Journal of Inclusive Methodology and Technology in Learning and Teaching
ISSN 2785-5104
Anno 5 n.3 (2025)

Edizioni Universitarie Romane
editoria scientifica dal 1952

Tinkering as Inclusive Practice: Technology-Enhanced Learning Spaces for Co-Constructing Knowledge

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Abstract: Tinkering is an inclusive, hands-on educational approach rooted in experiential learning, creativity, and material exploration. It recognizes learners as active agents and supports diverse, non-linear learning paths. Grounded in constructivist and embodied cognition theories, tinkering aligns with Universal Design for Learning by offering multiple ways to access, express, and engage with knowledge. Technologies, including AI, serve as flexible tools to enhance collaboration and personalization when used ethically. Teachers act as facilitators, guiding open-ended, creative challenges. Assessment is formative and multimodal, valuing process and participation. Tinkering fosters inclusive, dynamic learning ecologies that integrate body, mind, and technology.

Keywords: Tinkering; Universal Design for Learning; Educational Technologies.

1. Introduction

Starting from the awareness that contemporary learning environments are permeated by digital artifacts and mediated by algorithms, tinkering emerges as an educational paradigm capable of integrating body, materiality, and algorithms without falling into homogenizing drifts. First, technological devices are not merely executive tools but act as mediators that reconfigure the timing, sequences, and channels of the learning experience. Consequently, a form of pedagogical orchestration becomes essential—one that coordinates rhythms and transitions while avoiding both fragmentation and the standardization of learning paths (Rossi, 2016; Fabiano, 2025).

[1] Pur essendo il contributo frutto di un lavoro condiviso, Barra è autrice dei paragrafi 1 e 5. Ambretti è autrice del paragrafo 4. Sgambelluri è autrice del paragrafo 3. Sibilio è coordinatore scientifico del lavoro e autore del paragrafo 2. L'introduzione e le conclusioni rappresentano il risultato di riflessioni comuni tra le autrici Ambretti e Sgambelluri. Tutti gli autori hanno contributo alla revisione del contributo nella sua versione finale.

At the same time, the perspective of embodied didactics emphasizes how the body, in its perceptual, motor, and expressive dimensions, constitutes a mediator of learning in its own right. For this reason, instructional design must be conceived as an ecology interweaving body, environment, and artifacts, preserving agency and participation (Sibilio & Galdieri, 2022).

Within this multimodal ecology, algorithms operate as co-mediators: on the one hand, they modulate informational flows, feedback, and learning pathways, thus enabling personalized forms of learning and opening spaces for adaptive scaffolding; on the other hand, they demand transparency in their decision-making criteria and the preservation of learners' margins of choice, so that adaptivity does not turn into a hetero-directed hyper-adaptation. This entails the necessity of anchoring technical choices to explicit and verifiable inclusive purposes (Rossi, 2016; Fabiano, 2025).

In this framework, the Universal Design for Learning (UDL) provides a solid operational reference: multiple means of representation, alternative avenues for action and expression, and diverse engagement strategies make it possible to address differentiated learner profiles and paces. Furthermore, research on multimodality, presence, and agency in Virtual Learning Environments highlights that the quality of experience depends not only on the availability of channels but also—crucially—on their synchronization and on the degree of control that students can exert over them (Meyer et al., 2014; La Manna et al., 2024).

Ultimately, adopting tinkering as a paradigm—rooted in constructivist and constructionist frameworks, in embodiment, and in digital and algorithmic mediations designed according to UDL principles—makes it possible to expand learning opportunities without compromising agency and participation. On these grounds, the following analysis examines the theoretical and lexical foundations of the paradigm, defines the role of algorithms in instructional co-mediation, and discusses design implications and research trajectories related to effectiveness, learning ecologies, authentic assessment, and sustainability, thereby offering a coherent framework for inclusive and situated educational interventions (Rossi, 2016; Sibilio & Galdieri, 2022; La Manna et al., 2024; Fabiano, 2025; Todino et al., 2025).

1. Constructivist epistemologies and embodied frameworks of Tinkering

Tinkering, understood as an educational practice grounded in experimentation, creative exploration, and hands-on manipulation of materials, is deeply rooted in constructivist and constructionist epistemologies. Piaget (1970) had already emphasized that learning cannot be reduced to the mere transmission of

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information; rather, it consists of an active process of knowledge construction through the learner's interaction with the environment. The mechanisms of assimilation and accommodation, which mark the dynamic equilibrium of cognitive development, find in tinkering a privileged space for expression: by manipulating and recombining elements, learners continuously restructure their mental schemas.

Seymour Papert (1980), a student of Piaget, radicalized this paradigm by developing constructionism, according to which learning becomes particularly powerful when it occurs through the construction of shareable artifacts. The motto "learning by making" aptly applies to tinkering, where the material product—an object, prototype, or structure—acts simultaneously as a vehicle and catalyst for cognitive and creative processes. Although Papert envisioned the computer as a privileged medium for this kind of learning, his idea can be extended to any device or tool that stimulates design thinking, reflection, and collaboration.

The theoretical framework of tinkering is further enriched by insights from embodied cognition, which emphasize that cognitive processes are rooted in bodily experience and sensorimotor interactions (Varela et al., 1991; Lakoff & Johnson, 1999). From this perspective, the body is not an accessory to learning but an epistemic agent: through gestures, perception, and emotion, the learner constructs meaning. By inviting learners to manipulate, assemble, disassemble, test, and retest, tinkering becomes a true laboratory of embodied thought.

This view is reinforced by enactivist theories (Thompson, 2007), which describe cognition as an emergent process arising from the dynamic interaction between organism and environment. Tinkering thus constitutes an enactive context in which learning is not predetermined but emerges from exploration, negotiation with materials, and interaction with others. The body becomes a means of accessing knowledge, while the environment—both physical and digital—provides affordances that stimulate creativity and reflection.

John Dewey (1938) had already highlighted that concrete experience, when accompanied by reflection, forms the basis of meaningful learning. In this sense, tinkering aligns with Dewey's pedagogy of experience: error is not an obstacle to be eliminated but an opportunity to rethink processes, generate new strategies, and cultivate cognitive and emotional resilience.

To complete this framework, Bruner (1996) introduces the notion of learning as a narrative and cultural process. In tinkering, material construction is always also symbolic construction: the objects produced tell stories, embody meanings, and become nodes in a shared network of sense. Vygotsky (1978), for his part, underscores the role of social and cultural mediation: tinkering, when carried out in cooperative groups, activates zones of proximal development in which each learner can advance through interaction with peers and educators.

From an inclusive perspective, this interplay of theoretical frameworks acquires special significance. By valuing a plurality of languages and expressive modes, tinkering makes it possible to transcend uniform and standardized teaching models. Each learner—with their own cognitive, bodily, and emotional specificities—can find a space for expression and learning. Tinkerable practices, in fact, align closely with the principles of Universal Design for Learning (UDL) (Meyer et al., 2014), promoting accessibility, differentiation, and motivation.

In summary, tinkering is grounded in a rich web of epistemologies and educational theories—from Piaget's constructivism to Papert's constructionism, from Dewey's experiential pedagogy to contemporary embodied and enactivist perspectives, and including the contributions of Bruner and Vygotsky. This plurality of references demonstrates that tinkering is not merely a laboratory methodology but a genuine educational paradigm, capable of integrating body, mind, and environment within an ecological and inclusive process of knowledge construction.

2. Technological devices and algorithmic mediations in educational processes

In contemporary educational contexts, embodiment is not merely an operational support but an epistemic dimension that informs and transforms the learning experience. The resulting pedagogical practices are grounded in an ecological conception of learning, where body, environment, and artifacts constitute an interactive and dynamic system. This approach—aligned with the iterative and experimental logic of tinkering—guides instructional design toward forms of mediation capable of containing complexity without reducing it, while valuing flexible postures and processes of vicariance (Sibilio & Galdieri, 2022).

Within this framework, algorithmic mediation emerges as an additional and co-mediating component that contributes to shaping rhythms, interactions, and learning trajectories. Its effectiveness, however, depends on its ability to integrate coherently with the other dimensions of the didactic ecology, preserving agency, transparency, and learners' capacity for choice (Rossi, 2016; Fabiano, 2025).

In pedagogical discourse, mediation refers to the ensemble of processes and artifacts that transform experience into learning. In the pedagogical reinterpretation of digital artifacts, the convergence of languages and functions reshapes the timing, sequencing, and pacing of lessons—shifting them from linear to networked and hypertextual configurations (Rossi, 2016). Within this framework, algorithms are not merely technical accessories but didactic mediators embedded within artifacts, capable of orchestrating information flows, modulating presentations, and regulating feedback and navigation pathways (Rossi, 2016; Fabiano, 2025).

Studies on bodily potential highlight that the body, in its perceptual-motor and expressive dimensions, serves as a mediator of teaching and learning processes. This yields a conception of didactics as a complex system, governed by postures, vicariance, and semplessity—forms of adaptive simplicity that contain, rather than simplify, complexity (Sibilio & Galdieri, 2022).

From this perspective, algorithmic mediation must be understood within a body–environment–artifact ecology: the algorithm interacts with corporeality, influencing the rhythms and forms of interaction (multimodal synchronization, modulation of practice/feedback timing), while maintaining the primacy of presence and agency (Sibilio & Galdieri, 2022; La Manna et al., 2024). To ensure that algorithmic adaptivity does not degenerate into hetero-directed hyper-adaptation, it must be anchored to an inclusive framework that safeguards learners' informed agency and choice (Fabiano, 2025).

Developments in the museum field illustrate how AI and VR can enhance access, personalization, and engagement—through multilingual NPCs, conversational tutors, and immersive storytelling—provided they are guided by pedagogical and accessibility principles (Dewey, 1958; Hein, 2002; Kaplan et al., 2023; Wang et al., 2023; Shehade & Stylianou-Lambert, 2020; Chiscano & Jiménez-Zarco, 2021; Carci et al., 2019). These findings align with the view of the museum as a space for active experience and cultural dialogue, a model transferable to school contexts as multimodal and customizable learning environments (Todino et al., 2025).

As highlighted in the literature on digital artifacts, the integration of hypertext, simulations, and gamification renders the transitions among mediators increasingly fluid, requiring didactic orchestration of timing and transitions to prevent cognitive overload (Rossi, 2016). In a tinkerable perspective, the algorithm operates as a form of controlled-complexity scaffolding (thresholds, feedback, simple recognitions), integrating material manipulation with computational processes rather than replacing them. In virtual or hybrid environments, multimodality—textual, auditory, visual, and gestural cues—supports presence, participation, and sustained attention (La Manna et al., 2024; Todino et al., 2025).

In light of these theoretical frameworks, the design of algorithmic mediation must be conceived as a coherent and non-substitutive integration of the multiple levels composing the didactic ecology—body, environments, and artifacts—recognizing the algorithm as a co-mediator capable of modulating, but not replacing, the postures and actions that sustain learning (Sibilio & Galdieri, 2022).

A first key requirement concerns ecological alignment: technical decisions must arise from an understanding of bodily potential and the principles of vicariance and semplessity, which enable adaptive deviations and context-sensitive solutions in relation to intraindividual differences. The algorithm must thus be inscribed within this dynamic, expanding rather than constraining the agency of teachers and students (Sibilio & Galdieri, 2022).

At the same time, it is necessary to orchestrate the rhythms and transitions of mediation. The convergence of digital artifacts generates rapid shifts between immersion and distancing, with risks of fragmentation and hyper-stimulation. Didactic orchestration should therefore make explicit the sequences, pauses, channel changes, and levels of abstraction triggered by automation (Rossi, 2016). This underscores the importance of controllable multimodality: interfaces and contents must offer multiple affordances (textual, auditory, visual, gestural) that users can activate and synchronize according to their perceptual and cognitive needs, thereby supporting presence, interaction, and participation in virtual and hybrid environments (La Manna et al., 2024).

Simultaneously, algorithmic personalization must be grounded in inclusive and pedagogically transparent criteria—what adapts, when, and why—ensuring visibility of algorithmic functioning and preserving learners' decision-making space, thus avoiding forms of over-adaptation or hetero-direction (Fabiano, 2025). In this direction, experiences from the museum field show that AI and VR can support accessibility, multilingualism, and conversational tutoring without replacing educational guidance, provided that intentional design connects personalization, learning goals, and organizational sustainability (Todino et al., 2025).

Finally, documentation and formative feedback should be conceived as integral components of mediation: making the transformation of mediators visible (from doing to representation) and tracing shifts among perspectives (ego-, hetero-, and allo-centric) supports reflection and self-assessment, consolidating transferable learning (Rossi, 2016).

Overall, inclusive algorithmic mediation occurs when the orchestration of environments, corporeality, and artifacts preserves the centrality of experience and agency, while algorithms—made transparent in their logic—function as supportive devices for access, participation, and deep understanding.

Algorithmic mediation thus represents a layer of didactic mediation that interacts with corporeality, environments, and artifacts; to remain inclusive, it must be designed as a coherent integration of rhythms, channels, and postures, oriented toward agency and participation (Rossi, 2016; Sibilio & Galdieri, 2022; La Manna et al., 2024; Todino et al., 2025; Fabiano, 2025).

3. Universal Design for Learning as a paradigm for tinkerable inclusion

Within an inclusion-oriented pedagogy, Universal Design for Learning (UDL) emerges as a paradigm that offers flexible, adaptive, and plural design criteria capable of supporting differentiated learning without reverting to compensatory or standardizing logics (CAST, 2018; Rose & Meyer, 2002).

Its strength lies in the possibility of integrating, from the earliest phases of instructional design, the variability of learner profiles as a constitutive element of educational contexts. In this perspective, diversity is not perceived as a deficit to be normalized, but as an epistemic and relational resource that enriches teaching dynamics and fosters truly inclusive learning environments (Ainscow et al., 2006; Booth & Ainscow, 2011). Within this framework, UDL proves fully compatible with the tinkering paradigm, as it amplifies tinkering's exploratory, iterative, and embodied dimensions and provides a systemic framework for including students with differing needs, styles, and paces (Honey & Kanter, 2013; Resnick, 2007).

Tinkering, understood as an educational practice grounded in reflective making, creative manipulation of materials, and open-ended design, unfolds in environments where embodiment, artifacts, and digital mediations continuously interact (Martinez & Stager, 2013; Papert, 1980). This educational ecology is strengthened when UDL principles guide pedagogical action, outlining a design architecture that promotes access, fosters authentic participation, and ensures the meaningfulness of learning experiences for the plurality of learners involved (CAST, 2018; Novak, 2020).

The principles of UDL should not be understood as a set of procedures to be applied mechanically, but as structuring axes of intentional instructional design oriented toward guaranteeing each learner the right to authentic, meaningful, and generative participation (Meyer et al., 2014).

In tinkerable environments, UDL's contribution extends beyond facilitating accessibility to constructing learning spaces in which agency, motivation, and the plurality of communicative modes are recognized and valued (Deci & Ryan, 2000; Kress, 2010). The presence of digital artifacts and algorithmic mediations does not merely expand the instrumental repertoire of instruction; it reconfigures the very conditions of pedagogical action (Selwyn, 2016; Dede, 2009). Consequently, adopting UDL assumes a strategic role in steering such interventions toward inclusive, transparent, and measurable objectives that sustain learning processes in their bodily, cognitive, and relational complexity (CAST, 2018; Florian & Black-Hawkins, 2011).

The close connection between UDL and tinkering is also evident in the management of rhythms, transitions, and postures across physical, digital, and hybrid learning environments. The heterogeneity of mediators—bodily, material, symbolic, and digital—requires a design attentive to the harmonious integration of communication channels, enabling students to orient themselves within instructional flow, to manage diverse tools deliberately, and to self-regulate their level of participation (Jewitt, 2008; Kress, 2010). In this sense, UDL offers a crucial perspective for preventing the integration of technologies from devolving into fragmentation or sensory overload, thereby preserving the centrality of educational experience and shared meaning (Sweller et al., 2011; Mayer, 2009).

Pedagogically, tinkerable inclusion supported by the UDL paradigm rests on a non-reductionist conception of support—one that does not merely guarantee alternative points of access, but promotes authentic, relational, and transformative forms of learning (Vygotsky, 1978; Rogoff, 2003). Tinkering is never neutral: it activates prior knowledge, engages emotion, and stimulates dialogue and the negotiation of meaning (Engeström, 2001; Dewey, 1938). UDL provides a methodological framework for keeping choice open, legitimizing multiple forms of expression, and guaranteeing margins of adaptation that do not compromise equity but, on the contrary, realize it (CAST, 2018; Tomlinson, 2014).

The transformative potential of this synergy is fully realized in hybrid learning ecosystems linking universities, schools, museums, and makerspaces, where tinkerable practices—enhanced by digital mediations, VR, AI, and sensory devices—enable the construction of personalized and inclusive experiences (Edelson, 2001; Peppler & Bender, 2013). To achieve this, however, intentional instructional design is required, oriented toward accessible affordances, legible interfaces, and transparent criteria for adaptivity (Norman, 2013; Gibson, 1979).

Ultimately, adopting UDL as a paradigm for tinkerable inclusion means embracing a theoretical and operational framework capable of integrating complexity, embodiment, and algorithms within an ecological pedagogical perspective. It means reimagining instruction as a plural and dynamic space where error is an opportunity for growth, difference is a resource, and invention is not a privilege but a right (Freire, 2018; Biesta, 2010). In this framework, tinkering constitutes a transformative praxis which—illuminated by UDL principles—makes it possible to construct learning environments that welcome and value all subjectivities, keeping at the center lived experience, relationship, and the authenticity of learning (Dewey, 1938; Wenger, 1998).

4. Learning ecologies and the design of tinkerable environments

The current international debate on the "ecology of learning" prompts an interdisciplinary, multidisciplinary reflection on the relationship between individual ecology and life environments as an indissoluble bond between learning and its constitutive components.

Every individual activity, as Morin (2001) emphasizes, is in fact the manifestation of the interconnection within a complex and dynamic system of contexts, tools, social interactions, experiences, and cultural practices that contribute to the learning of an individual or a group. This systemic approach requires a more articulated view of education—one capable of valuing the plurality of influences acting on cognitive and formative processes—within an ecological, transdisciplinary perspective.

It follows that any activity is ecologically defined (Bateson, 1972) insofar as it synthesizes communicative and perceptual processes occurring within a broader system composed not only of individuals but also of relationships, symbols, contexts, and environments. In Bateson's view, any human behavior is ecologically defined and makes sense only in relation to:

1. Dynamic interaction;
2. The environment understood as an ensemble of interconnected systems (microsystem, mesosystem, exosystem, macrosystem) that mutually influence one another;
3. The role of context as adaptation to the surrounding environment.

What is original in a didactic–educational reading of learning ecologies is the attention to each subject's biography as a parameter for locating and selecting instructional practices within a catalog of possible options. These choices are oriented toward bringing out human capabilities, whose progressive development depends significantly on the broader social and institutional context in which individual activity unfolds. Each individual is naturally situated within an ecological system delineated by that individual and "is conceived as a set of structures included one within another, like a series of Russian dolls" (Bronfenbrenner, 1986, p. 31).

Accordingly, the spread of eco-didactics operates as reflection–action within formal environments (family, school, local authorities, cultural institutions, etc.), and especially within non-formal and informal learning environments (virtual settings, nature parks, etc.). It constitutes a complex, articulated reflection–action on the immense possibilities for learning from experiences and contexts, in relation to both natural and virtual environments.

Consequently, "the school, by opening itself to out-of-school experiences and reconstructing codified knowledge through the allure of the freer, more vital

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knowledges of the environment, has the concrete possibility of motivating children and adolescents to discover signals of knowledges that are still unexplored, still not-yet, rich in otherness" (Frabboni & Pinto Minerva, 2014, pp. 128–129). In this way, the knowledge acquired across real and virtual spaces "does not constitute mere experience, but an attempt that implies a change."

Leaving the school to encounter the surrounding environment means educating for ecological thinking and connections, that is, fostering the capacity to "look far ahead" (Frabboni & Pinto Minerva, 2014, pp. 128–129). To begin rethinking the complexity of the real, in Morin's view, entails:

- the multidimensionality of problems (social, environmental, cultural);
- awareness of the limits of knowledge;
- the necessity of connecting knowledge, information, and emotions.

In this sense, the environment presents itself as a vast archive of socio-relational documents with cognitive–transformative impact.

It is therefore necessary to promote—starting from school yet extending across all informal educational settings, from local institutions to associations—a form of education that abandons the exclusive logic of traditional learning places in order to:

1. Recognize and recover the variety and diversity of forms, developmental pathways, and temporalities of both natural and human-made environments;
2. Formulate hypotheses to be actualized into design ideas for rethinking and recomposing spaces and times.

From a formative standpoint, the ecological approach thus opens toward the realization of tinkerable environments, that is, spaces intentionally designed to stimulate experimentation, creativity, and meaning-making through making. Such environments are characterized by several key features:

- the presence of heterogeneous, manipulable materials (technological and non-technological);
- flexible spatial organization;
- opportunities for group work;
- an adult role configured as facilitator rather than transmitter of knowledge.

Tinkerable environments are intentionally designed to promote learning through exploration, construction, and experimentation. They arise from the intersection of constructionist pedagogy (Papert, 1980) and maker-movement practices, with particular attention to freedom of action, creative uses of technology, and the valorization of error as an integral part of the educational process.

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These environments differ from more traditional educational settings through several core characteristics, including:

1. Availability of heterogeneous materials—unstructured, reconfigurable objects;
2. Flexibility and adaptability—furnishings are often mobile or modular; work surfaces are ample and accessible; tools are visibly and neatly available. The space invites action and supports diverse forms of work: individual, collaborative, exploratory;
3. An environment-as-third-teacher philosophy—the physical organization reflects an educational vision in which the environment itself functions as a third educator.

From a didactic perspective, tinkerable environments invite collaborative work and peer learning, configuring themselves as true learning ecologies in which materials, spaces, people, and technologies co-construct experiences rich in meaning. They offer students competencies for facing uncertainty, cultivating curiosity, and becoming active protagonists of their own learning. The didactic originality of tinkerable environments lies in a vision of learning ecologies aimed at overcoming the fragmentation of knowledge, integrating mind, emotion, and relationship, and fostering awareness and responsibility.

This vision invites a deep rethinking of the very meaning of sustainable education, entrusting the teacher with the role of supporter of exploratory processes—capable of posing stimulating questions, aiding reflection, and documenting—without anticipating solutions. In other words, the teacher guides without directing, in line with the goal of learning by discovering through doing: learning to pose questions, to modify a project while it is in progress, and to learn from errors. This orientation also implies formative, qualitative assessment, which takes into account process documentation, metacognitive reflection, and active participation.

In this perspective, the tinkerable environment increasingly responds to an ecological necessity aimed at constructing sustainable educational pathways, consistent with the attainment of true learning—namely, "not that which merely changes behavior, but that which changes the very way of learning itself" (Bateson, 1972).

5. Research perspectives on inclusive tinkering

Although tinkering is now well established as a pedagogical practice in schools, museums, and fab labs, it remains a continually evolving research terrain, rich in challenges and potential. On the one hand, existing studies have demonstrated its

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positive impact on creativity, critical thinking, and collaborative capacity (Rosenbaum & Resnick, 2013). On the other, open questions persist that call for further empirical investigation and theoretical refinement.

A first area concerns measuring the effectiveness of tinkering in relation to diverse learner profiles. We need to understand how this approach adapts across ages, sociocultural backgrounds, and special educational needs. Some studies have highlighted tinkering's potential to promote self-determination and agency (Aiello et al., 2017), yet longitudinal research is needed to track medium- and long-term impact. Particular attention should be paid to learners with disabilities, for whom tinkering can offer personalized and meaningful pathways aligned with Life Design principles and Universal Design for Learning.

Operationally, UDL-informed tinkering entails multiple means of representation (e.g., diagrams, tactile models, short subtitled/TTS videos), alternative avenues for action and expression (physical constructions, digital prototypes, audio recordings), and engagement strategies (choices, roles, and adjustable pacing), governed by explicit criteria of adaptivity and transparency (Meyer et al., 2014). In a heterogeneous classroom, the same tinkerable task can be offered with varied access points (visual instructions + audio + gestural modeling), alternative action tools (slow manual/robotic manipulation + thresholded microcontrollers), and diverse formats for sharing results (physical model, narrated video, concept map), while maintaining equivalence of learning goals.

At the applied level, educational ecosystems connecting schools, museums, and makerspaces are particularly fertile for tinkerable practices enriched by digital tools (VR/AR, microcontrollers, gestural interfaces) and by distributed collaboration and documentation. In museums, AI and VR show significant potential for supporting access, personalization, and engagement—from multilingual NPCs to conversational tutors—so long as they are guided by explicit, inclusion-oriented pedagogical and ethical criteria; analogous logics can be transferred to school settings provided that mediation is clearly and intentionally designed. In this perspective, technologies such as educational robotics, augmented reality, 3D printing, artificial intelligence, and virtual environments broaden possibilities for design and accessibility: VR for accessible immersive narratives with avatars/NPCs and personalized pathways; AR to overlay visual cues and sensory supports; soft robotics with thresholded feedback for fine motor skills; 3D printing for tactile prototypes; and AI tutors as metacognitive scaffolds (Todino et al., 2025; La Manna et al., 2024).

However, as Luckin (2018) cautions, introducing such technologies raises ethical and pedagogical questions: How can we ensure transparency in algorithmic processes? How can we prevent forms of exclusion tied to the digital divide or to

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biases embedded in systems? Future research must examine how to keep learners' agency at the center, avoiding the displacement of tinkering's exploratory and creative core by automation. Here, human-in-the-loop principles, transparency of adaptive criteria, data minimization, and explainable recommendations are crucial (Fabiano, 2025).

A third research avenue focuses on learning ecologies (Barab & Roth, 2006). Tinkering is not confined to the classroom; it traverses formal, non-formal, and informal spaces, linking schools, science museums, makerspaces, and local communities. Studying these ecologies means observing how tinkering experiences intertwine with individual biographies and social contexts to yield plural, distributed learning networks. Literature on multimodality and embodiment in virtual learning environments (VLEs) shows that presence and agency are preconditions for genuinely inclusive participation and should guide the design of hybrid school–museum–community ecosystems (La Manna et al., 2024; Sibilio & Galdieri, 2022). From an inclusion standpoint, it becomes vital to analyze how these ecologies can reduce educational inequalities and expand access to innovative learning opportunities, especially for students from underserved contexts.

A fourth direction concerns documentation and assessment. While tinkering privileges process and creativity, schools require tools to account for outcomes. Traditional assessments based on standardized tests are ill-suited to capture the richness of tinkerable processes. We therefore need authentic, multimodal, and narrative assessment methodologies that recognize the value of collaboration, metacognitive reflection, and the plurality of expressive modalities. In this sense, documentation—via learning logs, photographs, videos, concept maps, as well as digital tools and collaborative platforms—becomes an integral component of both pedagogy and research. Ongoing documentation (journals, video, digital logs) should be designed as part of the mediation itself, making visible the transitions and rhythms among mediators (manual, iconic, digital) to support reflection and self-assessment (Rossi, 2016).

Finally, new perspectives open around socio-ecological sustainability. When critically oriented, tinkering can serve as a laboratory for education in responsible, sustainable citizenship. The use of recycled materials, attention to the environmental impact of technologies, and reflection on consumption models can transform tinkering into an opportunity to develop ecological awareness and social responsibility. Inclusion thus extends beyond the individual to the collective and planetary levels, embracing the principles of the 2030 Agenda.

In summary, research on inclusive tinkering unfolds along at least five trajectories: (1) evaluating impact across diverse learner profiles; (2) exploring integration with emerging technologies and AI; (3) analyzing learning ecologies and socio-material networks; (4) developing authentic assessment practices and participatory documentation; and (5) investigating the nexus between tinkering and sustainability. This is an open, ongoing project in which pedagogy, technology, and empirical research must remain in constant dialogue. Consolidating tinkering as an inclusive paradigm means recognizing its dynamic, plural, and generative nature—capable of aligning innovation, equity, and social justice.

Conclusions

The analysis conducted thus far confirms that the tinkering paradigm offers a particularly effective and innovative educational approach to today's learning environments, where bodily, material, and digital dimensions coexist. Through the synergistic integration of body, matter, and algorithms, tinkering moves beyond reductive and standardizing visions, opening a space for instructional design that values complexity and students' active participation.

Within this context, the central role of technological devices emerges with force: no longer regarded merely as tools, they function as mediators capable of reconfiguring the timing, sequencing, and modes of educational interaction. Their thoughtful integration calls for pedagogical orchestration that balances flexibility with structure, avoiding both fragmentation and the homogenization of learning pathways.

Likewise, the bodily dimension proves essential not only as a sensori-motor component but as a fundamental mediator of the educational experience—one that fuels material inquiry and iterative design, the cornerstones of tinkering itself. The resulting ecological perspective emphasizes the interdependence among body, environment, and artifacts, thereby promoting inclusive learning oriented toward agency.

The incorporation of algorithms into this didactic ecology adds another layer of complexity and opportunity, creating space for personalization and adaptive scaffolding. However, their adoption requires transparency and learner autonomy to avoid passive, non-intentional forms of adaptation. In this sense, Universal Design for Learning (UDL) provides a valuable framework for designing educational environments that respond flexibly and inclusively to diverse needs and learning styles.

On the applied level, collaboration among schools, museums, and makerspaces constitutes fertile ground for experimenting with tinkerable practices enhanced by advanced digital technologies such as VR, AR, microcontrollers, and gestural interfaces. These ecosystems also foster distributed collaboration and documentation—key elements for constructing authentic, situated learning. Museum experiences with AI and VR further confirm that technological innovation can support access, personalization, and engagement, provided it is embedded within rigorous, inclusion-oriented pedagogical and ethical designs.

In sum, adopting tinkering as a didactic paradigm—rooted in constructivist and constructionist approaches and integrated with digital and algorithmic mediations designed according to UDL principles—offers a promising avenue for expanding learning opportunities without sacrificing participation and learner autonomy. This horizon opens important directions for research and development in instructional design, authentic assessment, learning ecologies, and sustainability, with the goal of building educational environments that are increasingly inclusive, effective, and responsive to ongoing technological and social transformations.

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