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Inven!RA: a contribution towards platforms aligned with Digital Transformation in Education

Inven!RA: Um contributo para plataformas alinhadas com a Transformação Digital na Educação

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Abstract. The social transformations empowered by technological development were further accelerated by the COVID-19 pandemic and the rapid expansion of generative artificial intelligence. In education, these drivers have highlighted barriers to the acknowledgment and embracing of such transformations. One such barrier is the circumstance that current digital platforms replicate or encourage pre-digital teaching and learning processes. To foster transformative changes in education, we need technologies that do not merely reproduce current processes, but rather inspire stakeholders (teachers, students, administrators, decision-makers) to change, rather than bind them. The challenge lies in designing technological platforms that support new pedagogical methodologies: strategies, practices, and concrete acts grounded in epistemologies that rely on mutual, networked interventions of people and technologies in both digital and physical spaces. Methodologies that aspire to cognitive complexity, acknowledging the hypercomplex nature of current contexts. Educational technologies must therefore be aligned with new epistemologies, with new pedagogical methodologies, and their implementations. In this work, we present a proposal for a technological architecture aligned with the digital transformation of education: Inven!RA, which aims to guide the production of ecological interaction platforms in cognitive ecosystems, within hypercomplex networks of human and non-human participants, where teaching and learning occur.

Keywords: Digital Education; Digital Transformation; System Architecture; Digital Platform; Cognitive Ecosystem

Resumo. As transformações sociais potenciadas pelo desenvolvimento tecnológico mais foram impulsionadas pela pandemia COVID-19 e pela rápida expansão da inteligência artificial generativa. Na educação, estes impulsos mais evidenciaram barreiras ao reconhecimento e abraço dessas transformações. Uma dessas barreiras é a circunstância de as plataformas digitais atuais reproduzirem ou encorajarem processos pré-digitais de ensino e de aprendizagem. Para potenciar transformações na Educação, precisamos de tecnologias não reprodutoras dos processos atuais, que instiguem os intervenientes (professores, estudantes, administrativos, decisores) à mudança, em vez de os condicionar. O desafio está na conceção de plataformas tecnológicas que sustentem novas metodologias pedagógicas: estratégias e práticas e atos concretos fundamentados em epistemologias que se sustentem em intervenções mútuas, reticulares, de pessoas e tecnologias, em espaços digitais e físicos.

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Metodologias que ambicionem a complexidade cognitiva, assumindo a natureza hipercomplexa dos contextos atuais. As tecnologias educativas precisam por isso de estar alinhadas com as novas epistemologias, com as novas metodologias pedagógicas e as suas concretizações. Neste trabalho, apresentamos uma proposta de arquitetura tecnológica alinhada com a transformação digital da educação: a Inven!RA, que visa orientar a produção de plataformas de interação ecológica em ecossistemas cognitivos, em redes hipercomplexas de participantes humanos e não humanos, onde ocorrem o ensino e a aprendizagem.

Palavras-chave: Educação Digital; Transformação Digital; Arquitetura de Sistemas; Plataforma Digital; Ecossistema Cognitivo

I. INTRODUCTION

We live, before, during, and after formal education, in a hyperconnected reality (Floridi, 2015): each heartbeat, each breath, occurs alongside transmissions between our smartphone and digital services. Moreover, every surrounding citizen, each machine we encounter, interacts similarly. Distant systems interconnect and make decisions based on data from everyone and of everything: even the clouds captured by satellites are processed by weather prediction algorithms that lead us to decide on a route or to abandon the thought—determining worldwide behaviors and attitudes. In other words, the physical, biological, and digital are mixed, hybridized, in osmosis.

This hyperconnected reality transcends the human perspective: it includes biological and technological elements, and hyperobjects: complex and multifaceted entities such as biodiversity, cities, climate, or the Internet (Morton, 2013). It is a reality of active entities: we humans are not the only active and communicating beings on the planet. Viruses, forests, and even geophysics, climate, and ecology, algorithms, and artificial intelligences in co-intelligence with us (Mollick, 2024), as well as sensors and actuators, trivial or complex, all are active and intercommunicating entities (di Felice, 2020). In this reality, each entity does not act alone, does not create reality by itself: there is a "symbiosis of creation" where each entity creates the world with others. This was synthesized by Harraway in the term "sympoiesis" (2016).

Therefore, educating within and for this hyperconnected, sympoietic reality requires acknowledging and embracing it. That is, it requires an educational paradigm that acknowledges and embraces hyperconnectivity. This is the problem and challenge that guides us because most educational perspectives have specific focuses: on the human who learns, on the physical, biological, or technological object that conveys knowledge, on the relationship between them. Even when the specific focus of the perspectives is replaced by connections, as in the case of connectivism (Downes, 2022), the human fulcrum of these connections remains.

For an educational paradigm to assume and embrace the entirety of this hyperconnected, sympoietic reality, it must consider the human being as one entity among many others: other biological (non-human) entities, technological entities, and complex entities, all articulated in a network. It should not be focused on subjects, nor on objects, nor only on the links between humans. All these entities continuously articulate, forming an ecology, instead of subject-object dualisms. Therefore, we can summarize the challenge of such a paradigm in the following enunciation: overcoming a dualistic anthropocentric vision to inhabit an ecological era.

Responding to this challenge, to realize it in education, an educational paradigm must articulate with elements that form a theoretical-methodological system (Dmitrenko et al., 2015): the epistemologies, the methodologies, and the concrete pedagogical approaches. Or, from a more pragmatic field application perspective, a paradigm is articulated with concrete actions, practices, and strategies (Beck et al., 2024). Thus, these elements must also be coherent with this ecological perspective: a hypercomplex, hyperconnected, sympoietic perspective. Teachers, students, contents, concepts, competencies, instruments, schools, spaces, cities, technologies, and hyperobjects, all are interacting and interdependent. All are participants, acknowledged as such in the epistemologies, methodologies, and approaches—and, for this reason, also acknowledged as such in the strategies, in the practices, and in the actions. An example of a contribution consistent with this perspective is the cognitive policy of Kastrup (1997a), which considers cognition as a reciprocal relationship between the world and knowledge. Other contributions are multiplying in the literature, with various pedagogical perspectives, emerging as the hyperconnectivity of the modern world becomes evident: for example, Digital Education, which considers that the boundary between the digital and physical worlds is a diffuse one (Dillenbourg, 2016); Hybrid and Multimodal Education (Schlemmer, 2016); Mobile, Pervasive, and Ubiquitous learning (Peña-Ayala & Cárdenas, 2016); approaches that aim to explore emerging technological dynamics through games or gamification (Plass et al., 2015); Immersive Learning, combining technology, narrative, and agency (Mystakidis & Lympouridis, 2023); Co-intelligence (Mollick, 2024) or even the OnLIFE Education Paradigm (Schlemmer, di Felice, et al., 2020), specifically directed at hyperconnectivity.

The perspective we present is that the preponderance, in these pedagogical proposals, of the active role of digital technologies, is not a mere circumstance. We start from the argument of di Felice (2020) that digitalization enhances hyperconnectivity more notably because it promotes the transubstantiation of the elements of reality. That is, digital technologies, being agents of this digitalization, provide each part of the network more perception of its existence and a greater ability to participate. Illustrating with more concrete aspects for education: consider the use of mobile devices connected by wireless networks, devices that contain sensors (including geolocation), now commonly owned by every individual. These devices allow students and teachers to perceive local and remote reality in multiple ways, combining and overlapping data from people, objects, locations, complex environmental entities, and situations (Schlemmer, 2016). And these

devices act without the need for human initiative: something as simple as alerting that they are low on battery affects their bearer's decisions: to save battery, by rethinking their actions, or not to do so, accepting the looming loss of connectivity; or plan a way to overcome this circumstance. The external world, affecting multiple systems or detected by them, will generate notifications or changes to the current information or of actions initiated by the devices, reaching the human beings who carry them. Consequently, digital technologies are predominant in the pedagogical proposals that have been emerging, as mentioned above, because these technologies do more than just be a technological infrastructure: by the transubstantiation of di Felice (2017) they enable deep and complex connections. They enable these connections at the level of the cognitive perception of individuals and enable ubiquitous participation in this hyperconnected reality (Jenkins & Deuze, 2008).

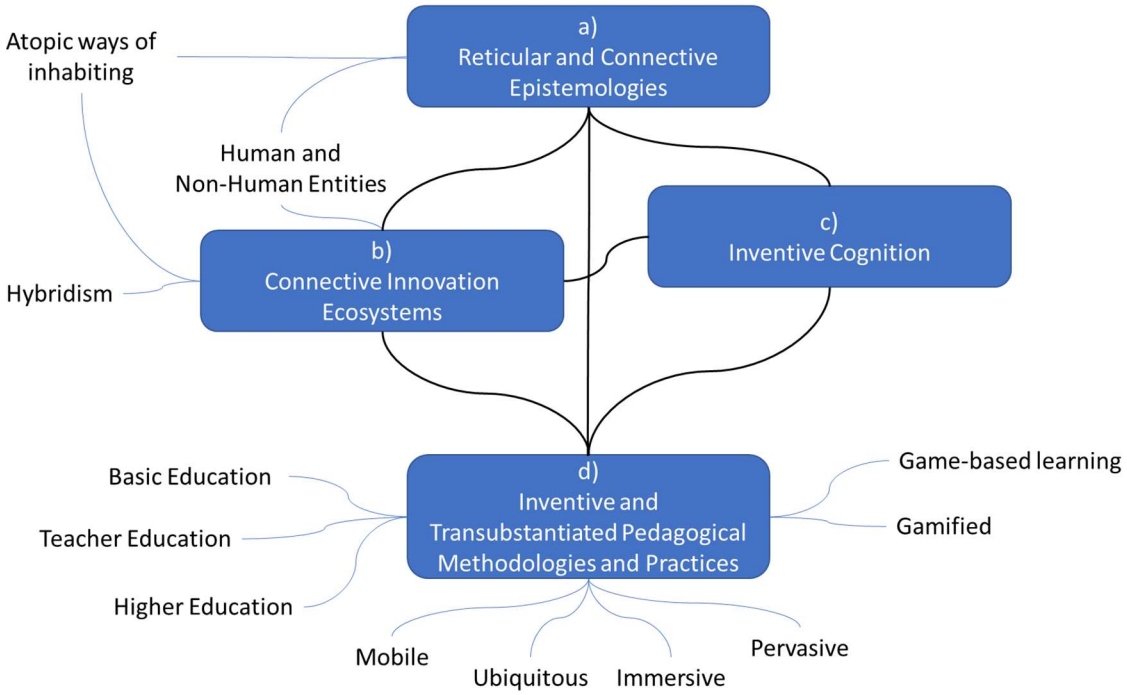
The perspective of the OnLIFE Education Paradigm (Schlemmer, di Felice, et al., 2020), as mentioned earlier, embraces this view of reality as being hyperconnected (everything connected to everything) and sympoietic (everything creating together). It sees teaching and learning as phenomena that emerge from actions among all entities, some human, others organic but non-human, others not even organic, as outlined above. Which is the same as saying that the phenomena of teaching and learning emerge from transorganic connective acts. Since this transorganic interconnection (the transubstantiation of di Felice) is enhanced by networked digital technologies, OnLIFE Education gives them the corresponding preponderant emphasis: in its educational architecture, in the curriculum, in pedagogies, in methodologies, in strategies, in practices, in actions, in contents.

Consequently, it is in this context of hyperconnectivity and digitalization that resides one of the most significant educational challenges of the present day.

II. APPROACH TO THE PROBLEM: CONCEPTUAL INTERSECTION AND REFLECTIVE PRACTICE

Addressing in practice the complexity outlined in the previous grounding fits within the so-called "wicked problems" (Rittel & Webber, 1973): elusive, complex, and transforming in response to the very intervention that mistakenly aims to resolve them directly. Therefore, we adopted an approach of progressive analysis and intervention, which might allow us to understand and progressively interpret this problem and the contours of its possible resolution, pursuing an improvement both in methodologies and practices: of ways to operationalize pedagogical interventions, as well as the means that enable them to review or influence each other. We thus acted within a research-development-training triad.

Figure 1. *Conceptual network approach to the problem*.



Source: Developed by the authors.

This dynamic of research, as a conscious approach to the complex nature of the problem, originated in contact with the social platforms at the beginning of the millennium (including the virtual worlds of that time). Their exploration revealed their nature, for teaching and learning, as hybrid and multimodal spaces (i.e., combining face-to-face and online aspects, synchronous and asynchronous, conjugated and distributed, etc.). This exploration also led us to debate the nature of knowledge and its networked construction, resulting in the conceptual network that coalesced to approach this problem (Fig. 1). The triad supported by this conceptual network helps us understand the transformations required by hyperconnectivity and digitalization in education.

The four fundamental concepts of the network are:

a) **Networked and connective epistemologies**, which look at the hypercomplex networks of interacting entities, where knowledge emerges from the whole and not from particular points: it is atopic (di Felice, 2012);

b) **Connective innovation ecosystems**, which consider education as a living and cognitive ecosystem, where various entities are interconnected and interdependent: humans, non-humans, and hyperobjects (Capra, 1996; di Felice, 2012; Haraway, 2016; Latour, 2007; Morton, 2013);

c) **Inventive cognition**, which regards knowledge as emerging from interventions in the world by multiple entities (multiple agencies); a knowledge that leads each entity to invent meaning for itself and for the way it views the world and intervenes in it;

therefore, it is a view of cognition in which disparate, disruptive meanings continuously emerge (Kastrup, 1997b);

d) **Inventive and transubstantiated pedagogical methodologies and practices**, created over the years to materialize on the ground the previous concepts, developed in contexts of Basic Education, Higher Education, and Teacher Education, involving principles of gamification, game-based learning, immersive learning, mobile learning, ubiquitous learning, and pervasive learning – as such as those originating in virtual worlds, which catalyzed this process (Morgado, 2022; Schlemmer, 2016; Schlemmer, Morgado, et al., 2020).

The first of these concepts (a) starts from a view of digital networks as bearers of complexity: that is, the characteristics and phenomena of digital networks are more than what is individually found in each of their parts (Doolittle, 2014). But beyond a complex nature, this concept (a) denotes that digital networks are composed of other networks, themselves complex: thus, digital networks are a hypercomplex phenomenon (Fernandes et al., 2019). Each act in a hypercomplex network is unprecedented and unrepeatable: its effects emerge, instead of being predictable consequences, because they depend on minuscule differences in initial conditions and their own history (di Felice, 2020; Lorenz, 2008). Viewing hypercomplex networks as the bases of knowledge, through the connections between their entities (di Felice, 2017), these epistemologies are said to be networked and connective (di Felice, 2012). Consequently, knowledge emerges from the whole, thus being non-deterministic and unpredictable. It is not located in a place in space or time; that is, knowledge is atopic (di Felice, 2009).

The second of these concepts (b) is that hypercomplex networks, from which atopic knowledge emerges, are composed of a diversity of entities, beyond human beings. They are crossroads of multifaceted aspects, e.g., psychological, biological, physical, social, cultural (Capra, 1996). Not only by human entities but also non-human, whether biological, technological, or other (Latour, 2007), including hyperobjects: complex and multifaceted entities such as biodiversity, cities, climate, or the Internet (Morton, 2013); organizations, governments, companies, cities, communities, technological platforms, computer systems, mass media, biological organisms, etc. (di Felice, 2017, 2020) —in the current world, these include artificial intelligences, the dynamics of digital transformation, and the Internet of Things, swarms of automata. More than just being networks, they are ecosystems, where each entity interacts with the whole and depends on it, in a relationship of sympoiesis (Haraway, 2016), that is, of joint creation.

This concept (b) connects to the previous one (a) of an emerging view of knowledge, highlighting the preponderant factor of digitalization as enabling greater interconnection, interaction, and interdependence in these networks seen as ecosystems:

> Atopia is not a non-place. Atopia is not a new type of space, nor a simulacrum territory, nor could it be entirely defined as a post-territoriality, in the unique sense of overcoming the physical and geographic forms of space. It would be better to

> define it as the substitution of these by a digital and transorganic informative form, whose constitutive elements are digital information technologies, the informative ecosystems elaborated by geographic and territorial information systems, and social networks, composed by the fusion of intelligent collectives and by the hybrid forms of the dynamism of transorganic languages. Thus, an atopic inhabiting configures itself as the hybridization, transitory and fluid, of bodies, technology, and landscape, and as the advent of a new type of ecosystem, neither organic nor inorganic, neither static nor delimitable, but informative and immaterial (di Felice, 2009, p. 291).

Consequently, combining these concepts, education constitutes itself as a cognitive ecosystem, in which human intelligence is just one among other interdependent and interacting intelligences, with other entities that make up the ecosystem. The logic of education as being solely about humans gives way to a logic of interconnection, interaction, and interdependence among different entities, among different intelligences.

The third concept (c) is that as the nature and origin of knowledge have changed, so too has its acquisition and understanding changed (we will change these terms at the end of this paragraph): there is a new conception of cognition. If knowledge emerges from these networks, ecosystems of various entities, through transorganic connective acts, then cognition consists of participating in these ecosystems. Each entity acts in these ecosystems and interprets them, and this dynamic, "action-interpretation" is the new form of cognition. More than "acquiring" or "understanding," terms we used provisionally above, this new cognition makes knowledge emerge as a global property of intervening in the network, that is, it is an enactive cognition (Kastrup, 1997b; Varela et al., 2016).

This view of cognition as global dynamics of the ecosystem, where knowledge emerges, undermines the legitimacy of conceiving it as an autonomous individual cognitive action: the representational meaning disappears. Consequently, cognition from the perspective of an individual, of an artificial intelligence, of an organization, or of any other entity (tiny parts of the ecosystem) becomes a pragmatic action. Or, in the view of Kastrup (1997b), a "performative agency," where knowing is doing and interpreting, and vice versa. Learning, therefore, is not about acquiring facts or skills to fit into the world, but rather, effectively engaging with it: an embodied agency (Varela et al., 2016). By doing and interpreting, in this relationship with the ecosystem, each entity also makes itself, renews itself, interprets itself. Therefore, cognition in this perspective is also a reinterpretation of oneself and a reinvention of oneself, not just of the rest of the ecosystem: it is an inventive cognition (Kastrup, 1997a).

A corollary of this view on cognition is that learning implies modifying relationships between entities, as a global dynamic of the ecosystem. The learner continuously creates something in their relationship with the ecosystem, reinventing and reinterpreting. For example, tightening or enriching connections between themselves and other entities, or distancing and eliminating them, or changing the dynamics of articulation between other entities, in an infinity of possible interventions.

> The best learner is not one who approaches the world through crystallized habits but one who remains always in the process of learning, which can also be understood as permanent unlearning. That is, learning is to experiment incessantly, to escape the control of representation, ...to prevent learning from forming crystallized habits... it is to be attentive to continuous variations and rapid resonances, implying simultaneously a certain inattention to practical schemes of recognition (Kastrup, 1997a).

The fourth and final perspective (d) emerges from our efforts in the field to achieve practical realizations of concepts (a), (b), and (c). We designed, developed, monitored, and studied methodologies, strategies, and pedagogical practices that mobilized these concepts. Those very efforts assumed the previous perspectives: acting and interpreting in the ecosystem, creating changes in our relationships with other entities, such as students, schools, support technicians, technological platforms, for example. Changes were also introduced in the interactions and interpretations of these entities among themselves. From the outset, by introducing explicitly new practices and new concepts about knowledge, cognition, and learning into teacher training, directly affecting what entities do and interpret. But also, by looking in this way at the realization of these methodologies, strategies, and practices in basic and higher education. Just to mention a few examples resulting from this effort: the PAG (Gamified Learning Projects) and BVER (Reticular Ecological Living Library) methodologies (Lehnemann, 2022), the e-SimProgramming didactic approach (Pedrosa et al., 2022) and various pedagogical practices, such as: Mobile/Ubiquitous/Pervasive Extended Reality Gamification (MUP-ERG), "Contextual Hybrid Escape" (CHE) or "Inventive Immersive Gamification Experience" (iMERGE), realized in initiatives such as "Ghosts in the Museum", "In Vino Veritas" (Schlemmer & Moreira, 2022), "Alice in the Labyrinth of Learning" and "On the Tracks of the City of Itabaiana" (de Lima et al., 2023); "Agora of Knowledge" and MOBinvent (de Lima, 2021); or the view of immersion as an interpretive lens of learning as an emerging phenomenon of the system, narrative, and agency, and a guiding instrument for transformative interventions (Morgado, 2022).

III. THE NEED FOR PLATFORMS ALIGNED WITH DIGITAL TRANSFORMATION

The efforts presented in the previous section, which materialized theoretical concepts into concrete pedagogical strategies, practices, and actions, embracing and assuming the complexity of the ecosystem, highlighted limitations in practicability. From a human perspective, they require a lot of time and effort from teachers. This limitation is not mitigated by current technological platforms but is rather exacerbated, as these platforms steer towards traditional practices. From this realization emerged the challenge of designing platforms aligned with this ecosystemic vision: ecological interaction platforms. That is, platforms with the direct goal of supporting the development of this type of educational approaches.

Following the ecological perspective presented in the previous sections, we must remember that digital platforms themselves are entities of the cognitive ecosystem.

Within this large hypercomplex network, digital platforms are themselves complex networks, made up of interdependent entities that adapt and change. While among organic entities we have the exchange of information through energy and matter, in digital platforms, entities also exchange information, using digital data. In computer science, the current view of information systems refers to the former as "carbon agents" (people, plants) and the latter as "silicon agents," seeing this interconnection between digital platforms and biological systems as forming organizations that are bionic entities (Tribolet & Guerreiro, 2021) — a concept consistent with the transorganic vision we adopt.

The transformation promoted by digital platforms arises from their inclusion in the ecosystem. They interact with the other non-human and human entities of this ecosystem, in an interdependent relationship that transforms it. This transformation can be sustained, progressive, or as happened in the known cases of Uber and Airbnb, disruptive, when the innovation encompasses peripheral elements or introduces new ones and ends up witnessing the taking over of these elements over the previously predominant ones (Geissinger et al., 2020).

In education, the development and adoption of digital platforms is an expanding reality that was accelerated by the COVID-19 pandemic context, due to the then physical isolation needs. Such platforms embody visions about knowledge and cognition: they provide the environment for interactions, for the production and sharing of elements. This even if we did not consider their initiative capacity or their automations: any technological platforms enable or facilitate certain types of acts, encouraging them; they disable or hinder others, discouraging them. Thus, platforms are not just passive tools employed by other entities of the cognitive ecosystem: on the contrary, they also exert agency. That is, they are entities within the ecosystem, interpreting and interacting with others. When we consider the automations and initiative capabilities of technological platforms—not just historically but also now including artificial intelligence—their fundamental nature remains unchanged; it merely becomes more apparent.

Consequently, debating transformations in pedagogical strategies, practices, and actions with digital platforms, without recognizing that these platforms are entities with agency in the ecosystem, is to have a shortsighted debate. Our living space transforms us, and so do the platforms. Their structure, their capabilities, all contribute to modifying our roles and goals.

Consequently, empowering digital transformation, in its relationship with education, requires this recognition. Current educational platforms, designed for the roles of a previous era, must be modified, evolve or be replaced—under the risk of conforming the very emerging transformation to old objectives.

To understand how digital platforms in education might evolve to support transformations, we turned to the conceptual framework by Schlemmer & di Felice (2020), which presented a typology of four models, advocating the need to create the

last of them: Content Provision and Access Platforms, Interactive Platforms, Open World Platforms, and Ecological Interaction Platforms.

Content Provision and Access Platforms emerged in the context of Web 1.0 and are expressed in the first virtual learning environments (VLEs), such as Virtual-U (Harasim, 1999). Closed systems, made up of a set of tools centered on providing and managing information (static contents, mostly textual) and teacher-proposed tasks/exercises/tests/proofs. The student's role was to access them, consume the information, and perform the tasks. These platforms facilitated the transposition of the organization and structuring of teaching into disciplines and sequences of lessons, characterizing a front-end teaching, whose communication process is unidirectional (from teacher to students). They operated from a directive pedagogy perspective supported by behaviorist theories, founded on empiricist epistemology. In these platforms, both teaching and learning were conditioned to a relationship of use, of consumption of pre-existing information, from an anthropocentric perspective: only the human was considered a receptacle of knowledge, as a cognitive agent.

Interactive Platforms emerged within the scope of Web 2.0, which in addition to connecting computers, began to also connect people: it enabled them, beyond access and consumption of information, to produce content on the network, breaking with the separation between acts of production and consumption, since everyone could be producers, consumers, and co-producers. Archetypes of this era are platforms such as blogs, Wikipedia, or Facebook, among others, as well as those specifically with purposes of supporting education like Learning Management Systems (LMS), with Moodle being a common example. These LMS platforms incorporated elements of Web 2.0, enabling teachers to create and structure content and some level of authorship by students. They also allowed monitoring of the traces left during the interaction, as elements for the teacher to reorient the pedagogical practice, from the perspective of the development of a more relational pedagogy, based on interactionist epistemology. However, its practice, many times, remains centered on directive pedagogies, supported by behaviorist theories and grounded on empirical epistemology: it is not unusual for LMS platforms to be limited to being a repository of instructional materials, as previous VLEs. Although in the context of Web 2.0 the agency of non-human entities emerges, the teaching and learning processes of the LMS platforms remain focused on an anthropocentric worldview.

Open World Platforms (virtual worlds) in turn, emerged in their social momentum in the middle of the first decade of the 21st century, through systems like Activeworlds, Second Life, OpenSimulator, and others. They arise in the context of connecting to the Web with alternative interfaces to the traditional browser, providing 3D environments, with forms of interaction common to the universe of videogames. As referred, previous platforms connected people and constituted spaces for creation. In them, the presence of other entities results from vestiges of their actions (e.g., posts in forums) or from tags announcing the eventual availability of other people to interact. In open world platforms,

the way to inhabit them highlights the sensation of human presence. In them, a body becomes the metaphor for interaction. It is through a digital body ("avatar") that the human interacts with the virtual world as part of that very world—and allows the virtual world to interact with them (Morgado, 2009). This concept of virtual presence within the world had emerged well before, in the textual MUD systems, originating at the end of the 1970s and already described as open and creative educational practices in the 1990s (Turkle, 1998), but emerged in their fullness ten years later, in that era of the beginning of the century. There are, of course, platforms with this interaction paradigm that are closed to modification and creation, and others that are open. We consider that for education, particularly relevant are the latter, for the dynamics they allow, in our positioning aligned with the digital transformation in education. Teachers and students inhabit these open world platforms that provide a high level of mutual interaction, authorship, co-authorship, and presence.

Ecological Interaction Platforms will have to emerge. They will have to respond to the previously described context of the hyperconnectivity, of a hyperconnected reality where everything can communicate and interact as a cognitive ecosystem. These platforms will have to contribute to active agency in this ecosystem, interpreting and interacting, not only on the part of humans but also of the diversity of networked digital technologies, intelligent or not. From an educational perspective, Ecological Interaction Platforms will have to favor the active participation of entities in a context where the human being, connected to intelligences and various entities, is a co-producer, a co-interpreter. A context where all entities inhabit the cognitive ecosystem, where knowledge emerges from the whole, in an atopic way, not from specific parts. Thus, these platforms will contribute to overcoming the anthropocentric vision of the world and to the emergence of the ecosystemic vision (Schlemmer & di Felice, 2020).

Such platforms will have the capacity to provoke disruptive movements in Education, urging us to think in terms of pedagogies founded on reticular and connective epistemologies. By being aligned with the digital transformation in education, ecological interaction platforms will inevitably need to articulate with a new cognitive policy in education. This will imply profound changes in the functioning of educational institutions, not just in their pedagogical approaches, but also in their objectives, and consequently in their offerings and management. An example of a cognitive policy at this level is the aforementioned proposal of the OnLIFE Education Paradigm (Schlemmer, di Felice, et al., 2020), although we will certainly see a multitude of contributions emerging in the global debate in this area.

IV. INVEN!RA: A CONTRIBUTION TOWARDS PLATFORMS ALIGNED WITH DIGITAL TRANSFORMATION

A. Design

The proposal of an architecture for Ecological Interaction Platforms emerges from the need identified and defended in the previous sections. The name "Inven!RA" reflects its concept of enabling **Inven**tive agency, where knowledge (**!**) emerges in **R**eticular ecosystems, in an **A**topic manner.

It emerged from the iteration of design activities, over three stages:

1. Design and ideation workshop
2. Theoretical grounding
3. Educational-technological design

B. Stage 1 - Design and ideation workshop

The first stage of the Inven!RA architecture design was a design and ideation workshop, held between January and March 2019. Members of the research team (teachers, researchers, and their PhD students) participated in the meetings using the conceptual network to approach to the problem (Fig. 1).

A multiverse metaphor emerged: several "universes" with many worlds in each; each world with objects and relationships that would represent formal and informal knowledge. Such "worlds" might be specifications of knowledges, of inventive methodologies, and sympoietic pedagogical practices: inventive, immersive, OnLIFE, grounded in reticular and connective epistemologies, favoring atopic forms of cognition, inhabiting cognitive ecosystems in teaching and learning.

In this multiverse, each entity with agency (human or otherwise) takes on a role. In the role of *Explorer*, they collect "objects" to track their own journeys. In the role of *Inventor*, they create worlds or remix existing ones into new versions. Whether in the role of Inventor or Explorer, participants have a "backpack" where they can store "objects" when visiting worlds, or when hybridizing them in the creation of new ones. A collection of worlds forms a universe. As interactions of Inventors expand, new versions of this universe emerge, expanding it into a multiverse. Whenever Explorers visit worlds, they leave traces. Since these worlds are made of these "objects" both physical and digital, such an idealized platform supports the production of knowledge through transorganic connective acts, thanks to creating and intervening in these multiverses.

Following the workshop, this multiverse metaphor was the instigator for creating the Inven!RA logo, a butterfly, symbolizing metamorphosis (education as transformation) and, upon it, a network that highlights a transubstantiated and connective character.

That is, the butterfly, a product of metamorphosis, constituted of matter, is transubstantiated into information by digital means, which through connectivity is shareable, combinable... The Inven!RA butterfly thus symbolizing education as transformation of the network also references the butterfly effect, famously illustrated by the question "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" (Lorenz, 1972). A strong communication of the unpredictability that resides even in deterministic mathematical models, within the scope of the so-called chaos theory. This arose from Lorenz's observation that, even within the domain of classical physics, there are systems (referred to as 'chaotic') in which even minuscule initial variations can generate consequences so complex that predicting them becomes unfeasible or even impossible, leaving nothing to do but wait for time to reveal them (Lorenz, 1963). This view of systems from which non-determinable consequences emerge helps us reflect on the challenges of education when knowledge emerges, in a non-determinable way, from the complex interactions between entities of the ecosystem.

C. Stage 2 - Theoretical grounding

The concept emerged from the workshop was analyzed from an epistemological perspective through the theoretical lenses of section II of this work. From this analysis emerged the crucial need for the Inven!RA architecture to contribute to the creation of Ecological Interaction Platforms (mentioned in section III), capable of fostering joint, transorganic creation among multiple entities, including the methodologies and pedagogical practices themselves.

It was noted in this analysis the emergence in the proposal of the workshop of Stage 1 of specific terms for participants in Inven!RA: instead of terms like "teacher" or "student", the concept rather refers to a leveling of participants, who assume roles transiently: sometimes as explorers, sometimes as inventors. Intersecting this proposal with the organizational and sociological expectations of education, a consequent impact on the assessment process stands out: the relevance of tracking the traces of interactions (exploration and invention), of exploration collections and ongoing or already completed creations. There is in this focus on tracks, on the journey, a parallel with the *flâneur* of Benjamin (2009), through these acts of navigating worlds, interacting, collecting, generating new meanings, sharing, and co-creating. This parallel leads us to remember that walking in an uncommitted way can, on the one hand, leave the explorer "lost," in the sense of alienation, with a longing for guidance; but on the other hand, it also leaves them free, constituting an opportunity to explore and innovate.

This conflict, this tension between alienation and opportunity, embodies the latent risk of its drastic resolution: the option to revert to traditional processes, fighting the feeling of alienation. From this analysis, therefore, emerges the need for platforms aligned with the digital transformation in education to assertively address this tension, providing solutions that obviate it. Promising paths for this, from a theoretical perspective, might be the adoption of approaches that promote situation awareness of participants, a

concept originated in the area of decision-making in critical environments, such as the aviation sector or the military (Endsley, 2000). This theoretical finding, seemingly unexpected for education, was born itself from this wandering, exploratory process. It turns out to be indeed consistent with the epistemological principles presented in the first two sections of this work. In fact, in these areas, where the concept of situation awareness has emerged and developed, participants are permanently interactive parts, constantly interpreting and reformulating a complex ecosystem of multiple agencies, human and non-human, complex and hypercomplex.

D. Stage 3 – Educational-Technological Design

Following on from the previous stages, we crossed the perspectives developed therein with the possibilities of their computational realization. As described in the previous stage, it became necessary to:

a) support exploratory and creative interaction;

b) allow participants to assume different roles at different times;

c) have clear paths/traces of the participants;

d) sustain the situation awareness of the participants.

This intersection found a convergence between these needs and research problems in pervasive and immersive environments. In these areas of educational technology, it is reported that participants are also "lost"—one might even say "overwhelmed" by the loss of autonomy to decide and act consciously, which limits the teacher's intervention to proceed with pedagogical orchestration (Cardoso et al., 2020): it is difficult to plan the time and tasks, for both teachers and students; it is difficult to keep track of what each one is doing; it is difficult to assess and provide feedback (Marklund & Taylor, 2016).

It was also possible to ascertain emerging paths in computer science for solving these problems. Firstly (a) support for exploratory and creative interaction through the area of end-user development (Barricelli et al., 2019), which aims to empower users without specific technical training in computing, to modify and create digital artifacts, including interactive ones or even artifacts involving multiple technological platforms (Sanctorum et al., 2020). Then (b) the enabling of multiple roles for the same users, ensuring this perspective in the analysis and specification of information systems architecture, using the area of user-centered development, where it is common to use concepts such as profiles and personas (Ma & LeRouge, 2007), and also techniques of participatory design (Bødker et al., 2010).

To address (c), having clear paths/tracks, we noted the connection to the area of learning analytics, originally defined by George Siemens for the 1st International Conference on Learning Analytics and Knowledge, as "the measurement, collection,

analysis, and reporting of data about learners and their contexts, for the purpose of understanding and optimizing learning and the environments in which it occurs" (Siemens, 2010). From the perspective of classical participants (teachers and students), this automated process aims to free them from some administrative and repetitive tasks, giving them more time for informed pedagogical intervention. Finally, the answer to the need (d), to sustain the situation awareness of participants, aligns with computing sciences as part of Computer-Supported Cooperative Work (CSCW), where the concept of awareness is crucial, supporting the informed and enlightened agency of participants in non-linear and complex dynamics of interaction and action. In this area, work has recently been done not only on tools and processes to provide this awareness at the individual level but its emergence in social and group interactions, "We-Awareness" (Tenenberg et al., 2016).

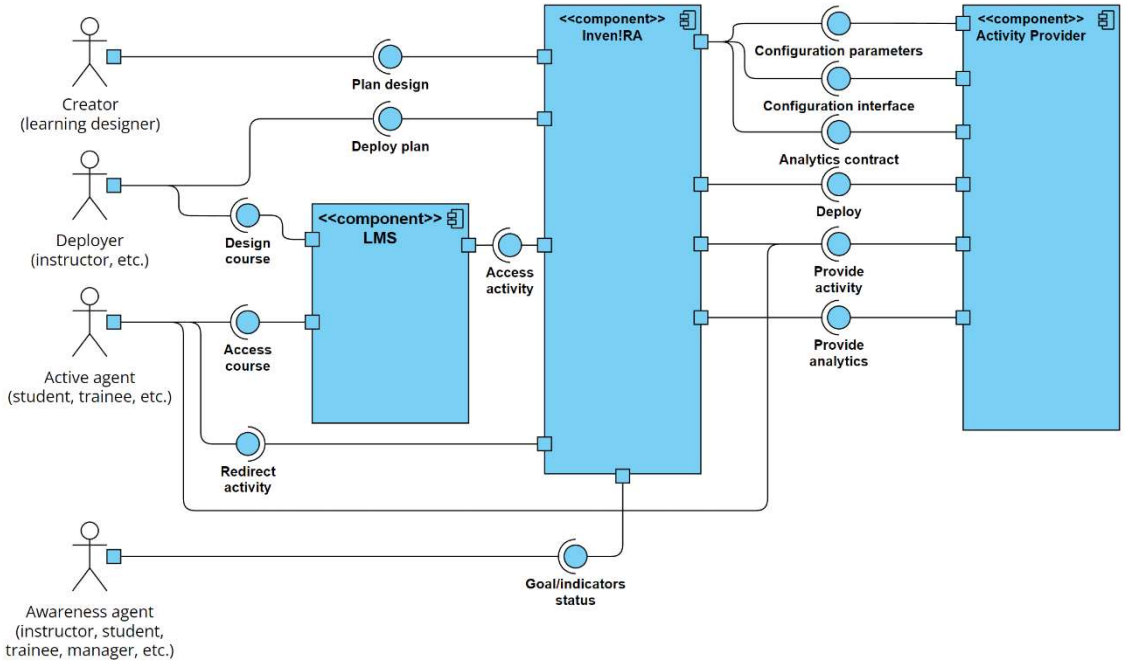
E. The Inven!RA architecture for ecological interaction platforms

The previous stages resulted in the proposal of the Inven!RA architecture, through iterations of design science research (Morgado et al., 2023). This architecture (Fig. 2) aims to guide the development of ecological interaction platforms, i.e., those that support the development of strategies, practices, and concrete acts in cognitive ecosystems.

Given the pervasive nature of the technological, human, and non-human systems that intervene in cognitive ecosystems, it is assumed as a necessity of this architecture that the various activities can occur on different technologies, not concentrated: even provided by different organizations. It also assumes the set of needs identified in the previous sections, such as the diversity of intervention profiles, the need to collect and remix from various sources. Thus, the Inven!RA architecture allows different interfaces for the participating entities, ensuring dialogue and information exchange. This dialogue allows the collection and treatment of analytics to monitor activities, consistently with the new ways of teaching and learning inhabiting a cognitive ecosystem:

> (...) "Our goal is not to be blinded by the traditional contexts of the classroom, but to provide an architecture broad enough to address any set of unconventional activities, the common denominator being that there are objectives to be achieved in a given set of activities and (...) monitoring the progress of users towards these objectives (...)" (Cruzeiro, 2020, p. 20).

Figure 2. *Component diagram of the Inven!RA architecture*.



Source: Morgado et al. (2023).

The current implementation of this concept (Morgado et al., 2023), presented in Fig. 2, advocates the creation of Inventive Activity Plans (IAP) by any participant assuming the role of *Creator* and operationalized by any participant assuming the role of *Deployer* (even though these roles can be performed by the same person or entity). Both roles result from a development of the Inventor role conceived in Stage 1. The IAPs are created by remixing activities hosted externally at "Activity Providers". These same IAPs can be reproduced, remixed, and reused (Cruzeiro, 2020) by deployers. The support for situation awareness, identified as a challenge in the theoretical grounding stage, is supported by connecting analytics to flexible tracking indicators (objectives, competencies, goals, challenges, missions, etc.) according to the participants' purposes (assessment, self-regulation, etc.). This is useful both for pedagogical orchestration and for organizational certification purposes, as well as for decision-making or initiatives by participants in general. Here too, there was a specialization of one of the roles conceived in Stage 1, in this case, the Explorer role, which has been developed into two distinct roles: the *Active Agent*, who participates in activities, and the *Awareness Agent*, who aims to become aware of their situation or that of other participants (roles that can, like the others, be performed by the same person or entity).

Finally, the Inven!RA architecture assumes that current Interactive Platforms (in the sense presented in previous sections) may be part of the cognitive ecosystem, simply ceasing to be the directors and conditioners of pedagogical agency. As can be seen in Fig. 2, the LMS appears as a "component": it is a vehicle to give participants access to activities, providing authentication or administration services, not the backbone of pedagogical structuring.

Current implementations of platforms, using this architecture, have realized it considering that each application case may have a different computational interface, in jargon known as the "front-end" (Cruzeiro, 2020). Front-ends have already been created for teaching microelectronics projects, for pervasive georeferenced serious games, and for activities in remote computer network laboratories (Morgado et al., 2023). These front-ends encompass only the functionalities of creating IAPs and monitoring analytics, using classic interactive platforms for the organizational integration of Inven!RA (an LMS—In the case of these implementations, Moodle). Although developed in academic research environments, the corresponding activities for these cases were created as autonomous systems, as if implemented and provided by third parties ("Activity Provider", as referred to in the jargon of the Inven!RA specification). The interconnection between the Activity Providers and the front-ends occurs at the technological heart of the platform prototypes that implement the architecture—in other words, in the jargon of computer science, in the "back-ends" of these platforms. The most recent version (Morgado et al., 2023) is operational within the teams of the INESC TEC laboratory (www.inesctec.pt) and evolving, with a computer server to support sustained development and research activities in this area.

VI. FINAL THOUGHTS

The design of an architecture for platforms in the field of education highlights the understanding of how knowledge is produced, which is expressed in the functionalities that the architecture offers for the development of pedagogical practices. The digital transformation of education, through platforms created based on this architecture, reflects not only the evolution of digital technologies and types of connectivity but also the understanding of what education is and how the processes of teaching and learning unfold. Although there has been an evolution in the development of digital platforms in education, the appropriation of more disruptive platforms does not easily occur in institutions, as the prevailing epistemologies, learning theories, methodologies, and pedagogical and administrative practices are closely linked to the current platforms, mutually hindering change if attempted partially.

However, the experiences we had during the pandemic, followed by the accelerated expansion of generative artificial intelligence, brought new challenges to educational institutions as we know them, limited to a specific geographical space, with a curriculum organized in isolated disciplines, distributed in synchronous classroom time, with methodologies and practices that respond to predominantly face-to-face teaching. These challenges require the transition from a classroom institution to a cognitive ecosystem: an ecology of platforms, data, access, and co-production of content interactively. That is, they require a shift from learning content to interactive connections, from individual learning to interdependent learning, including co-intelligences (Mollick, 2024). This requires deep structural transformations that involve the very idea of knowledge and a new cognitive policy in Education.

Thus, when we refer to the imperative need for the creation of Ecological Interaction Platforms, these are not understood merely as means or tools, not as "supports" for humans in a relationship of externality with something used to reproduce old ways of understanding the world. Precisely because they produce new forms of connection, communication, and interaction between various entities, Ecological Interaction Platforms must facilitate the creation of new ways of being, of inhabiting the cognitive ecosystem, new ways of teaching and learning. They must be aligned with the digital transformation in education, not merely its anchor or ballast.

We have outlined our contribution to the production of these platforms: a computer architecture to realize them, Inven!RA, which enables the creation, sharing, remixing, and deployment of new types of activity ecologies, new ways of thinking about the world, society, and education, in an understanding of a cognitive ecosystem where knowledge consists of intervention in the hypercomplex network of entities that integrate this ecosystem.

Given its degree of novelty, it becomes necessary to develop research activity to assess its effective limitations and potentialities, as well as paths for its development. Specifically, developing clear pedagogical, certification, and organizational methodologies that recognize the roles and responsibilities of the participants, with a view to clear implementation on the ground (strategies, practices, and concrete acts), considering the platforms as a clear participant in these methodologies and in the cognitive ecosystem. These methodologies are necessary both at the level of planning, preparation, implementation, and development of activities, and at the level of conflict resolution, evaluation, and certification. The platforms should be seen as provisional entities, transformable, that either enable or not the intervention of participants in the complex networks of cognitive ecosystems, and the architecture itself should be regarded as something transitory, changeable, with its own constraints to be identified and overcome, through reformulation or replacement.

In this evolutionary perspective, it is understood that Inven!RA – an architecture for Ecological Interaction Platforms – articulated with the cognitive policy that constitutes the OnLIFE Education Paradigm, can potentiate the effective digital transformation of education. In this way, it can also contribute to a better understanding of Digital Transformation in the broader fields of Social Sciences and Humanities, from the transformations in the fields of Education and Communication.

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