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Ethical enactivism for smart and inclusive STEAM learning design

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ABSTRACT

Current global challenges of the 21st century promote STEAM (science, technology, engineering, arts and mathematics) education and digitalization as a means for humans to be the central actors in the construction of a sustainable society that favors a sense of worth and global wellbeing. In this scenario, new educational technology tools and immersive learning affordances (possibilities), offer unprecedented potential for the design of smart and dynamic learning systems and contexts that can enhance learning processes across varied audiences and educational settings. However, current STEAM education practice lacks attention to equipping all citizens with the necessary skills to use digital technologies in an ethical, critical and creative way. This gap calls for attention in design processes, principles and practices that are attentive to ethical considerations and values-based approaches. On the other hand, in its formulation STEAM as an educational approach is framed in four fundamental pillars: creativity, inclusion, citizenship and emerging technologies, which also put attention on the inclusion of disadvantaged and underrepresented social groups during STEAM education design. Following an apparent need to explore ethical and inclusive design in STEAM education, and inspired in the 4E cognition framework, ethical enactivism and embodied and ecosomaesthetics experience design, here we propose a theoretical framework grounded on systems thinking for the design of smart and dynamic STEAM learning systems and settings. The framework is aimed at STEAM educational psychologists, educational technologists, learning designers and educational practitioners who wish to address the global challenges of 21st century education by means of creative, innovative and inclusive education design.

1. Introduction

The global challenges of the 21st century in the construction of a society 5.0, promotes digitalization as a means for humans to be the central actors in society that favor a sense of worth and global well-being [1]. The technological transition of humanity arose from

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mechanisms powered by water and steam, then electronics and later computing and cybernetics, to smart devices, mobile applications and artificial intelligence, representing the current spirit of the technological avant-garde [2]. In this scenario, immersive learning tools and affordances (learning possibilities), such as augmented reality, virtual reality, mixed reality and immersive learning environments, offer smart dynamic learning contexts that can enhance and maximize user experiences [3,4]. Likewise, the use of remote sensorization, big data and robotics within creative technologies open up entirely new opportunities ranging from surgery to art and personalized amusement park rides, as well as industrial robots [5,6].

Digital applications connected to the Internet of Things (IoT) using microelectronics and wireless technology can configure embedded systems collecting and distributing data in real time [7]. These important advances are permeating new ways of conceiving smart/adaptatives dynamic learning contexts with the potential to generate an impact on the economic industry and other diverse social spheres (e.g., fashion, events, gaming, education, and office) based on immersive interaction, such as for example the Metaverse [8]. To face these new challenges that involve inhabiting a complex and technological world, it becomes urgent to think about new educational approaches that can relieve a systemic and organic curriculum, while focusing on learners' embodied engagement strategies addressing the particular needs of local contexts. On the other hand, the use of these technologies call for considerations on inclusive and equal access to them, research and understanding on their influence in socio-affective areas, and strategies for their implementation with appropriate pedagogies, particularly in the new global post-pandemic contexts.

Educational policies worldwide have not remained indifferent to these new development scenarios in the 21st century, proposing integrated educational approaches such as Science Technology Engineering Mathematics (STEM) and Science, Technology Engineering Art and Mathematics (STEAM) to deal with these challenges. STEM embodies the North American ideals of the late 1990s promoting the articulation between life, education and work centered on industrialization and robotics [9]. On the other hand, STEAM in its reformulation at the beginning of 2011, is framed in four pillars such as creativity, inclusion, citizenship and emerging technologies [10]. Likewise, STEAM as an educational approach promotes the development of 21st century skills, such as critical and creative thinking, intellectual openness, responsible innovation and computational thinking [11]. The adoption of these approaches, in particular STEAM, turns out to be an auspicious field to catalyze the current challenges of the UNESCO 2030 Agenda based on individual, social and planetary well-being [12]. The achievement of this objective, as well as the development of 21st century skills, are urgent imperatives for educational organizations that aim to educate for peace, climate change mitigation, social and educational inclusion [13] in light of smart dynamic learning contexts with STEAM education.

Based on theoretical and empirical foundations in STEAM education, we identify as a knowledge gap the need to equip all citizens with the necessary skills to use digital technologies in an ethical, critical and creative way [14]. In particular, we allude to educational design with immersive and creative technology according to the four pillars of STEAM. The design of smart dynamic learning contexts with STEAM education requires not only new technologies and ad hoc pedagogies, but also new approaches to human cognition that promote constitutive ontologies of learning based on perception and action, such as the 4E of cognition approach: embodied, enactive, embedded and extended [15]. Here we adopt a digital innovation design approach based on dynamic systems, inspired from systems theory and complexity theory in education [16–19], that are founded on enactivism and ecological psychology [20–25]. These new situated, non-representationalist, and embodied approaches advance educational research that remains incipient in terms of how performing sensori-motor actions can contribute to the development of conceptual knowledge in expanded dynamic settings of interaction with humans and technology [26–28]. In this scenario, the use and spread of digital technology, tools and affordances in education has shown to improve the practice of teaching and learning across sectors [29].

In relation to the above and driven by the Sustainable Development goals that will help improve the way we live [30], here we explore how the design of digital innovation in education, based on the design of smart dynamic learning systems and contexts for STEAM education, ought to highlight ethical aspects linked to work with disadvantaged, indigenous and underrepresented communities. Based on theoretical and practical evidence, we reflect on how STEAM education and 4E approaches to cognition grounded on a systemic logic, provide a synergistic framework for the design of smart dynamic learning systems and contexts for ethical STEAM education. In doing so, we adopt an ethical enactivist approach [31] that seeks to broaden the traditional understanding of technological educational designs informing tacit knowledge in constrained settings of ethical action. We also allude to how STEAM educational designs can scaffold the practical understanding of traditional and indigenous worldviews, through the design of embodied, sensorial and somaesthetic immersive learning experiences [32]. Likewise, we argue how sensorization and robotics can configure forms of creative computational thinking that contribute to responding to socio-ecological problems in innovative and smart ways.

In this article we ask ourselves the following guiding research question: How can a smart digital design incorporate the ethical enactivist dimension in creative ways to promote critical and context-relevant STEAM learning ecosystems? To address this, we follow a systemic epistemology in the integration of new technologies and pedagogies in critically creative ways, along with a 4E cognition approach to human cognition, founded on an ethical enactivism of care for life and planetary wellbeing [31,33]. Our proposal could be of use to STEM and STEAM educational designers, researchers in 4E cognition and educational technologist researchers, designers and practitioners who wish to address the global challenges of 21st century education. We also see our proposal potentially contributing to the contemporary conceptual discussion on the theoretical and empirical foundations of 4E cognition and enactivism, regarding those incipiently smart digital design principles in educational contexts. Below we offer a position article that addresses the following topics: (i) educational challenges in the 21st century: STEAM education; (ii) approaches in 4E cognition: enactivism and ecological psychology for dynamic learning; (iii) design of smart dynamics contexts: immersive learning experiences and Maker Activities; and (iv), a theoretical proposal for the design of smart dynamic learning contexts and systems for ethical STEAM education.

2. Literature review

2.1. Educational challenges in the 21st century: STEAM education

Following a meeting at the United Nations Headquarters in New York in September 2015, just on the seventieth anniversary of the Organization, the new global Sustainable Development Goals had been agreed, called 'Agenda 2030', (RES/70/1) [34]. Agenda 2030 identifies the Sustainable Development Goals that will help improve the way we live. These objectives seek to address great challenges, such as the protection of resources, the reduction of poverty, and the provision of equal opportunities. These objectives are a guide to participate and build the world we want to achieve by the year 2030.

This new Agenda builds on three dimensions: economic growth, social inclusion and environmental balance. Within the Sustainable Development Goals, we can find: SDG1: No Poverty; SDG2: Zero hunger; SDG3: Good Health and Well-being; SDG4: Quality Education; SDG5: Gender Equality; SDG6: Clean Water and Sanitation; SDG8: Decent Work and Economic Growth; SDG9: Industry, Innovation and Infrastructure; SDG10: Reduced Inequalities; SDG11: Sustainable Cities and Communities; SDG12: Responsible Consumption and Production; SDG13: Climate Action; SDG15: Life on Land; SDG16: Peace, Justice and Strong Institutions; SDG17: Partnerships for the Goals. We can find references in SDG4 Quality Education, the need to guarantee inclusive, equitable and quality education, and to promote lifelong learning opportunities for all. This implies attention to the socio-cultural, demographic and environmental contexts, if sustainable development is to be achieved, where quality education is at the basis.

We aspire to a world in which respect for human rights and the dignity of people, the rule of law, justice, equality and nondiscrimination are universal; where race, ethnicity, and cultural diversity are respected and where there is equal opportunity to fully realize human potential and to contribute to shared prosperity; a world that invests in its childhood and where all children grow up free from violence and exploitation; a world in which all women and girls enjoy full gender equality and where all legal, social and economic barriers to their empowerment have been removed; a just, equitable, tolerant, open and socially inclusive world in which the needs of the most vulnerable are met [30, para. 16].

One way to address these sustainable development goals is through the challenges proposed by the Organization for Economic Cooperation and Development [12], who have reflected on the future of education and skills targeting the year 2030. The OECD proposes a set of guidelines for educational policies and schools, among which the agency of students and teachers in their learning experiences are highlighted. A focus on the need of dynamic and flexible curriculum to integrate the content and authenticity of the learning processes allowing to respond to real-life problems and transferability of knowledge, skills, attitudes and values is also stressed, revealing the integral dimension of the human being.

In order to incorporate these OECD guidelines for a relevant and sustainable type of education as 2030 challenges, it is necessary to attend the cultivation of 21st century skills in which critical thinking, intellectual openness, collaborative work, citizen training, responsible innovation and computational thinking stand out [35]. An alternative to respond to the educational challenges of the 21st century is the STEAM educational approach, presenting an auspicious field of innovation and development founded on four fundamental pillars: creativity, inclusion, citizenship and emerging and creative technologies [10]. In turn, a systemic curriculum of disciplinary integration, 21st century skills and digital innovation strategies ought to be based on solving real-life and authentic problems and challenges [36].

Real life problems and challenges are characterized by being complex (or 'wicked'), requiring inter and transdisciplinary approaches. Here, STEAM turns out to be useful as a comprehensive integral strategy seeking to empower individuals and communities by weaving science, technology, art and mathematics [37]. The ubiquitous connectivity of smart digital devices, the internet of things and new and emerging learning technologies are part of the global challenges in education aspiring to contribute to the individual, social and planetary well-being objectives set-out by the OECD [12]. The evidence of STEAM in educational organizations has made it possible to improve educational practices concerning collaborative work, the use of technology and the emphasis on scientific research and inquiry [38]. Quigley and Herro [39] have identified that using technology to solve a problem in which science, technology, engineering, arts/humanities and mathematics are integrated facilitates the understanding of content usually considered abstract. The monolithic imperative and the prescriptive nature of the study plans of school curricula have been counterproductive in responding to real problems that demand interdisciplinary cultivated skills along with the use of new technologies [11]. In tune with the 21st century skills, digital literacy is a critical skill for students to develop, replacing the idea of a consumer for that of a technology prosumer to fully participate in the rapidly transforming digital society [40].

The different facets that societies are taking in the future ahead of the 21st century depend largely on technological advances, where educational systems embracing digital innovation with STEAM not only can cultivate more capable individuals and communities in the development and use of digital technologies, but also can make them more reflective, critical and creative [41]. Given the current impacts of the COVID-19 pandemic, migration, climate change, and war, and the rise of smart technologies that are part of the current agenda of educational policies in the world to reformulate schools, STEAM provides an attractive pedagogical framework for addressing these complex and wicked problems [42].

STEAM as an educational approach can be embodied through the use of various active learning methodologies, such as projectbased learning accompanied by emerging technologies that encourage critical and creative thinking in students with the aim of addressing curricular contents through real and authentic problem-solving, contributing to sustainable education [25,43]. An example of the above is the design of learning ecosystems with immersive learning technologies, as well as the use of creative technologies linked to artificial intelligence and sensorization, which has provided multiple benefits to educational organizations addressing various community problems and challenges, e.g. see Eglash et al. [44] ethnocomputing, Eames and Aguayo [45] ecological literacy, Weiss et al. [46] medical innovation, Marcowitz and Bailenson [47] climate change. Much of this evidence has incorporated principles from STEM and STEAM approaches that highlight the ethical dimension of educational designs, especially the emphasis on learning by doing together.

2.2. 4E cognition approaches: Enactivism and ecological psychology for dynamic learning

The changes in teaching modes and the design of new STEAM learning ecosystems based on learning by doing and the use of emerging technologies, provide an attractive field for educational researchers and cognitive scientists who resist the dualistic perspective of an incorporeal intellectualism [25,48,49]. Abrahamson [50] argues that the notion of intelligence that we attach to human behavior generally stems from technological trends. Therefore, it is counterproductive for educational design in the 21st century to consider cognitivist foundations from the 20th century that relieve representationalism and the discontinuity between perception, cognition and action. In the case of first-order cybernetics, the focus is on the centralization and linearity of the processes characterized by the metaphor of mind as a computer, while second-order cybernetics is based on decentralization and non-linearity, relieving the notion of systemic thinking (also 'systems thinking').

The persistence of cognitivism that conceives the mind from a functionalist logic based on physical internal and external mental representations [51] has denied the relational ontology in which people and things are conceived as entanglements [52–55]. In response to this computationalist and anti-systemic tradition that breaks the continuity between perception, cognition and action, various systemic and embodied perspectives have proliferated, i.e., see phenomenology of perception [56], autopoiesis and cognition [57], enactivism [23], embodied cognition [58], mind and life [59], radicalizing enactivism [22], ecological brain [60] and Linguistics Bodies [61].

All these post cognitivist perspectives have been combined within the so-called 4E cognition approach: embodied [62], enacted [23], embedded [63] and extended [64]. With regard to embodied cognition, reference is made to the bodily realization of cognitive faculties in which the meaning of the agent emerges from the warp between the sensorimotor physiological level and the world on which it acts. Enacted cognition emphasizes the role of experience as embodied cognition, in which the structure of an organism is understood as its biological constitution, therefore organic, dynamic and in continuous structural coupling with the environment. Regarding embedded cognition, co-dependency of the cognitive system and the environment is revealed through the material commitment in the co-creation of cultural semantics and artifacts, including language and technological tools that allow the so-phistication and expansion of the capabilities of contextually substituted cognitive agents [65]. Extended cognition emphasizes the possibility that the cognitive system sometimes extends to external entities given a functionalist logic of decentralized and immaterial constitution of the biological person. Another relevant perspective that is currently of great interest to scientists, philosophers and educators is the ecological psychology proposed by Gibson [21], then further expanded by Rietveld and Kiverstein [66], which reveals the possibilities or affordances available in the environment as dynamic dispositions that are in tune with the capabilities of the agents.

Current research on enactivism is broadening its understanding in multiple variations such as autopoietic enactivism based on biodynamics and phenomenology required to enact sense-making cognitive structures [23]; sensorimotor enactivism whose focus is on perception based on the sensorimotor contingencies that occur between perception and exploratory activity [67]; and radical enactivism that is based on intelligent dynamic behavior in the absence of internal and external representations [22]. These variations of enactivism are united by a common commitment to understanding cognition as rooted in our engaged, bodily lives [68]. Like enactivism, the ecological psychology proposed by Ref. [21] and expanded by Rietveld and Kiverstein [66] is not committed to representations. In ecological psychology, perception is not a state of thought separate from the environment, but from the entire organism-environment system. Enactivism and ecological psychology share the idea of dynamic learning, through the formation of an expansive ecological niche of co-dependence between the perceptive capacities of organisms and the opportunities of the environment in the form of ever-evolving affordances.

The 4E's of cognition and ecological psychology offer a robust framework for understanding cognition and learning as a dynamic, embodied, non representationalist system. However, these approaches, and the material engagement of cognition that is based on the evolutionary premise that the type of mind we have depends on the type of tools we create and use [54], are incomplete if we want to address the design of dynamic learning ecosystems in the light of 21st century STEAM education. Even more so if they reveal the notion of learning by doing with others grounded in real and authentic contexts and problems of communities and the planet. Based on the above, enactive approaches and their ethical extensions become attractive [31,69,70], and, ecological psychology as a field of social possibilities allows us to understand cognition not only beyond the relationship with tools, but also with people in a broader social sense [66]. In particular, how tools, in this case immersive and creative technologies, can improve the quality of life of people, communities and/or the planet, as suggested by the OECD [12]. The first enactive approach to ethics was Varela's ethical know-how [71] in which ethics is deepened from an embodied, situated and historical conception in the engagement of the world with others.

These ideas are rooted in the foundations of tacit understanding and learning in which cognition is entangled with the world as a result of a history of structural couplings with the environment. The environment can be understood as the historical circumstance that emerges from different levels of normativity between cognitive agents, material artifacts and culture. In other words and following Varela [71], "in the perspective of perception as action, reality is not something given. It is dependent on the perceiver, not because he constructs the world in a whimsical way, but because what counts as the relevant world is inseparable from the structure of the perceiver" (p.7). At a broader level and co-dependent on optimal physiological conditions and perceptual and sensorimotor structures, values and normativity emerge in the maintenance of the individual in relation to others in a broader context of interaction dependent on coordination of sociolinguistic coordination [67,72,73].

The fundamental characteristics of ethical enactivism, unlike other approaches, is that it allows us to understand the interactions and their normative link based on the following assumptions: "(i) living organisms as a source of meaning and value, and (ii) social

interactions as second-person engagements that involve mutuality between agents to respond to the needs of the other" [31, p.9]. This extension to the ideas previously exposed with the concept of participatory sense-making [74], advances towards an understanding of social interaction beyond the possibilities and obstacles that emerge from the peculiar dynamics between agents. In particular, this enactive ethical proposal emphasizes "a source of universal value: life, i.e., care for life is prioritized as a moral foundation" [31, p.10]. Ethical enactivism accepts the moral relativism that promotes care for one's own autonomy and that of others, with the aim of cultivating the possibilities that maintain or increase identities in different cultures [33]. These identities are manifested in socio-cultural practices that structure patterns of activities and interactions between agents that count as morally right and wrong in a given circumstance.

3. Immersive learning experiences and Maker Activities

Both STEM and STEAM as educational and literacy approaches require the development of interdisciplinary competences in future citizens to respond to present and future scientific and technological challenges [75], and to solve the challenges of contemporary society [76]. New immersive technologies have a high potential for the development of STEAM practices and STEAM abilities, and for the creation of novel learning environments, enriching the experiences carried out in these environments. The development of virtual reality (VR), augmented reality (AR) and mixed reality (MR/XR) technologies and environments can offer interactive visualization in three dimensions, which can be widely used in fields such as commerce, industry, and education [77]. For example, in connection to AR and its use in education, the major findings, advantages, disadvantages and challenges have been systematized (i.e., see Refs. [46, 78–84]). T he advantages of using such technologies in the learning process of sciences, for example, is that they offer learners the possibility to engage with virtual immersive experiences connected to abstract or unobservable phenomena [85,86]. For example, exploring virtual environments, or using three dimensional (3D) digital models and affordances which, by different levels of interaction, can be manipulated (rotated, augmented) in real time using a mobile device.

This type of technology can favor the learning process of scientific concepts, the development of spatial and metavisual skills [87], the motivation for the use of technology [88], and social collaboration processes [78], among others. Recent findings indicate that AR can provide motivating and safe training scenarios in which some learners show high levels of satisfaction, regardless their level of education or the course contents [80,89,90]. VR, on the other hand, is a technology offering different degrees of immersion depending on the hardware and operating platform, which digitally has the potential to simulate the real world, or to provide experiential access to virtual and artificial worlds, allowing for a sense of presence [46], interaction, and spatial immersion. This in turn can generate motivation and stimulation in the learning process, as well as the development of abstract and imaginative abilities, the increase of creative design and innovation [91]. A recent revision compares groups that use VR and groups that don't, concluding that VR technologies positively, and significantly, can significantly impact learning processes and achievements, as well as promote and enhance motor skills, cognitive strategies and learning attitudes [92], because it offers a benefit over less immersive learning methods (as text and audio, for example) [93].

Maker activities, in contrast to immersive experiences, consider the use of a variety of technologies including 3D printing, laser cut, physical computing, programming, and everyday materials such as toys and handicrafts [94]. These activities integrated in formal, non-formal and informal learning environments have great potential to promote student's creative making and learning of content knowledge, design skills, innovation, and understanding of STEAM connected computing concepts. Students can change their will-ingness, their perception, and personal feelings during creative activities when they face manufacturing and design activities, with reported positive effects, enjoyment, and negative effects on anxiety [95]. Maker activities can be versatile and flexible, and are well-suited for taking place in formal, guided and collaborative formats, giving opportunities to increase learners' commitment, communication with others, and participation.

Computational technologies such as robotics, physical programming and computational thinking provide numerous opportunities to understand human-computer interaction, and the resolution of complex problems starting from computational thinking pathways, which have been strongly connected to STEAM subjects in education [96]. Prendes and Cerdán [97] document in a review of the literature the way these computational technologies have been studied in terms of performances such as creativity, spatial skill, attitude and willingness, and conceptual learnings in STEM and STEAM subjects, as well as how such technologies can promote so-cialization, collaborative, and cooperative skills among students. Thus, the implementation of these technologies offer real opportunities for the development of 21st century abilities and skills.

An interesting side point regarding the use of the technologies presented is the high representation of research related to learning modes in the literature, and a smaller representation of research related to affective dimensions and social abilities, even less so regarding students and learners with special, general, and specific needs in education, or in minority groups such as underrepresented groups, and indigenous and aboriginal communities [98]. Some familiar examples to us of the latest case in Chile include Aló et al. [99], focusing on underprivileged students in Chile from vulnerable public schools of southern Chile, developed a low-cost environmental monitoring system to assess attitudes and perceptions towards climate change following a STEM focus. Cano [100], on the other hand, focused its attention on the development of teacher STEM using educational robotics coming from a gender perspective. Merino et al. [86] designed a scaffolded learning sequence using AR to educate students about Chilean biodiversity using a native snail as a learning model from a STEM perspective, while Salvatierra and Cabello [101] recognise that the involvement of parents in early childhood STEM education is critical for children's self-capacity over STEM topics, yet underexplored. Campbell and Speldewinde [102] highlight the importance of integral learning in early childhood education, and how an early STEM education on children can contribute towards sustainable development goals.

4. Design principles for ethical smart STEAM dynamic learning systems and contexts

Our motivation to propose a framework for the development of smart dynamic learning systems and contexts for STEAM education based on new educational technologies, such as immersive learning and Maker activities, comes from the apparent reported gap in the STEAM education literature about the skills needed for the design, creation, implementation and use of digital technologies in ethical, critical and creative ways. In particular, we are interested in laying down foundational design principles in educational technology design, inspired from systems thinking and ethical enactivism, that are in line with the 21st century skills (critical thinking, creative thinking, intellectual openness, responsible innovation and computational thinking) and the four pillars of STEAM education: creativity, inclusion, citizenship and emerging technologies [10]. We see promising potential in the design and use of smart dynamic STEAM learning contexts and systems that follow ethical and values-based approaches to catalyze the challenges of the UNESCO 2030 Agenda in promoting social, ecological and planetary wellbeing.

Our starting premise is the epistemological view that cultural, socio-ecological, technological and educational phenomena are complex, unpredictable, ever-changing, and interrelated with many other dimensions with inherent complexity in unknown ways. These new complexities and interdependences in today's modern world demands a shift in perception and thinking, acknowledging that traditional and mainstream ways of thinking got us in the current planetary crisis in the first place [103]. One promising alternative to address complex and unpredictable phenomena is to adopt and embrace a systems thinking approach [104,105], based on systems theory, complexity theory and other theories alike (e.g. cybernetics and non-linear systems). In particular, both systems theory and complexity theory applied in education not only offer a way to understand social, cultural, ecological and technological in education, but most importantly, it also provides the necessary principles to create and design smart dynamic learning systems and settings, providing adaptable and flexible educational settings, environments and experiences that can be embedded within complex socio-cultural and socio-ecological settings [16,18].

Our second premise is the need to create and design educational technology affordances, systems, settings and environments that follow ethical and culturally responsive and values-based approaches to educational design. This point complements the previous one in that embracing a systems thinking approach on its own is insufficient to address inclusion, equity, responsible innovation and citizenship, following the challenges of the UNESCO 2030 Agenda. Educational psychologists, designers, technologists, researchers and practitioners ought to understand socio-cultural and socio-ecological phenomena as complex, and thus, create and offer learning opportunities that can adopt systemic and ethical principles accordingly. Having universal values such as love, compassion and care underpinning and driving educational design principles and processes becomes critical in the design of ethical STEAM dynamic learning settings and systems [106,107]. Here, new approaches to cognition coming from 4E cognition, and particularly, from ethical enactivism founded on the concept of ethical action and the care of life as a moral foundation, can guide the design of immersive and embodied learning targeted at STEAM educational goals and outcomes.

Finally, our third premise is to ground our proposal in innovative and creative making using the set of learning affordances offered by new educational technology tools, such as immersive learning, creative Maker activities, remote IoT (Internet of things) sensorization, robotics and big data, expanding the learning in digitally smart ways, when compared to traditional educational tools and affordances. Moreover, we argue that such smart technological learning affordances, settings and systems have the potential to bring about somaesthetics modes of learning, scaffolding practical ways of connecting and understanding traditional and indigenous



Fig. 1. Diagram showing the motivation (reported knowledge gap on the need to equip all citizens with the necessary skills to use digital technologies in an ethical, critical and creative way) and inspirations (systems thinking, 4E cognition and ethical enactivism, 21 century skills and STEAM pillars), and premises informing a framework for the design of ethical and inclusive smart dynamic learning settings. (i) Systems thinking and the design of dynamic systems.

worldviews through embodied and somaesthetics experiences. We summarize these ideas and premises in Fig. 1 below. In the next section, we expand on how these three key premises can inform the design of ethical and smart STEAM dynamic learning systems design.

Systems thinking refers to the ability to approach and understand complex phenomena by looking at it as composed by wholes, systems and relationships, rather than reducing it down into its parts [108]. Systems thinking is founded on systems theory, an interdisciplinary field of study that focuses its attention on the type of relationships that exist within the components of any given system. A system is understood as a whole composed of interconnected parts, where the nature of the interactions between the parts determine the qualities or 'properties' of the system [109,110]. Systems thinking emerges as an alternative to the analytical and reductionist thinking (i.e. the type of thinking that focuses on understanding things by reducing them into its parts) tradition dominant in Western societies [111]. Since social, ecological and planetary problems are increasingly complex, interdependent and globalized, they cannot be understood in isolation or by taking them apart anymore, but from a holistic and systemic perspective looking at how different components are interrelated between them.

One key characteristic of systems is that they are not static, but instead dynamic and in constant change, activity or progress. Moreover, the properties of a system cannot be found in its parts when looking at the parts alone. Instead, they are the result of the whole coming and interacting together, where properties and qualities of a system emerge as an arising and novel and coherent set of structures, patterns and self-organization [112]. Other properties of systems are that they possess boundaries and are immersed within a particular context, they have a function or purpose of being, and when looking at a collection or universe of systems, patterns of interactions tend to appear between them [104]. It is argued that any phenomenon can be understood from a systems thinking perspective, by developing a model or a theoretical representation of a system. In this sense, modeling a system is a subjective representational process, and thus subjected to the personal interpretation of the interpreter [105]. Fritjof Capra highlights that "mapping relationships and studying patterns is not a quantitative but a qualitative approach", pointing out to the importance of qualitative perspectives for systems thinking [107, p. 2].

Different authors have explored the application of systems thinking, systems theory, complexity theory and other similar approaches in education. For example, Jorg [113] looks at the reciprocal relationships existing between learning actors, where learning is seen as an emergent phenomena resulting from the coming together into shared action of such learning actors. For Sumara and Davis [24], this idea of reciprocal relationship or coupling between learners actors suggests that "a new transcendent unity arises when two or more persons come together in conversation or in any shared action" [24, p. 414]. In this respect, Aguayo postulates that technology-enhanced learning systems can be regarded as learning actors promoting and facilitating the emergence of the learning process [16]. Sumara and Davis [24] further contend that "the cultural practice known as 'education' occurs within and among complex systems that span several phenomenal levels", where "educational theories and practices that are inattentive to the particularities of context and, more specifically, that are inattentive to the evolving relations among these particularities, are no longer adequate" (p. 418). In other words, the learning process is influenced by its context.

Following the idea that the particular structure, organization and characteristics of the learning setting determines the outcomes of a learning process, Murray [114] asserts that we cannot make people learn directly, but we can create the right conditions where learners can connect with their own personal stories. Learning ought to be about doing interpersonal relationships within a particular school or learning setting, by creating the adequate conditions for the learning process to best occur [114]. Related to that, Davis and Sumara [18] report that complexity theory applied in education allows for the understanding of how complex learning systems can unfold into an educational system that can be purposely created and nurtured to facilitate the learning process. These authors highlight four key conditions for the creation and nurturing of educational systems: interactivity, diversity, means for learners to affect each other, and a decentralized control structure [18]. Coming from complexity theory in education, Morrison [19] states that leadership is critical to empower learners, where leadership implies being an enabler and facilitator of the learning process, rather than directing and gatekeeping learning.

Key considerations, or design principles coming from systems thinking, systems theory, and complexity theory in education (i.e., education as systems, consideration of the learning context, interaction between learning actors, conditions for the creation and nurturing of educational systems, and regarding educational systems as facilitators of learning), provide us with some guidelines to model, conceptualize and guide the design of dynamic and adaptable STEAM learning systems using new educational technology, immersive learning experiences and Maker activities within the framework of a systemic epistemology.

(ii) Ethics, values and ethical enactivism for STEAM education and planetary wellbeing

Addressing the implementation of the UNESCO 2030 Agenda by means of STEAM education and new learning technologies ought to include considerations for social inclusion, cultural values and a planetary ethics. From a systems thinking perspective, there can be many solutions to one given problem, but not all those solutions necessarily convey ethical principles and values. Thus the importance of addressing complex challenges in ethical and values-driven ways, with attention to inclusion, access and equity, when designing smart dynamic learning systems and settings. Inevitably, these systems and settings will be influenced and shaped by the culture in which, and for which, they are designed, which stresses the importance of taking into account the local cultural values and the suitable pedagogies fitting the target culture [115].

In our proposal we argue for a relevant theoretical expansion about ethical enactivism that serves as a basis as a cognitive proposal to support the design principles of smart dynamic learning contexts for STEAM education. The relationship between STEAM and enactivism is based on the revitalized pragmatism of the seminal works of Kilpatrick [116] and Dewey [117] with the current emphasis on learning by doing together derived from the principles of STEAM education. Interestingly, the current approach to ethical

enactivism and STEAM are rhizomatically linked to the sustainable development goals that outline the path of the 2030 education agenda. The focus of the 17 sustainable development goals is the respect, construction and appreciation of human rights that tend to improve individual, social and planetary well-being, especially for those underrepresented groups. From this, we reflect on the scope of post cognitivist approaches to cognition towards educational challenges for 2030 that promote a strong ethical commitment. We conclude that an ethical enactivist approach is in tune with these demands and for which we consider in this proposal.

The fundamental characteristics of ethical enactivism, unlike other approaches, is that it allows understanding interactions and their normative link based on the principles: "(i) living organisms as a source of meaning and value, and (ii) social interactions as second -person engagements that involve mutuality between agents to respond to the needs of the other" [31, p.9]. This extension to the ideas previously exposed with the concept of participatory sense-making [74], advances towards an understanding of social interaction beyond the possibilities and obstacles that emerge from the peculiar dynamics between agents or learning actors. In particular, the ethical enactive proposal emphasizes a source of universal value: life, that is, the care of the process of life is prioritized as a moral foundation. In this sense, the minimum condition of ethical normativity is the care of one's own life and that of others based on interactions of reciprocity and responsibility. Participating in interactions that reveal the ethical dimension of human living in its autonomy and simultaneously perceiving the vulnerability of the other, inhibits or morally enables action [31].

This aspect is fundamental for the design of smart dynamic learning contexts with STEAM, since it allows to highlight the fundamental pillars, such as inclusion, citizenship, creativity and technology by considering the characteristics of the others such as their identity and context. Unlike traditional research in STEM that focuses on the design of learning contexts with emerging technologies to enact disciplinary content, STEAM designs in the light of ethical enactivism catalyze more complex forms of participation that reveal the perception anchored in value systems that they consider life and the living body as a universal value. In this sense, the sociocultural experience and the shared values of the community are considered to give relevance to the design and creative making process. These types of dynamic and intelligent learning contexts enhance 21st century skills such as creativity, collaborative work, empathy and intellectual openness that reaffirm learning by doing together. Something similar to what Maturana [118] proposes when stating that education is a process of transformation of coexistence.

From the framework of STEM education, design principles have been proposed that allow for ethical harmony with the values and identity of historically underrepresented cultures, such as the case of Culturally Situated Design Tools [119]. These culturally situated design tools have a radically embodied and ethical foundation in creating value from indigenous knowledge in generative STEM tasks that inform science, technology, and math learning experiences based on the fabrication and sophistication of cultural artifacts [120]. A relevant case to illustrate the above is the Anishinaabe arcs created by high school students to represent deep indigenous knowledge through 3D computer modeling and simulation techniques [121]. Unlike traditional STEM application approaches that ascribe to cognitivism, generative STEM based on Culturally Situated Design Tools allow understanding scientific knowledge from ecological and embodied reciprocity with the material. In this sense, mathematics is known for the physical modeling of curves by bending woods: wood teaches humans. The consequence of this ecological and generative reciprocity between the cognitive agent and nature is that it avoids extractive epistemologies that encourage the felling of trees and forests, since trees help humans to deeply understand science and therefore, it minimizes the damage through respect for culture.

Hence, the design and implementation of smart dynamic learning systems and contexts ought to be infused with ethical principles and values to meet the UNESCO 2030 Agenda. We approach this from an ethical enactivist and 4E cognition approach, in considering learning by doing beyond specific actions with material resources, but rather aspiring to promote collaborative actions of learning by doing among all considering the needs and problems of the communities that often exceed curriculum guidelines. Here we propose an ethical enactive approach building from the 4E cognition framework into an ethics of life. Next we review the third and last key point informing ethical smart dynamic STEAM learning systems and contexts.

(iii) Smart affordances for inclusive dynamic STEAM learning systems and settings design

New smart technologies and systems connected to IoT devices and sensors transferring data to other devices and systems over the Internet in real time permit today the design of smart, dynamic and adaptable digital and immersive learning settings, experiences and environments, for example, based on mixed reality (XR) learning environments. Combining adaptable immersive learning environments responding to big data and real-time sensorization and smart IoT devices offers an abundance of innovative learning possibilities for learners from diverse backgrounds to engage with STEAM knowledge in authentic, self-determined and meaningful ways [122, 123]. Today, smart technologies can deliver rich and multilayered learning systems and settings that evolve over-time, responding to users' interactions in subtle ways while blending real, hybrid and immersive worlds, in turn facilitating users' learning experiences [124,125]. Such types of educational settings provide important potential for learning processes following 4E cognition logic, moving enactive and embodied modes of learning from the periphery to the core of learning design [126].

These new modes of user engagement provided by smart dynamic learning affordances and environments, following ethical principles and framed within a 4E cognition understanding of human experience, allow us now to consider an ecosomaesthetic of learning centered on universal values to promote a type of education that addresses the challenges of Agenda 2030 [106,107,127]. Connecting embodied and enactive learning experiences using new digital affordances and XR learning environments merging real and virtual worlds with feelings, emotions and embodied experiences provides us with the opportunity to design learning environments that not only are more attuned with non-Western worldviews and traditions—thus offering means to connect with indigenous audiences that are more grounded on a bodily and sensorial experiential relationship with the world [128], but also to design more inclusive learning experiences to reach-out to those disadvantaged, underrepresented and excluded groups in creative and innovative ways. In that regard, indigenous perspectives can offer new ways of understanding our critical relationships between people and nature, with

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new technologies offering a way to experience and learn from indigenous perspectives and more in accessible ways [128].

The grounding of smart dynamic learning systems and settings design into locally relevant contexts facilitates cultural meaningmaking of 21st century challenges and issues. Complementary to the interesting work of Eglash et al. [121] on culturally situated design tools, here we explore the design of smart STEAM dynamic learning systems and settings from an ethical enactivist and digital innovation in education approach. For this, we incorporate a theoretical model that reports on inclusive design principles and considerations to reveal values and ethical aspects when designing, implementing and using new learning technologies with different disadvantaged and underrepresented groups. Fig. 2 below presents an overview of the different conceptual, theoretical, practical and applied design principles and considerations informing the design of ethical smart dynamic STEAM learning systems and settings promoting social, ecological and planetary wellbeing.

The depth each set of consideration and/or design principle from Fig. 2 could reach during the implementation of the model presented above depends on the underlying aims and goals of each educational intervention, programme or project, as well as on the characteristics and needs of each educational setting and larger socio-cultural and socio-technological factors influencing its target audience. A possible set of sequential steps in the implementation of these design principles following STEAM ethical digital design principles we are currently exploring includes.

- 1. Design through early participatory processes of consultation with the community in all stages of the project.
- 2. Realize ethnographic, socio-cultural and cultural-historical partnership-driven research to understand the larger context and give contextuality to educational projects, programmes and/interventions.
- 3. Incorporate identified problems and needs of the communities to the design challenges.
- 4. Wherever possible, have members of the local target audience working closely with the design team, ideally leading design processes where appropriate.
- 5. Consider the natural and cultural heritage expressed in symbols, artifacts, tacit and intangible knowledge of local communities, such as the flora and fauna of the place and more.
- Promote an ethical enactive approach that promotes critical learning by doing among all, through recursive prototypes that offer multiple perceptual possibilities to unfold their experiences.
- 7. Co-design the prototypes with community representatives involving continuous content-context iteration to reaffirm relevance.
- 8. Validate the final prototype until reaching the majority consensus of the community, achieving acceptance and transferability.

This sequence has been recently tested in the context of Maker activities at an early childhood education Kindergarten at La Serena, in Chile, addressing the cultural and natural heritage of the region using the 'guanaco' (*Lama guanicoe*), a camelid from South America, as a central emblem. The guanaco is not only part of the cultural and natural heritage of the region, but also can usually be seen around the Kindergarten, thus representing a unique heritage feature to local children and community members. Figs. 3 to 5 below illustrate different aspects of the design principles sequential steps outlined above.



Fig. 2. Theoretical model depicting a set of considerations and design principles informing the design of inclusive ethical smart dynamic STEAM learning systems and settings grounded on a systems thinking logic, to promote social, ecological and planetary wellbeing through the goals of Agenda 2030.

In relation to the case of Maker activities, we present the eight principles presented previously as a proof of concept. Regarding principle (1) 'Design through early participatory processes of consultation with the community in all stages of the project', we systematically met with the educational community of the kindergarten to share initiatives and raise needs providing territorial relevance to the proposed STEAM intervention. In the beginning, (2) 'Carry out consultation, ethnographic, socio-cultural and cultural-historical research to understand the larger context and give contextuality to educational projects, programs and/interventions', we immersed ourselves as marginal natives in educational situations carried out by the garden educators child, with the aim of describing ethnographically in anecdotal reports the educational processes that would allow us to understand the learning context. In relation to principle (3) 'Incorporate identified problems and needs of the communities to the design challenges', we defined, in collaboration with the community, the problems linked to knowledge of the natural and cultural heritage of the place, which are rarely incorporated into learning situations. Regarding principle (4) 'Wherever possible, have members of the local target audience working closely with the design team, ideally leading design processes where appropriate', we continually met with educators and children to reconcile design perspectives and relevance to their possibilities, such as for example, the selection of the 'guanaco' (*Lama guanicoe*) as natural heritage, a camelid from South America that is characteristic of the context of the kindergarten.

From the outset, (5) 'Consider the natural and cultural heritage expressed in symbols, artifacts, tacit and intangible knowledge of local communities, such as the flora and fauna of the place and more', we decided with the kindergarten community, to incorporate the mixed reality digital continuum [129] to scaffold the understanding of fauna through the use of various technologies and analogue artifacts. In the initial stage, a drone was used to carry out a 360° virtual tour that could visualize the geographical points where different species live, including the 'guanaco', see Fig. 4. From the perspective of learning by doing together, providing different experiences with technologies and artifacts, principle (6) 'Promote an ethical enactive approach that promotes critical learning by doing among all, through recursive prototypes that offer multiple perceptual possibilities to unfold their experiences'. 3D modeling and augmented reality were used to provide different visual perspectives and 3D fabrication to promote kinesthetic perception, through the manipulation and haptic exploration of natural and cultural heritage artifacts, see Fig. 5.

With the objective of prototypes having scientific, pedagogical and territorial relevance validation, several meetings were held with the different actors such as a zoologist who validated the technical and scientific data sheet of the reality models, early childhood educators and families with their children who belonged to the kindergarten, plus the STEAM research team that ensured interdisciplinary, ethical and pedagogically active coherence. In this last point we allude to principle (7) 'Co-design the prototypes with community representatives involving continuous content-context iteration to reaffirm relevance'. Finally, principle (8) 'Validate the final prototype until reaching the majority consensus of the community, achieving acceptance and transferability, was achieved when the ethical and active STEAM learning ecosystem is possible to be transferred to other members of the local community, who can validate the scope and use of the intervention in different kindergartens in the area.

Despite the above case study, a current limitation of our proposition is its theoretical nature. Further research, practical and applied case studies involving immersive learning environments, IoT sensorization and Big Data across socio-cultural contexts and settings are required to improve and consolidate the theoretical model, as well as those set of steps that can effectively assist in implementing dynamic, inclusive and ethical smart learning environments across socio-cultural settings.

5. Discussion

Following a theoretical review, here we propose a framework for an ethical enactive smart STEAM dynamic learning systems and settings design framework addressing the reported gap in STEAM education literature, i.e. to equip all citizens with the necessary skills to use digital technologies in an ethical, critical and creative way [14]. For this, we explore the synergy between the challenges of the



Fig. 3. Consultation (A) and participative co-design sessions (B) with a local Kindergarten community, as part of a Maker case addressing the natural heritage of the Coquimbo Region in Chile.



Local context, characteristics and needs

The "Guanaco" (Lama guanicoe)

Figure in school courtyard

Fig. 4. Examples of principle (5) 'Consider the natural and cultural heritage expressed in symbols, artifacts, tacit and intangible knowledge of local communities, such as the flora and fauna of the place and more' showcasing the 'guanaco' (*Lama guanicoe*) (B), an illustrated paint of the guanaco outside the kindergarten (C), and an aerial view of the 360° virtual tour showcasing the local area (A).



3D model

Augmented reality Printed model

Educational sheet

Fig. 5. Aspects of the mixed reality digital continuum, showing (A) a 3D model figure of the 'guanaco', (B) an augmented reality visualization of the 3D model, (C) a Maker Activity 3D printed figure of the 'guanaco', and (D) an educational sheet about the 'guanaco'. Consultation and participative co-design sessions with a local Kindergarten community, as part of a Maker case addressing the natural heritage of the Coquimbo Region in Chile.

UNESCO 2030 educational agenda based on the sustainable development goals, the STEAM educational approach, the ethical enactive approach from the 4E cognition framework, the evidence on immersive technologies such as augmented reality, virtual reality, mixed reality and Maker Activities that explore and connects with IoT, 3D, Robotics and Big Data, and the potential of embodied and ecosomaesthetics learning experiences in reaching out to disadvantaged and underrepresented communities. As a result of this synergy, we propose a set of principles to create and design educational technology affordances, systems, settings and smart environments that follow ethical and culturally responsive and values-based approaches to educational design. Our proposal is based on a robust framework of contemporary evidence that emphasizes embracing systemic thinking to face the complex challenges of the 21st century. These challenges correspond to more inclusive, creative, environmentally responsible societies characterized by sustainable innovation.

We follow the STEAM approach for smart dynamic learning systems and settings design, since it is based on a synergistic curriculum of disciplinary integration, 21st century cognitive, intrapersonal and interpersonal skills and the pillars of inclusion, creativity, citizenship and immersive technologies and creativity. The roots of STEAM are based on learning by doing among all and for all, which is why it is in tune with contemporary approaches of 4E cognition (embodied, enacted, embedded and extended) that highlight embodied, anti-representationalist and situated cognition. In particular, we emphasize ethical enactivism that promotes care for one's

own autonomy and that of others, with the aim of cultivating the possibilities that maintain or increase identities in different cultures. Ethical enactivism not only allows us to understand that cognition is inextricably linked to perception and action with technologies, but also how technologies improve perception and action in culturally situated contexts, while caring for self, others and life on the planet.

This latter aspect is critical for the design of immersive, adaptable and intelligent learning environments that offer a plethora of learning possibilities for learners from underrepresented communities and beyond to engage in authentic, self-determined, and meaningful ways. The use of immersive and creative technologies framed in ethical design principles that recruit socioculturally mediated tacit knowledge, are very useful for educators, designers and educational researchers who wish to move towards a sustainability education promoting planetary wellbeing in the 21st century. Inspired by the importance of this quest, our design proposal, nourished by systems thinking and ethical enactivism, aims to enhance the perspective of educational designers when developing immersive and creative technologies for STEAM education.

6. Conclusion

Here we set out to explore and consider how a smart digital design can incorporate an ethical enactivist dimension in creative ways to promote critical, inclusive and context-relevant STEAM learning ecosystems. In doing so, we considered philosophical, theoretical and practical aspects from 21st century skills, STEAM pillars, 4E cognition, systems theory, new immersive and smart technologies and pedagogy, and ethical enactivism informing a set of design principles for the design of ethical and inclusive smart learning ecosystems. We tested our framework in a real world case study at a kindergarten in La Serena, Chile, around the 'guanaco' as a natural and cultural heritage figure relevant to the local community. However, further research and practice is required to validate the framework across different social, cultural, ecological and technological settings, particularly, within indigenous, relegated and marginalised communities. We encourage educational psychologists, educational technologists, learning designers and educational practitioners who wish to address the global challenges of 21st century education by means of creative, innovative and inclusive education design, to consider our framework and set of theoretical premises and practical design principles put forward here.

Future studies in the area of STEAM and ethical activism should incorporate implementation and evaluation proposals that contribute to understanding educational design from different contexts. Using mixed methods can strengthen the power of the design in relation to the variety of cases and/or sample size according to the claims of the researchers. This would help regional educational policies to guide digital innovation design principles that point towards socio-ecological sustainability, natural and cultural heritage, and socio-emotional well-being in schools. Likewise, the ethical enactivist approach within the framework of the 4E cognition applied to smart design STEAM, provides a fertile field for new research that wishes to explore learning by doing, through sociomaterial practices based on cultural, social and technological systems [65].

Another aspect to consider in future research is to strategically use artificial intelligence from an ethical, cultural and embodied perspective [130], which compromises the development and improvement of educational products, artifacts, or designs, without sacrificing human values and well-being. An ethical and embodied AI in education can have a high experiential component, leading to the enactive approach. Generative intelligence such as Chat GPT will require a clear problem or challenges to carry out a purpose, as well as a set of conditions that contribute to the relevance of the person and their context: There is much to be, if we want emerging technologies to work effectively in sociocultural contexts without being a Trojan horse [131].

Author contribution statement

Claudio Aguayo: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper. Ronnie Videla: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Francisco López-Cortés: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Sebastián Rossel: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Camilo Ibacache: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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