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Ottobre 2025

Universal Design of Learning, gamification and artificial intelligence: an integrated model for teacher education¹

Universal Design of Learning, gamification e intelligenza artificiale: verso un modello integrato di Universal Design of Learning per la formazione degli insegnanti

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Doi: https://doi.org/10.14668/QTimes_17404

ABSTRACT

The recent Universal Design of Learning (UDL) 3.0 Guidelines highlight the value of cultivating joy and play through “Consideration 7.3.” Drawing on neuroscientific research on the importance of

¹ Il contributo è frutto dell’opera condivisa degli autori. Tuttavia, si attribuiscono a Lia Daniela Sasanelli i paragrafi 4 e 5; ad Umberto Barbieri i paragrafi 2, 3 e 6; a Raffaele Di Fuccio i paragrafi 1 e 7.

play, this paper begins by examining its fundamental role in child development, where it nurtures essential cognitive, social, and emotional skills. Within the UDL framework, storytelling emerges as a powerful medium for play and learning, allowing children to explore imaginary worlds, understand cause-and-effect relationships, and develop empathy. Digital storytelling, enriched by multimedia and interactivity, further enhances this process by making narratives more engaging, accessible, and personalised. The integration of Artificial Intelligence introduces new opportunities to create and adapt digital stories to individual learners, supporting creativity and inclusion. Yet, effective use of these technologies requires targeted teacher training to transform the “technological gap” into “digital wisdom,” fostering a reflective and responsible pedagogical approach. This paper explores the potential of digital storytelling and AI within the UDL 3.0 framework, examining their implications for teacher education.

Keywords: Universal Design for Learning, gamification, inclusion.

RIASSUNTO

Le recenti Linee Guida dell’Universal Design for Learning (UDL) 3.0 evidenziano l’importanza di promuovere la gioia e il gioco (Considerazione 7.3). Partendo dalle evidenze neuroscientifiche sul ruolo cruciale del gioco, il presente contributo ne analizza la funzione fondamentale nello sviluppo infantile, sottolineando il contributo allo sviluppo di competenze cognitive, sociali ed emotive essenziali. Nell’ambito dell’UDL, la narrazione si configura come un potente strumento di gioco e apprendimento, che consente ai bambini di esplorare mondi immaginari, comprendere relazioni di causa-effetto e sviluppare empatia. La narrazione digitale, arricchita da elementi multimediali e interattivi, potenzia ulteriormente questo processo, rendendo le storie più coinvolgenti, accessibili e personalizzate. L’integrazione dell’intelligenza artificiale apre nuove prospettive per la creazione e l’adattamento di narrazioni digitali su misura per ciascun studente, favorendo al contempo creatività e inclusione. Tuttavia, l’efficacia di tali tecnologie dipende da una formazione adeguata degli insegnanti, fondamentale per trasformare il “divario tecnologico” in “saggezza digitale” e per adottare un approccio pedagogico riflessivo e responsabile. A tal proposito, il contributo approfondisce il potenziale dello storytelling digitale e dell’intelligenza artificiale nel contesto dell’UDL 3.0, con particolare attenzione alle implicazioni per la formazione docente.

Parole chiave: Universal Design for Learning, gamification, inclusione.

1. INTRODUCTION

In recent years, there has been a growing recognition of the importance of integrating joy and play as essential elements within the learning process (Jeet & Pant, 2023). Educators and teachers acknowledge that learning should be enjoyable and engaging (Suwarni *et al.*, 2024). Although the

inclusion of joy and play is not a new concept, it has gained renewed attention due to increasing awareness of their pivotal role in fostering effective educational experiences. When students feel emotionally connected and motivated, they are more willing to take risks and overcome learning challenges (Shean & Mander, 2020). The presence of joy and play enhances intrinsic motivation, which is the ultimate goal for all learners (Valerio, 2012). Given the growing significance of these elements in education, it is crucial for teachers to adopt strategies that regularly incorporate them into teaching activities. UDL is now recognised as a systemic educational framework designed to optimise learning processes in an inclusive way (Rose & Meyer, 2002; Meyer, Rose & Gordon, 2014; Lohmann *et al.*, 2023; Priyadharsini & Mary, 2024). It values the individual variability of students. UDL is rooted in cognitive neuroscience and aims to eliminate barriers to learning by providing flexible methods of presentation, engagement and expression that accommodate the diverse needs of all learners. The creation of universal, flexible and adaptable curricula ensures equal access and participation opportunities, promoting an approach that embraces plurality in terms of needs, prior experiences, interests and personal characteristics (Sasanelli *et al.*, 2025). Play is a fundamental component of child development, contributing significantly to cognitive and social growth (Veraksa & Samuelsson, 2022). Compared to existing studies (Luckin & Holmes, 2016; Skene *et al.*, 2022), this contribution, by proposing the integration of the “neurocognitive triad of joy”, aims to fill a specific gap: the absence of integrated training models for teachers in the integrated 0-6 system that translate neuroscientific evidence into evidence-based practices aligned with Consideration 7.3 of the UDL 3.0 Guidelines (CAST, 2024).

2. THE BRAIN ARCHITECTURE OF GAMING

Neuroscientific research has confirmed that the brain regions responsible for cognitive processing and memory are developed through play activities (Liu *et al.*, 2017; Hamilton, 2023).

The dopaminergic system is the fundamental neurochemical substrate that supports play-based learning in early childhood because dopaminergic neurons increase their firing rate when rewards exceed expectations, generating positive prediction errors that strengthen the neural pathways associated with successful behaviours (Schultz, 2016). During play, unexpectedly positive outcomes - such as success in social interactions or mastery of new skills - trigger the release of dopamine, which reinforces learning behaviours through mechanisms of enhanced synaptic plasticity. Research shows that social play is naturally reinforcing, being modulated by the same neural systems that mediate the positive subjective properties associated with food, sex, and psychoactive substances (Trezza *et al.*, 2010). Studies in animal models reveal that neonatal dopaminergic lesions compromise play behaviour patterns, with dopamine acting in the nucleus accumbens being particularly crucial for the affective qualities associated with play activity (Kostrzewa, 2022). The developing brain shows particularly high dopaminergic system activity during the first year of life, with receptor density remaining high until the age of 4 (Rothmond *et al.*, 2012), making this period critically sensitive to play-based interventions. Positive emotions also enhance memory formation through multiple neurobiological mechanisms. The amygdala-hippocampal system processes emotional content, with positive emotions directing additional attentional resources towards emotionally significant information and promoting bottom-up processing that increases awareness (Tyng *et al.*, 2017). Studies on sleep-dependent consolidation conducted with preschool children show that naps

enhance memory for emotional content, with benefits extending to the following night's sleep (Souabni *et al.*, 2025). The mirror neuron system provides the neurobiological foundation for vicarious learning through storytelling and embodied simulation. Mirror neuron activity is detectable from birth, with EEG studies showing desynchronisation of the mu rhythm in infants as young as 6 months when observing goal-directed actions, and the frequency of this mu rhythm increases with age, from approximately 7 Hz at 6 months to 9 Hz by 4 years, indicating progressive maturation of the system (Nyström *et al.*, 2011). Storytelling activates embodied simulation networks that support vicarious learning through multiple mechanisms. Near-infrared spectroscopy studies reveal that storytelling significantly alters prefrontal cortex activation patterns in children, with familiarised children showing sustained activation compared to reading picture books (Ohgi *et al.*, 2018). Children mentally simulate the movements of characters during narrative comprehension, with simulation constrained by expectations about the duration of the action and psychological factors. The mirror neuron system demonstrates remarkable experience-dependent plasticity. Children show stronger responses to actions in their motor repertoire, with motor experience predicting the strength of mirror neuron responsiveness - early maternal mirroring of infant expressions at 2 months predicts stronger MNS responses at 9 months, highlighting the importance of the quality of social interaction for optimal development of the system (Meltzoff *et al.*, 2019).

3. NEURAL SYSTEM INTEGRATION AND IMPLICATIONS FOR LEARNING

Recent advances in network neuroscience reveal sophisticated interconnections between reward systems, the DMN, and mirror neurons that form the foundation for integrated learning models. The anterior insula serves as a critical hub connecting the DMN and MNS networks, playing a causal role in switching between networks and detecting salient stimuli; the posterior cingulate cortex/precuneus acts as a “rich club” node facilitating communication between systems, while the medial prefrontal cortex integrates mentalisation processes with embodied simulation mechanisms (Molnar-Szakacs & Uddin, 2013). Meta-analytic evidence from 39 studies involving 3,893 children shows that guided play has greater positive effects than direct instruction on early mathematical skills ($g = 0.24$), shape knowledge ($g = 0.63$), and task switching/executive functions ($g = 0.40$) (Skene *et al.*, 2022). This superiority results from guided play's ability to simultaneously engage reward prediction error learning, creative problem-solving networks, and social simulation systems.

Gamification during learning activities is associated with the deactivation of the default mode network, which is significant because off-task behaviour is linked to DMN activation (Fry, 2024). Educational gamification exploits multiple neurotransmitter systems: dopamine provides reward prediction error signals, serotonin modulates cognitive flexibility during exploration, and endogenous opioids enhance the pleasurable aspects of goal achievement and flow states. Studies show a 13.5% reduction in exam failure rates and significant improvements in exam scores with gamified approaches (Fry, 2024).

3.1 Towards an Integrated Model of Joyful Learning

This analysis establishes the neurocognitive triad of joy—reward systems, default mode networks, and mirror neurons—as the neurobiological foundation for play-based learning in early childhood.

This model differs from Chatterjee and Vartanian's (2014) *aesthetic triad* (sensory-motor, emotion-valuation, meaning-knowledge), which addresses aesthetic experiences broadly; our triad reconfigures these systems specifically for educational contexts, emphasising DMN-mediated creative cognition and the documented functional coupling between reward processing and mirror neuron responsiveness (Molnar-Szakacs & Uddin, 2013). Meta-analytic evidence supports this integration: game-based learning produces moderate-to-large effects on cognitive and social-emotional outcomes in early childhood ($g = 0.48\text{--}0.52$; Alotaibi, 2024), while neuroimaging demonstrates reward-enhanced connectivity between DMN and ventral striatum during task performance (Dobryakova *et al.*, 2017).

The triad aligns directly with UDL 3.0's Consideration 7.3 ("Cultivating joy and play"), which emphasises identity-affirming, emotionally engaging environments (CAST, 2024). Generative AI extends these principles through personalised narrative generation: LLM-powered systems like StoryMate activate all three neural systems simultaneously via adaptive storytelling (Chen *et al.*, 2025), producing effect sizes of 0.45 on early learning outcomes when pedagogically integrated (Yang *et al.*, 2024). Educational environments engaging reward processing, creative exploration, and social simulation are optimally positioned to support brain development during the critical birth-to-six period.

3.2 Alignment with UDL Principles

The principles of UDL align directly with neuroscientific findings regarding individual variations in brain networks. No two brains are identical - neural pathways form unique configurations like fingerprints - making learner variability predictable and accommodatable through systematic design (Rose *et al.*, 2013). The three brain networks of UDL (*cognitive, affective, and strategic*) correspond to distinct neural processing systems that can be optimised independently through multiple means of representation, engagement, and expression. Educational technologies equipped with adaptive algorithms demonstrate the ability to create personalised learning experiences that adapt to individual cognitive load, improve engagement in children with learning difficulties, and enhance understanding through real-time feedback mechanisms. However, systematic reviews examining the impact of digital technology on children aged 0-12 reveal mixed evidence, with high-quality educational content showing more promising results than passive screen time (Luckin & Holmes, 2016).

4. CULTIVATING JOY AND PLAY: A UDL PRIORITY

The effective implementation of the three UDL principles - designing multiple means of engagement, representation and action and expression - mainly relies on one strategic tool: the UDL Guidelines. First developed by the Centre for Applied Special Technology (CAST) in 2008, the Guidelines are a dynamic and flexible resource that evolves in line with advances in learning research and best practices in inclusive education and instruction (Hitchcock *et al.*, 2002). The Guidelines offer a solid theoretical framework, supported by scientific evidence from the fields of neuroscience and developmental psychology (CAST, 2024), and are useful for identifying and proactively addressing barriers to learning, as well as for intentionally designing environments and experiences that value students' different cognitive and learning styles. The most recent version of the UDL Guidelines (3.0),

published in July 2024, places crucial emphasis on including playful elements in learning environments and on the importance of joy (Holflod & Skovbjerg, 2025; Pedersen & Skovbjerg, 2025).

4.1 Analysis of UDL Consideration 7.3

Consideration 7.3, entitled '*Cultivating joy and play*', has been incorporated into Guideline 7, "*Design options for accommodating interests and identities*". Within the UDL framework, play and joy are recognised as tools that facilitate learning and development across all age groups, from children to adults, by fostering an emotionally engaging environment (Martinsone *et al.*, 2023; Sasanelli *et al.*, 2025). Scientific research shows that play is an intrinsically motivating activity that stimulates epistemic curiosity, a sense of wonder, and imaginative abilities (Dirkx, 2001; Neale *et al.*, 2018; Bolzan *et al.*, 2020; Schlesinger *et al.*, 2020). These elements facilitate the construction of new knowledge and the development of cognitive, social, and emotional skills. Play enables children to experiment, explore and manipulate the world in a safe environment, thereby encouraging risk-taking, problem-solving and creativity.

Brougère's (1999) work provides a foundation for understanding play's role in learning, where it is seen as a tool that is socially negotiated and constructed. This tool is ideal for informal learning, as it can stimulate intrinsic motivation.

Furthermore, the concept of the "*paradox of play*", whereby enjoyment of play translates into learning, reflects UDL's call to design activities that capture students' interest and motivate them to participate actively in the learning process. Scientific research shows that play, in its many forms (sensory, symbolic, imaginative and motor), is an intrinsically motivating activity that stimulates epistemic curiosity, a sense of wonder, and imaginative abilities (Singer *et al.*, 2006). These elements facilitate the construction of new knowledge and the development of cognitive, social, and emotional skills. They allow children to experiment, explore, and manipulate the world in safe environments that encourage risk-taking, problem-solving, and creativity (Lillard *et al.*, 2013; Neale *et al.*, 2018). This playful dynamic activates the 'neurocognitive triad of joy' (discussed in Section 3.1): dopaminergic reward reinforces exploratory behaviours (Schultz, 2016); DMN deactivation promotes states of creative flow (Fry, 2024); and mirror neurons support vicarious learning through embodied simulation (Meltzoff *et al.*, 2019). This translates the paradox into an evidence-based, neurobiological mechanism for inclusive learning. These elements promote the construction of new knowledge and the development of cognitive, social and emotional skills. Play enables children to experiment, explore and manipulate their surroundings in a safe and controlled environment, thereby encouraging risk-taking, problem-solving and creativity (Lillard *et al.*, 2013). UDL recognises that the experience of play is subject to variability at both the individual and group levels; therefore, it emphasises the importance of offering a variety of options and supports that allow everyone to access playful and joyful experiences (Rose & Meyer, 2002). Play is also associated with joy, a positive emotion closely linked to psychological well-being and self-efficacy. When students are happy and engaged, they are more likely to persevere in the face of challenges, actively engage in the learning process and develop a sense of belonging to the school community (Fredrickson, 2001). For the most vulnerable students, particularly those belonging to historically marginalised groups, joy acts as a resilience mechanism against oppressive systems, promoting self-esteem, cultural identity, and empowerment (Ginwright, 2016).

Various examples to promote and enhance joy and play are given in consideration 7.3 (CAST, 2024).

- *We cultivate play in a variety of ways, encouraging different types of play.* These include sensory play, which stimulates the senses through materials and concrete experiences, and symbolic and imaginative play, which allows children to represent reality in new ways. Artistic activities, such as drawing and dramatisation, are also essential for expressing creativity.
- *Opportunities for exploration, experimentation and discovery should be integrated into the learning environment.* In line with the constructivist approach, students must be given the chance to actively explore, experiment with new ideas and discover concepts and solutions independently.
- *Create spaces that allow children to experience joy through connections with their identity, sense of self and community.* The learning environment must promote psychological well-being and allow children to express their identity and feel part of the school community. This can be achieved through activities that value personal experiences and promote positive interdependence and a sense of belonging.
- *Facilitate opportunities for students to feel proud of their achievements to support the development of self-efficacy.* Provide opportunities for students to recognise and celebrate their successes to encourage intrinsic motivation and perseverance.
- *Incorporate narrative techniques and exploit the use of stories,* as they are recognised as a joyful and playful means of promoting learning and strengthening memory.

We will focus on this final point, reflecting in particular on digital storytelling as a tool that fosters a playful and collaborative learning environment. We will consider the playful power inherent in stories, as well as the introduction of generative artificial intelligence tools.

5. THE POTENTIAL OF STORIES IN THE INTEGRATED 0-6 SYSTEM: A TOOL FOR PROMOTING JOY AND PLAY

Jerome Bruner explored the power of storytelling in depth, distinguishing between two fundamental modes of thinking: paradigmatic (logical-scientific) and narrative (Bruner, 1986). The latter is essential for understanding human intention and action. It allows us to organise experiences, connect events in causal sequences, and attribute meaning to the world (Lyle, 2000; Esteban, 2002). Narrative is not merely a vehicle for information; it is also a mental tool and a cognitive frame through which experiences are constructed on a meaningful subtext. Recognising the interactive nature of cognitive development within a cultural context and the essential narrative nature of this interaction is crucial for renewing pedagogical thinking (Esteban, 2002; Christensen, 2015). From this perspective, storytelling is proposed as a methodological framework that organises the entire learning process around a coherent narrative. This approach is based on a constructivist conception of learning, in which the learner is an active agent in constructing their own knowledge. As Bruner (1986, 1990) postulated, learning is an intrinsically active process. The learner is the protagonist of their own understanding through exploration, experimentation, and reflection. It is also contextualised and situated, meaning that the acquisition of knowledge is not an end in itself, but is oriented towards the development of skills that can be used in real and meaningful contexts.

- *Transactional*: knowledge emerges from intersubjective sharing, mediated by symbolic systems such as language.
- *Co-constructed*: meaning is the result of plural negotiation and finds its most complete expression in collaborative interaction between peers.
- *Social*: education is a social phenomenon that benefits both the individual and the community, contributing to cultural preservation and renewal.

There is a clear synergy between storytelling and the principles of UDL 3.0, as both emphasise the importance of accommodating individual differences and fostering flexible and inclusive learning environments. The human brain is predisposed to processing narratives (Willems *et al.*, 2020; Song *et al.*, 2021). Narrative structure helps us to make sense of events, understand cause-and-effect relationships, remember important details, and grasp complex ideas (Yarkoni *et al.*, 2008; Negrete, 2021). Therefore, integrating narrative elements means capitalising on a natural cognitive process, making learning more effective, enjoyable and engaging. The joy experienced during narrative-based learning stimulates neural circuits associated with reward, thereby consolidating memories and promoting a positive attitude towards future learning. Using digital stories can particularly improve communication skills, increase motivation and create social connections, thereby increasing engagement (Ivala *et al.*, 2013; Lin & Chang, 2021; Asli *et al.*, 2023). The emotional engagement generated by storytelling supports motivation and facilitates understanding, making learning less stressful and more open to individual expression. In this context, the teacher takes on the crucial roles of storyteller, facilitator, and co-creator of knowledge in line with UDL, which emphasises the importance of providing multiple ways to interact with educators and peers.

5.1 Storytelling and digital storytelling in the integrated 0–6 system

Storytelling is a valuable tool within the integrated 0-6 system for cultivating narrative thinking, promoting play and joy, and developing essential skills. Integrating digital technologies further enhances this potential, making the tool more dynamic, accessible and engaging in full harmony with UDL principles. Digital storytelling enables the creation of rich, interactive narrative experiences incorporating multimedia elements such as videos, animations, images, sounds, and music. These elements make stories more engaging and offer multiple means of representation, supporting students with different sensory needs and learning styles in line with UDL. In particular, digital stories can improve communication skills, increase motivation, and foster social connections, thereby enhancing learner engagement in the learning process (Ivala *et al.*, 2013; Papadimitriou *et al.*, 2013; Undheim & Jernes, 2020; Lin & Chang, 2021; Asli *et al.*, 2023). Children who interact with the story in a playful way, personalising the experience and becoming digital storytellers themselves thus strengthen their agency and self-efficacy.

Using technology in storytelling promotes and implements 'UDL Consideration 7.3 in multiple ways, as outlined below.

- *enhancement of playful elements and promotion of the emotion of joy*: interactive elements, animations and soundtracks can make digital stories extremely entertaining, cultivating sensory, symbolic and imaginative play (Marín Díaz *et al.*, 2020). Digital storytelling applications and platforms often include mechanics similar to those found in gaming,

- promoting exploration and discovery and fuelling intrinsic curiosity (Moreno Lucas, 2017; Alotaibi, 2024);
- *improved accessibility*: Technologies offer features that adapt the presentation of stories, ensuring all children can access the content and actively participate in the narrative experience, regardless of their abilities;
 - *identity and community development*: Creating and sharing digital stories in the classroom or online can strengthen children's sense of self and connection to the learning community. They can recount their own experiences, explore different cultures and express their identities, thereby promoting empathy and intercultural understanding;
 - *experiencing self-efficacy*: the process of creating a digital end product gives children a sense of pride in their achievements, thereby strengthening their self-efficacy. The creative process, which is often collaborative, also fosters problem-solving and critical thinking abilities (Pattiruhu *et al.*, 2023; Debrenti, 2024);
 - *promoting engagement and motivation*: digital stories can evoke strong emotional responses, which are crucial for engagement and memorisation. The combination of visual and auditory elements creates a more immersive experience, which increases attention and persistence. Emotions play a vital role in motivation and learning in the classroom.

6. ARTIFICIAL INTELLIGENCE IN SUPPORT OF DIGITAL STORYTELLING

The intersection of digital storytelling and AI represents an emerging frontier in contemporary pedagogy, providing sophisticated tools for creating, developing and sharing narratives for educational and didactic purposes (Rahiem, 2021; Tarigan *et al.*, 2024). This synergy enhances the inherent potential of digital storytelling, which is defined as the integration of multimedia elements such as images, graphics, music, and audio, by incorporating the analytical and generative capabilities of AI and machine learning. This integration enables educators to create personalised learning experiences, stimulate cognitive and emotional development, and foster a sense of cultural belonging by generating content that resonates with students, promoting a sense of belonging and identity - a goal deemed essential for UDL.

The applications of AI in digital storytelling span several pedagogical dimensions. The first concerns the enhancement of linguistic and narrative skills. AI is an effective catalyst for optimising students' linguistic abilities and narrative competence (Preethika & Shetty, 2023; Tarigan *et al.*, 2024). Human-AI multimodal co-creative storytelling systems have been designed to facilitate children's narrative development by helping them to understand inter-elementary connections, image-text correspondences and narrative consequences at various levels of complexity. Similarly, implementing Large Language Models (LLMs) has been shown to be effective in mathematical language teaching. The 'Mathemyths' system is one example of this, supporting the co-creation of stories with children. Studies have shown that interaction with AI-based conversational agents can enhance narrative comprehension and engagement in pre-school children to a similar extent as human interaction, thereby promoting language development (Xu *et al.*, 2021; Ginting *et al.*, 2023).

The second dimension relates to the personalisation of stories. AI, and LLMs in particular, enable the dynamic personalisation of narratives, tailoring them to the individual needs of pre-school students and making them more relevant and engaging (Almoussa & Alghowinem, 2022; Makridis *et al.*, 2024;

Chen *et al.*, 2025;). This adaptive capacity is evident in the generation of bespoke stories to familiarise children with tangible programming robots, for example, by integrating computational learning into a meaningful narrative context. Platforms such as 'StoryMate' and 'FairyLandAI' demonstrate the potential of LLMs to enhance the experience of reading and creating personalised fairy tales, thereby stimulating imagination and supporting bespoke learning journeys (Capuano *et al.*, 2015; Makridis *et al.*, 2024; Chen *et al.*, 2025). AI-powered personalisation of learning has been shown to have a greater impact on student progress than traditional teaching approaches. Finally, AI enhances creativity: AI can facilitate creativity in children, particularly through LLM-guided storytelling and interaction with social robots (Ali *et al.*, 2021; Elgarf *et al.*, 2024).

Recent studies suggest that access to AI-generated ideas can result in more creative, better-written and more enjoyable stories, particularly for less experienced writers. Interacting with AI-based frameworks such as 'Tinker Tales' supports narrative development and AI literacy in early childhood by promoting collaborative story creation and exploration of narrative elements in an engaging environment. In particular, social robots have been shown to promote social, emotional and cognitive development by stimulating children's creativity through collaborative storytelling and idea generation (Clark *et al.*, 2018; Ali *et al.*, 2021; Susanto *et al.*, 2023; Elgarf *et al.*, 2024).

The rapid development of artificial intelligence necessitates targeted teacher training to prepare educators to effectively integrate these resources into the classroom. Reflection on the use of AI in educational digital storytelling paves the way for a broader consideration of the crucial role of teacher training in the field of new technologies. Only by adequately developing digital pedagogical competence will teachers be able to transform technology from mere technical support into a true, integrative element of the learning process, as discussed in more detail below

6.1 Artificial Intelligence and Teacher Training

In the context of the neurocognitive triad of joyful play outlined in the previous chapter, a fundamental question emerges for the practical implementation of these neuroscientific principles: how can teacher training in artificial intelligence and new technologies transform the “technological gap” into digital wisdom, creating effective bridges between embodied learning and adaptive technologies to optimise dopaminergic, creative and social simulation processes in 0-6 educational services? This question is particularly relevant considering that recent meta-analytic evidence reveals moderate positive effects (effect size = 0.45) of AI and digital technologies on early learning outcomes (Yang *et al.*, 2024), but only when implemented through teacher training that overcomes technical barriers to embrace true digital pedagogical competence. The transformation required is not simply about acquiring technical skills but rather developing what Prensky (2010) calls "digital wisdom" - the ability to make prudent decisions about when, how and why to use technology with young learners. Our approach differs from existing training models that focus solely on technical AI skills (Su & Yang, 2022; Labadze *et al.*, 2023), as it integrates neurocognitive understanding of the joy triad with explicit alignment to UDL 3.0 principles, ensuring that technology serves embodied and socially-mediated learning rather than replacing it.

The journey from technical competence to digital pedagogical wisdom represents a paradigm shift in teacher training. Traditional TPACK (*Technological Pedagogical Content Knowledge*) models have proven insufficient for the 0-6 age group, leading to the development of “ecological TPACK” frameworks that incorporate environmental factors specific to early childhood educational contexts

(Dong & Yang, 2024). This evolution reflects the growing recognition that early childhood educators need competencies that transcend technical skills to embrace a deep understanding of child development in the digital age. The European Commission's DigCompEdu framework, adapted specifically for early childhood contexts, articulates six areas of competence ranging from professional engagement to facilitating students' digital skills (Redecker, 2017).

Similarly, UNICEF's Digital Competence Framework for Educators (2023) emphasises inclusive digital practices, children's rights in digital environments and developmental appropriateness, which are particularly critical in the 0-6 age group.

Technological distance is the primary barrier to the effective adoption of educational technologies, surpassing in importance the limitations of access or technical skills (Mercader & Gairín, 2020). This gap manifests itself in multiple dimensions: philosophical discrepancies between constructivist pedagogies and structured digital tools, evolutionary limitations in the design of educational technologies, and practical challenges in implementation in authentic early childhood settings.

In the Italian context, research conducted within the integrated 0-6 system reveals significant cultural differences between digital self-assessment and actual competence (Limone *et al.*, 2022). Research shows that addressing the technology gap requires understanding the professional identity and pedagogical values of educators, not just providing technical training (Otterborn *et al.*, 2019). As already highlighted, the gap between authentic learning experience and the student can be amplified or reduced by technology depending on how it is integrated into the educational process.

Recent research articulates how AI transforms Vygotsky's Zone of Proximal Development into what is referred to as a learning field - a probabilistic space of multiple evolutionary trajectories mediated by predictive analytics (Rigopouli *et al.*, 2025).

This represents a fundamental expansion of the ZPD concept, moving from static support structures to dynamic, real-time adaptations based on neuroplasticity biomarkers and multimodal feedback loops. Adaptive learning technologies demonstrate 30-40% improvements in retention rates compared to conventional methods when implemented correctly (Chen *et al.*, 2020). These systems analyse streams of biometric, behavioural, and contextual data to create individualised learning paths, with advanced systems incorporating cultural pattern detectors to adapt to knowledge patterns (Sasanelli *et al.*, 2025). Such personalisation connects directly to the concept of “semantic islands” discussed earlier, allowing AI to intercept and facilitate the expansion of each child's unique cognitive connections. Social robots are particularly effective in special education settings, improving joint attention and theory of mind development for children with autism spectrum disorders (Belpaeme *et al.*, 2018). These findings are directly linked to the activation of the mirror neuron system discussed above, suggesting that social robots can act as mediators for vicarious learning when designed appropriately. However, research reveals important limitations because, when compared to non-intelligent tutoring systems, the advantages of AI are mitigated, suggesting that the quality of pedagogical design matters more than technological sophistication (Létourneau *et al.*, 2025). Most studies focus on short-term outcomes within individual courses or semesters, creating gaps in our understanding of long-term developmental effects.

6.2 Concrete Tools and Critical Skills for Teachers

Educational chatbots for lesson planning show a 36% increase in educator confidence (Labadze *et al.*, 2023). Studies on ChatGPT show mixed results for generating lesson plans for nursery school,

with particular effectiveness in creating inclusive play activities when guided by pedagogically informed prompts. However, implementation challenges include the risk of over-reliance on data-driven insights and the need for critical evaluation of potentially biased or inaccurate AI recommendations. Effective integration requires teachers to develop pedagogical prompt engineering skills - the ability to formulate requests to AI that reflect appropriate developmental principles and specific educational objectives (Barbieri *et al.*, 2025). This skill is directly linked to an understanding of the neurocognitive triad: teachers must know how to request activities that simultaneously activate the reward, creativity and social simulation systems.

Natural language processing for the generation of personalised stories is particularly promising, with systems such as StoryMate demonstrating high child engagement and educational value (Chen *et al.*, 2025). These systems successfully adapt linguistic complexity according to developmental stage and integrate educational standards through retrieval-augmented generation (RAG) approaches. The ability to generate personalised narratives is directly linked to the activation of the Default Mode Network and mirror neuron system discussed above, and AI-generated stories can be calibrated to activate specific neural networks, facilitating both creativity and vicarious learning through embodied simulation (Ninaus & Sailer, 2022).

The main barriers to adoption include a lack of knowledge and trust in AI as a primary obstacle, insufficient access to training, time constraints, and fear of job displacement, with teacher anxiety particularly pronounced among female educators, while institutional barriers include inadequate infrastructure, policy gaps, and resource constraints.

Facilitators for successful adoption emphasise practical training over theoretical knowledge, sustained support rather than one-off workshops, peer learning through communities of practice, and context-specific training tailored to age levels and subject areas. Institutional support includes leadership buy-in, clear ethical guidelines, technical infrastructure, and collaborative cultures that emphasise experimentation and learning from failure.

Critical competencies for effective integration include understanding that abstract thinking develops from embodied experiences, designing screen-based activities that incorporate physical movement, and maintaining human agency in AI implementation. Emphasis is placed on “human-in-the-loop” approaches, identifying three key areas where educators must remain central: moment-to-moment decision-making in the classroom, planning and reflection processes, and technology selection and evaluation (Ninaus & Sailer, 2022)

Meta-analytic evidence from 30 studies reveals significant overall positive effects ($g = 0.45$) of ICT in early childhood education, with stronger impacts on subject knowledge acquisition (effect size = 0.59) and moderate effects on language skills (effect size = 0.24) (Ruijia *et al.*, 2025). Educational apps demonstrate medium-sized impacts in literacy (ES = 0.35) and mathematics (ES = 0.29) comparable to tutoring interventions. The optimal duration of the intervention appears to be 6-18 weeks, with shorter and longer implementations showing insignificant effects (Kim *et al.*, 2021). This finding has important implications for professional development and implementation planning, suggesting that sustained but not indefinite interventions produce the best results.

Therefore, the effective integration of AI into teacher training for the 0-6 age group requires an approach that recognises and values the neurocognitive triad of joyful play, using technology to amplify rather than replace natural learning processes.

7. CONCLUSIONS

In conclusion, the analysis conducted highlights a profound convergence between the new UDL 3.0 Guidelines, in particular “Consideration 7.3” dedicated to the cultivation of joy and play, and the latest neuroscientific discoveries. The neurocognitive triad – which integrates reward systems, default mode networks and mirror neurons – provides a solid biological basis that legitimises play not as an ancillary activity, but as a fundamental element for effective and meaningful learning in early childhood. In this scenario, digital storytelling, enhanced by the generative and adaptive capabilities of Artificial Intelligence, emerges as a pedagogical tool of choice. It offers unprecedented opportunities to create personalised, inclusive and deeply engaging narrative experiences, fully in line with UDL principles. However, the potential of these technologies can only be fully realised through a radical rethinking of teacher training. The crucial challenge is not to bridge a mere technical gap, but to transform “technological distance” into “digital wisdom”. It is imperative to train educators who are able to critically and consciously integrate these tools, using them as effective cognitive scaffolding that amplifies natural and embodied learning processes, without ever replacing them. Only in this way will it be possible to build educational environments that not only embrace the diversity of each child, but also actively promote joy as an essential driver of knowledge and development.

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How to cite this paper: Sasanelli, L.D., Barbieri, U., Di Fuccio, R. (2025). Universal Design of Learning, gamification e intelligenza artificiale: verso un modello integrato di Universal Design of Learning per la formazione degli insegnanti [Universal Design of Learning, gamification and artificial intelligence: an integrated model for teacher education]. *QTimes webmagazine*, anno XVII, n. 4, 33-51.

Doi: https://doi.org/10.14668/QTimes_17404