Birch [21] similarly show that contemporary universities are becoming increasingly data-driven organisations through changing technological, organisational, commercial and governance arrangements. Their analysis includes an "existential" dimension concerned with how datafication changes universities themselves as social institutions.

These developments are particularly significant for socially sustainable digital education because infrastructures distribute possibilities.

A platform may make some activities more visible than others.

Analytics may define engagement through behavioural categories.

Assessment systems may privilege certain forms of output.

Institutional workload arrangements may determine how much responsive feedback can realistically be provided.

Commercial technologies may constrain institutional control over pedagogical environments and educational data.

The strong behavioural bias identified in higher education learning analytics illustrates this problem. Bergdahl et al.'s systematic review of 159 studies found that 95% measured engagement through observable behavioural activity, while cognitive, social and emotional dimensions received substantially less attention. Infrastructures therefore do not merely record educational activity; they may also influence what becomes institutionally legible as educationally significant. Infrastructural sustainability erodes when platform or analytics choices are made primarily for administrative efficiency or commercial convenience, narrowing what can be recognised as legitimate participation; it is regenerated through institutional control over technological choices—data-governance decisions, platform procurement criteria and professional autonomy over how analytics are used—that keep infrastructure answerable to pedagogical purposes rather than the reverse.

Infrastructural sustainability is consequently not synonymous with reliable technology. Reliability is necessary, but a technically stable infrastructure may still constrain relational or participatory possibilities.

The relevant question is whether infrastructures support the pedagogical purposes they are expected to serve.

This includes not only accessibility but also flexibility, institutional autonomy, teacher agency, data governance and the capacity to adapt technological arrangements when they conflict with pedagogical aims.

Recent critical work on digitalised higher education also points to growing dependence on large commercial infrastructures and to the ways platformisation can redistribute organisational power over educational environments [19,21]. This reinforces the need to treat infrastructures as pedagogical and institutional arrangements rather than merely technical systems.

Infrastructural sustainability therefore asks:

Do the technological and institutional conditions of digital education enable the relationships, temporalities and forms of agency that the educational model seeks to sustain?

5.5. An Integrated Framework for Socially Sustainable Digital Education

The four dimensions are interdependent.

Relational sustainability requires time for interpretation and response.

Temporal sustainability depends on institutional and technological arrangements that permit differentiated rhythms.

Participatory sustainability depends on whether learners are recognised as legitimate contributors and whether infrastructures provide meaningful opportunities for agency.

Infrastructural sustainability matters pedagogically insofar as it supports—or undermines—the other three dimensions. This also means that infrastructural sustainability is a different logical type from the other three: it functions as an enabling condition rather than a co-equal dimension defined by its own distinctive relational content. It is retained as a fourth dimension, rather than folded into the others as background, because sustainability failures are frequently traceable to concrete infrastructural choices—a platform default, a workload model, a data-governance decision—and because the design principles developed in Section 6 require a dimension through which institutional practice can intervene directly.

Relational and participatory sustainability, in particular, address closely connected but logically separable questions and should not be treated as interchangeable. Relational sustainability asks whether a contribution is noticed, interpreted and pedagogically answered: its locus is the act of recognition and response. Participatory sustainability asks whether a contribution can alter the course of shared educational activity—curricular sequencing,

the direction of inquiry, and subsequent teaching decisions: its locus is causal influence over what happens next. The two can come apart in practice: a learner may be heard and validated without this changing anything about how the course proceeds (recognition without influence), and a structural choice available to learners may redirect shared activity without passing through an identifiable act of response (influence without a recognition episode). Where they coincide, as they often do, the coincidence is empirical rather than definitional, and the dimensions remain analytically distinct even when their erosion and regeneration mechanisms interact.

Their relationship should therefore be understood as **ecological rather than additive**. Figure 1 represents this ecological structure.

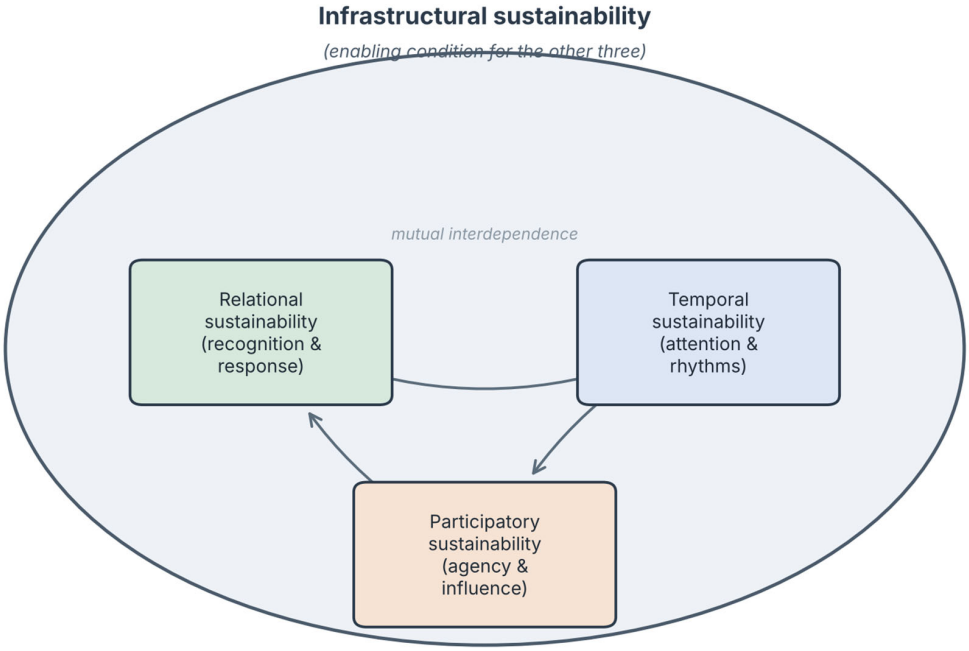


Figure 1. The four dimensions of socially sustainable digital education as an ecological system, with infrastructural sustainability as an enabling condition for relational, temporal and participatory sustainability.

The framework can be summarised as shown in Table 3:

Table 3. The four dimensions of socially sustainable digital education: what must be sustained, the central concern, and the guiding question for each.

Dimension	What Must Be Sustained?	Central Concern	Guiding Question
Relational	Recognition and pedagogical response	Quality of educational relationships	Can participants become recognised and receive meaningful pedagogical responses?
Temporal	Attention and differentiated rhythms	Time for interpretation, reflection and response	Can learning unfold through more than one legitimate rhythm while preserving opportunities for attention, interpretation and response?
Participatory	Agency and meaningful influence	Capacity to act and contribute to shared inquiry	Can learners exercise meaningful agency and influence shared educational activity rather than merely demonstrate participation?
Infrastructural	Conditions enabling the other dimensions	Platforms, institutional arrangements and data infrastructures	Do the technological and institutional conditions of digital education enable the relationships, temporalities and forms of agency that the educational model seeks to sustain?

The framework is not intended as a checklist or as a validated measurement instrument. Nor does it imply that every educational environment should maximise each dimension in the same way. Different programmes, populations and educational purposes will require different configurations.

Its purpose is analytical: to make explicit the conditions that may be obscured when sustainability is evaluated primarily through access, continuity, efficiency or scale.

The four dimensions also provide a way of distinguishing **socially sustainable digital education** from a generic account of educational quality. The distinctive contribution of a sustainability perspective lies in its concern with whether these pedagogical conditions can be **maintained and reproduced over time**, including under conditions of technological change, institutional expansion and increasing automation.

This emphasis on durability does not imply stability in the sense of preserving a fixed arrangement. The conditions identified by the framework may need to be reorganised as technologies, learner populations and institutional constraints change. Sustainability therefore refers to the continuing capacity to regenerate meaningful educational conditions, not to maintaining identical pedagogical forms over time.

Socially sustainable digital education can therefore be defined as **the capacity of a digitally mediated educational ecology to maintain over time the relational, temporal, participatory and infrastructural conditions through which meaningful educational participation remains possible.**

This definition does not suggest that the same relationships or practices should remain unchanged. Sustainability here refers not to preservation of a fixed pedagogical arrangement but to the continuing capacity of educational environments to support recognition, attention, agency and pedagogical response as conditions change.

This distinction is important. A sustainable educational ecology must also be capable of adaptation.

What needs to endure is not a particular technology, activity or teaching method but the **capacity to reproduce the conditions through which education remains meaningful**.

5.6. Relation to Established Frameworks

RDP is developed in dialogue with three established frameworks rather than independently of them: the community-of-inquiry model of social, teaching and cognitive presence [11], Stenalt's domains of digital student agency [17], and Daniela's distinction between pedagogical, technological and socio-ethical sustainability [3]. Table 4 summarises what RDP incorporates from each, what it reformulates, and what it adds.

Table 4. RDP's relation to three established frameworks: what it incorporates, what it reformulates, and what it adds.

Framework	What RDP Incorporates	What RDP Reformulates	What RDP Adds
Community of Inquiry [11]	Social, teaching and cognitive presence as relational preconditions for online learning	Presence is treated as necessary but insufficient; RDP asks whether presence becomes a pedagogically consequential response, not only whether it is established	An explicit sustainability framing: whether presence and response can be reproduced as scale, automation and institutional conditions change

Table 4. *Cont.*

Framework	What RDP Incorporates	What RDP Reformulates	What RDP Adds
Stenalt's domains of digital agency [17]	Agency as relational, cultural, technological and temporal rather than purely individual	Agency becomes one dimension (participatory sustainability) within a four-dimensional ecology rather than the central construct	Links agency explicitly to infrastructural and institutional conditions of durability and to design principles for sustaining it
Daniela's pedagogical/technological/socio-ethical sustainability [3]	The move beyond technological sustainability toward pedagogical and ethical concerns	Differentiates social sustainability specifically (relational, temporal, participatory, infrastructural conditions) from the broader socio-ethical category	Four analytically distinguishable dimensions operationalised into design principles (Section 6) and erosion/regeneration mechanisms (Section 5)

6. From Framework to Design Principles

The four dimensions are primarily analytical, but they also have implications for pedagogical and institutional design. The principles below translate the framework into reflective orientations rather than a universal method. Their purpose is to connect sustainability with ordinary decisions about interaction, time, participation, infrastructure and organisational support.

6.1. Design for Recognition and Response

Opportunities to interact do not ensure that contributions are noticed or consequential. Socially sustainable design should therefore create credible mechanisms through which learner participation can be interpreted, taken up and connected to subsequent activity. Pedagogical response need not be immediate or individualised in every instance; its significance lies in making participation matter within the educational process.

This may involve structuring discussion around interpretation rather than posting frequency, creating opportunities to revisit contributions, or ensuring that learner questions and ideas can shape subsequent activity. The design principle is design interaction so that participation can become recognised, interpreted and educationally consequential.

6.2. Design for Temporal Diversity

Digital flexibility can coexist with compressed schedules and expectations of continuous response. Temporal sustainability therefore requires pedagogical arrangements that legitimate asynchronous participation, reflection, revision and delayed contribution where appropriate, without making slowness an end.

Temporal diversity may involve alternating periods of interaction and consolidation, allowing contributions to develop over time or avoiding unnecessary demands for constant visibility. The design principle is designing educational time so that reflection, delay and revision remain legitimate alongside more immediate interaction.

6.3. Design for Agency and Plural Participation

Visible participation does not necessarily imply agency. Learners require opportunities to make meaningful choices, influence shared inquiry and contribute through different legitimate modes. The aim is not unlimited choice but participation that has educational consequences within a coherent learning structure.

Plural participation also requires attention to accessibility and expressive form. Written, oral, visual or multimodal contributions may make different learners pedagogically visible. The design principle is design participation so that learners can exercise meaningful agency and become educationally present through more than one legitimate form of contribution.

Importantly, plurality is not achieved simply by multiplying formats. Different modes must be institutionally and pedagogically legitimate; otherwise, multimodality can remain cosmetic while a single dominant form continues to determine whose participation counts.

6.4. Design Infrastructures in Relation to Pedagogical Purposes

Platforms and educational technologies should be evaluated not only for functionality but also for the forms of visibility, participation and agency that they organise. Analytics may support intervention while privileging behavioural traces, and automated systems may increase efficiency while narrowing what can be interpreted.

Generative AI is one illustrative example of these dynamics, since it redistributes authorship, mediation and pedagogical responsibility. A recent systematic review of higher-education applications documents uses across learning support, writing, feedback and pedagogical design while also identifying implementation challenges that depend on the surrounding educational context [31]. Its adoption should therefore be examined in relation to the educational ecology rather than treated as a self-evident improvement. The design principle is: evaluate technologies according to the forms of agency, visibility, participation and pedagogical response that they enable or constrain.

A bounded comparison is offered by Yao, Wang and Sun [32], whose survey of 462 Chinese professional designers relates AIGC adoption intentions to perceived ease of use, usefulness, technological and interactive features, and dimensions of technological readiness. Their study concerns professional adoption rather than educational outcomes. It is relevant here only to distinguish the determinants of uptake from the separate pedagogical question of whether adoption sustains learner recognition, agency and interpretative judgement.

The same principle applies to learning analytics, automated feedback and other data-intensive systems. Their use should be examined in relation to the educational purposes that they are expected to serve and to the forms of dependence, visibility and professional discretion that they create.

6.5. Design Institutional Conditions for Responsiveness

Responsiveness must also be institutionally possible. Relational response requires time, temporal flexibility requires curricular room, and pedagogical adaptation requires professional judgement. These capacities are shaped by workload, staffing, platform choices and the degree of professional autonomy available to educators.

If responsiveness can be sustained only through invisible additional labour, it is not socially sustainable. The design principle is therefore: design organisational conditions that provide sufficient time, professional autonomy and infrastructural support for pedagogical responsiveness to remain viable.

6.6. A Reflective Design Heuristic

The five principles can be summarised as a reflective heuristic, as shown in Table 5:

Table 5. Reflective design heuristic: design orientation and guiding question for each sustainability dimension.

Sustainability Dimension	Design Orientation	Reflective Question
Relational	Recognition and response	How can learner contributions become interpreted and consequential?
Temporal	Differentiated rhythms	Where is there legitimate space for reflection, delay and revision?
Participatory	Agency and plural presence	How can learners influence the educational process and participate through different legitimate modes?
Infrastructural	Pedagogy-informed technology	What forms of participation, visibility and agency does the infrastructure enable or constrain?
Institutional/transversal	Conditions for responsiveness	Do educators have sufficient time, autonomy and support to sustain responsive pedagogy?

To apply the heuristic to a proposed platform, policy or course change, record (i) the organisational pressure or intended gain, (ii) which pedagogical condition may be displaced, (iii) the pathway of erosion, (iv) the feasible repair or regeneration mechanism and who is responsible for it, and (v) what longitudinal learner and educator evidence would show that the repair succeeded or failed. These are illustrative audit prompts rather than validated design prescriptions.

These questions are diagnostic rather than prescriptive: they help educators and institutions examine whether everyday design and organisational decisions are consistent with the pedagogical conditions that they seek to sustain.

The movement from framework to design is therefore a movement towards reflective pedagogical judgement, not a fixed set of techniques.

Social sustainability is therefore produced—or weakened—through ordinary pedagogical and institutional decisions.

7. Discussion: Reframing the Social Sustainability of Digital Education

The framework reframes digital sustainability as a pedagogical as well as technological and institutional problem. Educational systems may remain operational and scalable while the conditions that make education relationally meaningful weaken. The contribution therefore lies in asking not only whether digital education can persist but also what educational conditions must remain possible as it persists and changes.

7.1. From Sustainable Provision to Sustainable Educational Experience

The first contribution is the distinction between sustainable educational provision and sustainable educational experience. Provision concerns whether institutions can continue offering education through reliable, accessible and viable arrangements. Experience concerns whether recognition, agency, differentiated temporalities and meaningful pedagogical response can also endure.

The distinction is analytical rather than oppositional. Reliable infrastructure is a precondition for meaningful digital education, but continuity of provision does not by itself demonstrate the sustainability of the educational experience. A platform may remain stable while interaction becomes procedural, or a programme may expand while reducing the pedagogical resources available for substantive response.

A sustainability perspective therefore adds a temporal and institutional question to discussions of educational quality: can the conditions supporting educational value be

maintained under expansion and technological change? This is the point at which social sustainability contributes something more specific than a general claim about good digital pedagogy.

This distinction also helps avoid conceptual stretching. Social sustainability is not being used here as a substitute for educational quality, inclusion or care. Its specific contribution is to foreground the durability and reproducibility of the social and pedagogical conditions on which those qualities depend as infrastructures, populations and institutional arrangements change.

7.2. Social Sustainability as an Ecological Property

A second contribution is to locate sustainability in educational ecologies rather than in individual educators. Teachers may be expected to provide responsive, inclusive and agentic learning, but their capacity to do so depends on platforms, workload, curriculum and institutional cultures. AECED research on institutional transformation similarly shows that democratic and pedagogical change depends on governance arrangements and organisational conditions, not only on individual practice [7].

This ecological framing guards against a common individualisation of responsibility. A teacher may value reflective participation while working within compressed schedules or seek relational forms of teaching while institutional systems reward rapid completion and easily quantifiable outputs. The quality of pedagogical response is therefore partly a property of the environment in which professional judgement is exercised.

It also prevents sustainability from becoming a moral demand for unlimited teacher availability. Responsive pedagogies may be labour-intensive, and their viability depends on whether institutions recognise the time, expertise and organisational resources required to sustain them. Without this institutional dimension, responsiveness risks becoming an aspiration maintained through professional overextension.

This matters especially at scale. If meaningful response and professional judgement can be maintained only through increasing amounts of invisible labour, the arrangement is difficult to describe as socially sustainable. The framework therefore asks whether educators and learners are structurally enabled to enact the relationships that an educational model claims to value.

7.3. Measurement, Automation and the Sustainability of Pedagogical Judgement

A third implication concerns data, automation and generative AI. Digital environments generate extensive behavioural traces that can support intervention, but what is visible to a system is not equivalent to what is educationally meaningful. Reflection, recognition and agency are only partially represented by behavioural data. Measurement should therefore inform pedagogical judgement without defining its boundaries.

This principle is not an argument against analytics. It is an argument for epistemic modesty about what analytics can establish. Behavioural patterns may indicate where further attention is needed, but they cannot by themselves determine the meaning of participation or absence. Social sustainability therefore depends partly on retaining professional capacities for interpretation alongside increasingly automated forms of classification.

A similar caution applies to claims of AI-enabled personalisation. Personalised output may increase convenience or support, yet social sustainability also concerns shared educational spaces, collective knowledge construction and the continued possibility of human disagreement and interpretation. These relational qualities cannot be assessed solely through individual performance gains.

Generative AI is a further, more recent illustration of this issue, adding new layers of mediation between learners, educators and knowledge. Review evidence shows rapid expan-

sion of pedagogical uses in higher education alongside persistent questions about verification, learning processes and appropriate educational use [31]. From a social-sustainability perspective, the more consequential question is which capacities—such as meaningful authorship, agency, interpretation and pedagogical judgement—remain possible as AI becomes embedded in educational practice.

Sustainability here does not mean preserving existing practices unchanged. Technologies and pedagogies will continue to develop. What needs to remain possible is the capacity to sustain meaningful educational relations, responsible authorship and professional judgement under new conditions.

7.4. Conceptual Boundaries and Future Research

The framework remains conceptual. Its four dimensions should not be treated as validated indicators, a maturity model or a measurement scale; their function is analytical. Although the empirical literature engaged most directly in this article is concentrated in higher education, the underlying mechanisms—relational response, differentiated temporal rhythms, participatory agency and infrastructural mediation—are not specific to that sector; the framework is therefore proposed at the level of digital education generally, while recognising that its configuration is likely to vary across sectors. Empirical work should examine how they operate across online, blended, adult and professional education and how their configurations differ across institutions, disciplines and learner populations.

Empirical refinement should also examine the framework from the perspective of different participants. What institutions regard as flexible or inclusive may be experienced differently by learners and educators, and the same infrastructure may enable participation for some while constraining it for others. Such work would help determine where the four dimensions reinforce one another and where social sustainability involves unavoidable trade-offs rather than simple optimisation.

Longitudinal research is especially important because sustainability concerns what can be maintained over time as enrolment, platforms and automation change. Future studies should also examine tensions among the dimensions—for example, whether greater temporal flexibility complicates collaboration or whether personalised systems strengthen individual support while weakening shared educational experience.

A further challenge is operationalisation without reducing relational phenomena to narrow behavioural indicators. Qualitative and mixed-method approaches may be particularly useful for studying recognition, agency, temporal experience and pedagogical response. Generative AI is one such context, among others such as large-scale online programmes or analytics-intensive platforms, because it changes infrastructure, authorship, temporalities and professional judgement simultaneously.

Several claims advanced above are asserted conceptually rather than demonstrated and should be treated as priorities for empirical testing. First, the claim that infrequent or delayed participation can be pedagogically substantive would be disconfirmed by evidence that low-frequency, high-latency contributors show reliably weaker learning outcomes than frequent contributors across contexts, rather than outcomes that depend on how their participation is interpreted. Second, the claim that professional judgement outperforms algorithmic adaptation in ambiguous situations is scoped specifically to ambiguity; it would be disconfirmed by evidence that adaptive systems achieve comparable or superior outcomes in situations that are genuinely ambiguous or non-routine, rather than merely complex but well-specified. Third, the distinction between responsiveness and accommodation, clarified in Section 3 through the criteria of purpose-connectedness, interpretive judgement and consequentiality, would be disconfirmed if responsive design features showed no measurable difference from simple preference-accommodation in their effects on participation or

learning. Testing these claims would also help operationalise the framework—for instance, through process-tracing of how specific responses are interpreted and taken up—without reducing relational phenomena to behavioural counts alone.

The framework should therefore be understood as a conceptual proposition open to the empirical refinement outlined above, rather than a complete theory of sustainable digital education.

7.5. Theoretical Limitations, Operationalisation and Disconfirmation

The proposed categories remain sensitising constructs rather than independently validated variables. The research base is concentrated in higher education, and the meaning of a 'consequential' intervention can differ across disciplines, accessibility needs and institutional contexts. In particular, a human response is not automatically superior to an automated one; delayed participation is not invariably substantial; and pedagogical challenge is not evidence of responsiveness by itself. These are contextual propositions, not empirical conclusions.

Operationalisation should therefore use evidence that retains meaning and temporality: learner interviews and stimulated recall to investigate experienced recognition; comparison of contributions with subsequent discussion, feedback and curricular decisions to trace uptake; diaries and repeated interviews to examine temporal pressure; and governance, staffing, procurement and workload records to track infrastructural capacity. Platform logs may assist sampling and triangulation but should not be treated as stand-alone measures of relational presence or agency. Repeated observation across semesters, enrolment changes or platform transitions is particularly important for separating momentary quality from regenerative capacity.

Three empirical tests merit priority. First, whether infrequent or delayed contributions can substantially affect inquiry should be tested by tracing their intellectual uptake relative to timing and frequency; reliable absence of consequential uptake across comparable cases would count against the claim. Second, educators' situated decisions should be compared with appropriately specified automated interventions in genuinely ambiguous cases; comparable or better system performance on educationally defensible outcomes would limit any claim of human advantage. Third, learner influence and the maintenance of curricular standards should be studied together; if apparently responsive changes consistently weaken attainment without increasing meaningful participation, the proposed distinction between responsiveness and accommodation requires revision. No single behavioural metric should determine these tests.

8. Conclusions

This article has argued that the sustainability of digital education cannot be understood through technological continuity, access, resilience or scalability alone. These conditions are necessary, but they do not establish whether digitally mediated education can sustain the relationships, temporalities and forms of participation through which learning remains meaningful.

Responsive digital pedagogy was developed as a framework for addressing this problem. It conceptualises responsiveness as both relational—the capacity to interpret and respond to learners and emerging situations—and ecological—the capacity to attend to the technological, temporal and institutional conditions that organise participation and agency.

The article's principal conceptual contribution is the four-dimensional account of socially sustainable digital education: relational, temporal, participatory and infrastructural sustainability. These dimensions are not a checklist or measurement scale. They identify in-

terdependent conditions whose viability should be considered as digital education expands, becomes more data-intensive and incorporates new forms of automation.

This perspective also reframes digital transformation. Platforms, analytics and generative AI should be considered not only in terms of operational capability but also in terms of how they reorganise attention, agency, recognition, authorship and pedagogical judgement. Social sustainability therefore concerns the continuing capacity of educational ecologies to support meaningful participation under changing conditions, rather than the preservation of technologies or practices.

Responsibility for that capacity is distributed. Educators exercise pedagogical judgement, learners participate in shaping educational relations, and institutions organise the temporal, technological and professional conditions within which responsiveness can occur. This is why social sustainability cannot be reduced either to individual teaching quality or to technical infrastructure alone.

Accordingly, the framework is best understood as a way of making otherwise backgrounded conditions visible: not as a prescription for one form of digital education, but as a basis for asking whether arrangements can continue to support meaningful educational relations over time.

The framework now requires empirical refinement across educational contexts and over time. Its guiding proposition is simple: the sustainability of digital education depends not only on whether education can continue but also on whether it can continue to sustain the conditions that make education meaningful. Such work should also test where institutional constraints make these conditions difficult to sustain in practice.

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