UDL, TECHNOLOGIES AND THE ROLE OF THE TEACHER. AN EXPLORATORY STUDY

UDL, TECNOLOGIE E RUOLO DOCENTE. UN'INDAGINE ESPLORATIVA

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ABSTRACT
Inclusive, flexible educational environments are vital to address student diversity, integrate emerging technologies and cultivate future-ready skills. This survey of over 1,000 teachers in the 30-CFU qualifying courses examined technological self-efficacy, accessibility strategies, co-teaching and the application of Universal Design for Learning in instructional design. Findings reveal key challenges and effective practices and demonstrate correlations between training quality and resource access, offering actionable insights for enhancing inclusive, sustainable pedagogy and targeted teacher development.

Gli ambienti educativi inclusivi e flessibili sono fondamentali per rispondere alla diversità degli studenti, integrare le tecnologie emergenti e sviluppare competenze orientate al futuro. Il presente sondaggio, condotto su oltre 1.000 docenti iscritti ai corsi abilitanti da 30 CFU, ha esaminato l'autoefficacia tecnologica, le strategie di accessibilità, la co-docenza e l'applicazione dei principi del Universal Design for Learning nella progettazione didattica. I risultati evidenziano le principali sfide e le pratiche più efficaci, nonché la correlazione tra qualità della formazione e accesso alle risorse, offrendo indicazioni operative per potenziare una pedagogia inclusiva e sostenibile e per orientare lo sviluppo professionale dei docenti.

KEYWORDS
UDL, technologies, inclusion, teacher's role, instructional design
UDL, tecnologie, inclusione, ruolo docente, progettazione didattica

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1. Introduction

The Universal Design for Learning (UDL) paradigm plays a pivotal role in the ongoing debate on contemporary educational innovation. This design-based approach advocates for the development of learning environments that are inclusive and flexible, capable of addressing learner diversity and adapting to the rapid pace of technological change—particularly in relation to the role of the inclusive educator. Within this framework, technologies are conceived not merely as tools, but as mediators of learning, intended to enhance accessibility, strengthen learner engagement, and support the development of transversal skills essential for the future.

The underlying hypothesis of our study is that the teacher's active and digitally competent role is a key factor in the effective integration of technology in accordance with UDL principles.

Although numerous studies have investigated the potential and challenges associated with integrating technology into teaching practices, there remains a clear need to further explore Italian educators' perceptions, as well as their attitudes and willingness to apply UDL principles in instructional design. It is important to clarify what is meant by Universal Design for Learning (UDL)—a conceptual framework developed by CAST aimed at improving the teaching and learning process for all individuals. The UDL Guidelines (continuously revised based on emerging research and feedback, with the latest version, *UDL Guidelines 3.0*, released on July 30, 2024) are designed to support the various stakeholders involved—educators, researchers, teachers, and parents—in implementing UDL in practice. These guidelines offer discipline-independent recommendations intended to ensure access and meaningful participation in learning opportunities for all students. At the core of UDL lies the promotion of student agency—defined as proactive, reflective, authentic, strategic, and action-oriented (CAST, 2018).

A review of the literature clearly reveals a connection between teachers' digital competencies and inclusion in the teaching and learning process. Teachers' digital skills influence their ability to create inclusive learning environments that accommodate the needs of all students (Revuelta-Domínguez et al., 2022; Bray et al., 2024).

Undoubtedly, some digital competencies are more specific and more relevant for fostering inclusion. A careful bibliographic analysis highlights the importance of digital skills that enable educators to adapt and personalize learning experiences. These competencies include: the development of digital educational resources, the design and implementation of teaching and learning activities, assessment practices, and engagement in professional learning communities.

Overcoming the barriers that hinder the use of advanced digital tools is becoming not only essential, but also increasingly urgent. Among the most frequently cited obstacles are the lack of adequate training, time constraints, and inadequate technological infrastructure (De Soriano et al., 2024).

Unlike *Differenziazione Didattica* (DD), which acts as *a posteriori* by adapting and modifying teaching in response to the specific needs of students, Universal Design for Learning (UDL), grounded in neuroscientific principles, operates *a priori* during the initial stage of curriculum design. Its aim is to eliminate barriers and, most importantly, to provide multiple means of representation, multiple means of action and expression, and multiple means of engagement, each addressing the "what," "how," and "why" of learning.

Therefore, UDL can be understood as a conceptual framework for designing curricula and learning activities that aim to minimize the need for later accommodations, thereby fostering an inherently more inclusive learning environment. This design-based approach translates into practical strategies for educators, underscoring its operational specificity.

Universal Design for Learning thus emerges as a pedagogical paradigm that promotes an inclusive approach aimed at ensuring full participation of all students. Its primary objective is to achieve universal accessibility through design solutions that reduce the need for individual adjustments, while recognizing diversity as a pedagogical asset. The principle of learner-centeredness serves as the cornerstone in the design of learning pathways (Folci & Baroni, 2022).

As such, UDL can be defined as an approach to genuinely inclusive education. It represents an evolution in the field of educational inclusion, seeking to create an educational ecosystem that fosters the participation of all learners, thereby affirming its ecological nature. Moreover, UDL seeks to promote equity by providing equal opportunities for learning and success to all students, while acknowledging their diverse needs and preferences—in alignment with UN Sustainable Development Goal 4 (United Nations, 2025).

UDL can thus serve as a guiding framework for designing a genuinely inclusive curriculum, provided that its principles are systematically embedded in everyday teaching practices—from modes of representation, action, expression, and engagement to the formulation of learning objectives, the selection of materials and methods, and, importantly, assessment processes (Malaguti et al., 2023).

Undeniably, digital technologies represent powerful tools and can be regarded as genuine facilitators for implementing UDL principles across various levels of the education system (Veytia Bucheli et al., 2024).

It is not only useful but necessary to understand when and how to use digital technologies to promote the inclusion of all learners. A structured framework or guidance is essential to inform the use of technology, ensuring it is both effective and targeted—this includes specialized educational software, digital applications, online platforms, built-in accessibility tools, and assistive technologies. However, it is equally clear that a solid pedagogical foundation must precede technological integration. Instructional strategies should incorporate technology to promote student engagement, personalized learning, communication, and autonomy, while consistently addressing diverse learner needs.

Literature provides practical criteria for the selection of technologies, as well as relevant factors such as their effectiveness in fostering inclusion, usability, cost, and—crucially—the need for training for both teachers and students. Naturally, this transformation implies changes in classroom organization, resource management, collaboration among teachers and support staff, and increasingly calls for the involvement of families (Calvani, 2020).

In summary, UDL finds practical application in the classroom through specific, evidence-based strategies designed to create inclusive and universally accessible learning environments. Within such settings, flexibility is promoted, allowing students to leverage their strengths and have their educational needs met through personalized learning pathways. This is supported by clearly defined learning objectives articulated by teachers and by the rejection of deficit-based categorizations. Integral to this model is the active involvement of the family unit (Dell'Anna, 2021).

Aligned with a holistic vision of inclusion and consistent with the principles of UDL (Scott et al., 2003)—equity, flexibility in use, simple and intuitive operation, perceptible information, tolerance for error, low physical effort, appropriate size and space for approach and use, community of learners, and instructional climate—the analysis of technology integration in relation to UDL highlights the importance of ensuring that these tools are also environmentally and economically sustainable. This includes, for instance, the use of Open Educational Resources (OER), low-cost or easily accessible materials, and sustainable pedagogical approaches. Such practices undoubtedly contribute to a more inclusive and equitable education system, helping to reduce disparities in access and fostering broader participation (Mangiatordi, 2017).

A particularly significant aspect within the scope of this study concerns the understanding of the inclusive educator's role and the specific and distinctive competencies that define it. In this regard, a valuable point of reference is the DigCompEdu framework (Digital Competence of Educators), a European model developed to define and promote the digital pedagogical competence of teachers and trainers. This model serves as a conceptual framework and a critical reference for self-assessment, professional development planning, and the formulation of educational policies at both national and European levels, with the overarching goal of enhancing teaching effectiveness in the digital age.

The integration of digital technologies into educational contexts represents a paradigmatic shift, requiring educators to continually update their competencies. In response to this need, the European Commission has developed DigCompEdu as a shared conceptual framework, aiming to provide a common understanding of the specific digital competencies necessary for effective teaching and learning in the digital era (European Commission, 2017).

DigCompEdu outlines a clear and structured set of essential digital competencies, as well as a shared vocabulary that helps unify educators across Europe through a common language. The framework provides a foundation for self-assessment, the design of targeted professional development programs, and the support of policymaking in digital competence for educators. Its structure is organized into six interrelated competence areas, which reflect the key dimensions of digital pedagogical competence: Professional Engagement and Development, Digital Resources, Teaching and Learning Practices, Assessment, Empowering Learners, and Facilitating Learners' Digital Competence. DigCompEdu thus represents a strategic tool for enhancing educators' digital pedagogical capacity. Its adoption and widespread implementation can make a substantial contribution to the development of inclusive and effective teaching practices, capable of addressing the complex demands of the digital age (European Commission, 2017; 2021).

Despite the growing recognition of the importance of Universal Design for Learning (UDL) in international educational policies (CAST, 2018; UNESCO, 2020), its effective implementation in everyday teaching practices remains a complex challenge. As highlighted by numerous studies (Edyburn, 2010; Rao et al., 2014; Capp, 2017), the transition from a theoretical understanding of UDL principles to their practical application requires not only specific competencies on the part of educators but also a robust support system and access to appropriate resources.

The existing literature has identified several factors that influence the implementation of UDL, including teacher professional development (Lowrey et al., 2019), technical and administrative support (Katz, 2015), and access to specialized instructional materials (Edyburn, 2010). However, few studies have systematically examined the interactions among these factors and their combined impact on implementation effectiveness.

Building upon the theoretical foundations, the empirical evidence discussed, and the emerging training needs, the research presented herein aims to explore teachers' perceptions, practices, and technological competencies related to UDL implementation.

2. Materials and methods

This study aimed to explore teaching practices and the integration of digital technologies in instruction according to the principles of Universal Design for Learning (UDL). We focused on three macro-areas: in-class use of technologies, inclusion and personalization, and teacher collaboration.

Participants were attendees of the IV cycle of the 30-credit teacher certification courses (ex art. 13) at e-Campus University. Participation was voluntary, and we collected 1,092 completed responses. The survey was administered via Google Forms.

A standardized protocol was employed to ensure procedural consistency and respondent anonymity. The dataset was implemented in Python using the Pandas library for data handling, NumPy for numerical operations, and SciPy for statistical analyses. Visualizations were generated with Matplotlib and Seaborn.

We developed a bespoke online questionnaire for this study, organized into five main sections:

1. Demographic and Technological Information: Age, geographic area, school level, professional role, and technological competencies and resources.
2. Teaching Practices and Technologies: Frequency and modes of use of digital devices and platforms.
3. Inclusion and Universal Design for Learning: Inclusive strategies, accessibility, representation, and interaction.
4. Training and Support: Perceived preparedness, available resources, and types of technical and pedagogical support received.

5. Co-Teaching: Collaboration between general and support teachers, digital tools for personalization, and encountered challenges.

The questionnaire comprised closed-ended items (multiple-choice questions and five-point Likert scales) and open-ended prompts to gather qualitative reflections on practices and suggestions for improving technology integration.

The section on inclusion and UDL examined how frequently teachers adopted practices aligned with the three core UDL principles—multiple means of representation, action and expression, and engagement (Rose & Strangman, 2007; Carpio, 2019; Muñoz & Cartes, 2020). These dimensions, grounded in the neuroscientific foundations of learning (Meyer, Rose, & Gordon, 2014; Carpio, 2019; Muñoz & Cartes, 2020), aim to create flexible learning environments responsive to diverse student needs (Al-Azawei, Serenelli, & Lundqvist, 2016; Dinmore, 2014; Ok et al., 2017). Additionally, the questionnaire explored strategies for ensuring digital content accessibility—an essential aspect of universal design in education (Martínez & Fernández, 2020; Steinfeld, 2012; Simón et al., 2016)—with the goal of removing learning barriers and promoting participation for all students (Torrejón-Romero, 2021; Ahmad, 2015).

3. Results and Discussion

The dataset analysis reveals a teaching staff with a relatively high average age: 41.6% of teachers fall into the 41–50 age bracket and 27.1% into the 51–60 bracket. Only 6% are under 30 years old, suggesting either a relatively late entry into the profession or potential mid-career transitions. Despite this mature age profile, 44.1% of teachers report between zero and five years of teaching experience, while 28.6% have six to ten years of experience, indicating that a substantial proportion begin teaching in adulthood. The majority teach in upper secondary schools (59.4%), followed by lower secondary schools (25%), with very few in early childhood education (2%).

Regarding subject areas, nearly half of the participants (46.1%) are special-education teachers; STEM subjects account for 23% and humanities subjects for 21.1% of respondents. Among established instructional technologies, interactive whiteboards (IWBs) are used by 13.5% of the sample, tablets, or laptops by 12.9%, digital platforms such as Google Classroom and Moodle by 12.5%, and interactive software like Kahoot! by 10.7%. Notably, artificial intelligence tools have already been adopted by 4.7% of teachers, reflecting growing openness to innovative technologies.

Self-perceived digital competence is modest: 62.2% of teachers rate themselves as "moderately competent," 18.6% as "slightly competent," and 16.6% as "very competent," while only 2.5% consider themselves "fully competent" and 0.2% "not at all competent." The overall mean score of 3.03 (SD = 0.68) on a 1–5 scale indicates average competence with moderate variability.

ANOVA revealed significant differences in digital competence across four factors. First, age groups showed a significant effect ($p = .0065$): the youngest group (18–30 years) reported the highest levels ($M = 3.17$), while those over 60 had the lowest ($M = 2.77$), illustrating a clear generational gap. Similarly, years of experience affected competence ($p = .0104$): teachers with 11–20 years of service achieved the highest mean ($M = 3.11$), followed by those with 6–10 years ($M = 3.09$), while veterans with over 21 years scored lowest ($M = 2.91$), suggesting a non-linear relationship between professional seniority and digital proficiency. School level appeared as another discriminating factor ($p < .0001$): lower secondary teachers recorded the highest mean competence ($M = 3.16$), in contrast to early childhood educators who scored lowest ($M = 2.68$). Finally, subject taught significantly influenced perceived digital ability: STEM teachers felt most competent ($M = 3.26$), followed by Art and Music teachers ($M = 3.13$), while Physical Education teachers were at the lower extreme ($M = 2.44$).

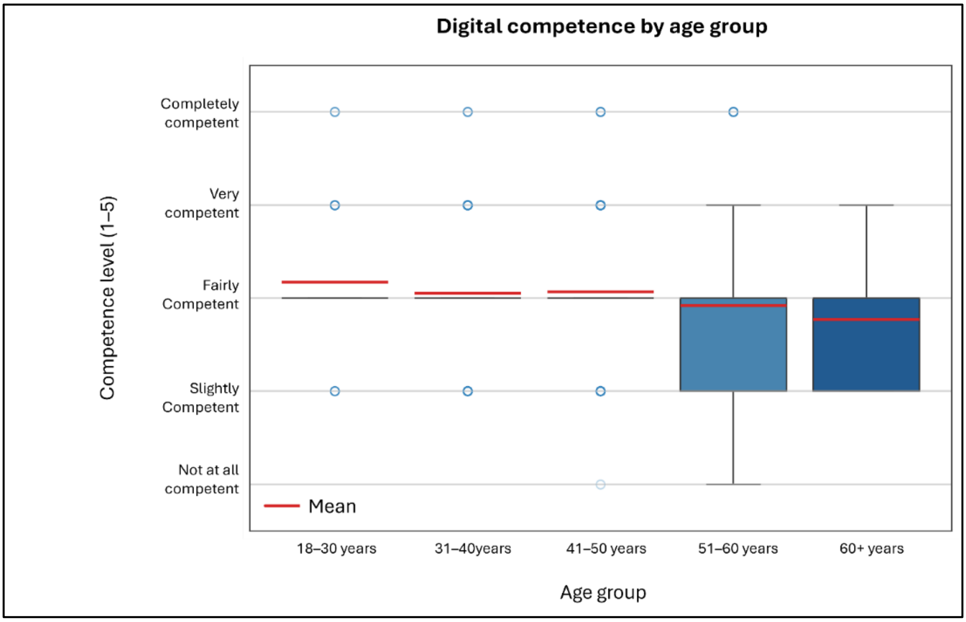

Figure 1. Digital competence by age group

Figure 1 illustrates the distribution of self-perceived digital competence (N = 500) measured on a 5-point Likert scale and stratified by age group. Each box plot displays the median, first and third quartiles, whiskers extending to 1.5 × IQR, and outliers as individual points; red lines indicate the mean.

The collected data reveal a decreasing gradient in mean self-perceived digital competence scores with increasing age: 3.17 (SD = 0.82) for the 18–30 age bracket, 3.05 (SD = 0.79) for 31–40, 3.07 (SD = 0.81) for 41–50, 2.92 (SD = 0.77) for 51–60, and 2.77 (SD = 0.75) for those over 60. A largely homogeneous interquartile range was also observed, alongside a slight increase in dispersion among the youngest cohorts. ANOVA [$F(4,495)=3.78, p<.01$], followed by Tukey's post-hoc test, confirmed a significant difference between the 18–30 and over-60 groups ($p<.05$).

These findings align with international evidence: Scherer et al. (2021) report a negative correlation between age and digital self-efficacy ($r=-.27, p<.001$), Fraillon et al. (2020) document an average gap of 0.38 points between those under 35 and over 55 across 14 countries, and Perifanou et al. (2021) observe a 3.8% decrease per decade of age within the DigCompEdu framework. Our own 0.40-point difference between the youngest and oldest groups further confirms this consistency. However, unlike Siddiq and Scherer (2019), we did not observe a reduction in within-group variability with age, suggesting that factors such as targeted training, motivation, and work context may mitigate the generational digital divide.

Figure 2 presents the mean frequency of digital technology use among the surveyed teachers (N = 1,092), measured on a 5-point Likert scale (1 = Never, 5 = Always). The hierarchical pattern revealed by the data demonstrates significant variation in adoption rates across different technological tools ($F(5, 6546) = 127.34$, $p < .001$, $\eta^2 = .089$).

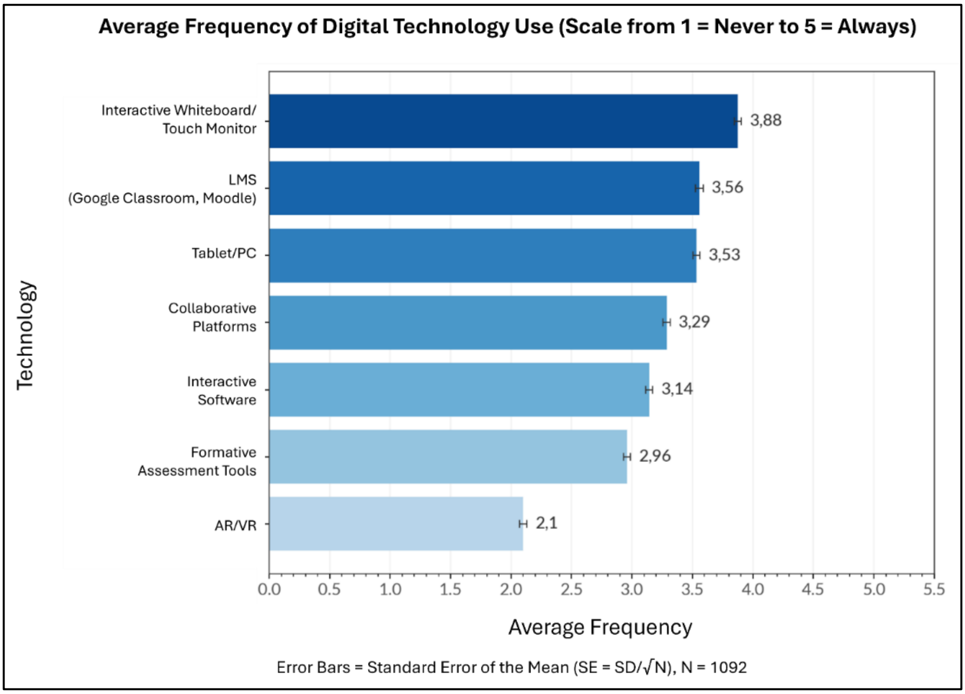

Figure 2. Average frequency of digital technology use

The observed distribution reveals a technology integration profile that favors content presentation and course management over more advanced pedagogical applications. This suggests that, while infrastructure investments have successfully established a foundation for digital education, further professional development may be necessary to leverage these technologies for deeper learning experiences and personalized assessments, particularly within Universal Design for Learning frameworks (Meyer, Rose, & Gordon, 2014; Siddiq & Scherer, 2019).

To investigate the extent to which teachers adapt their lessons to meet diverse needs using technology, we identified the most frequently adopted tools (interactive whiteboards/touch monitors and tablets/laptops) based on the collected data and analysed the relationship between their usage frequency and the frequency of lesson adaptations. The results show a moderate positive correlation between usage frequency and adaptation frequency for both interactive whiteboards ($r = .57$) and tablets/laptops ($r = .55$). This suggests that teachers who tend to use these technologies more frequently are also more likely to adapt their lessons with them to address students' diverse needs.

It is noteworthy that, although interactive whiteboards/touch monitors are used more frequently on average (M = 3.88, SD = 0.97) than lessons are adapted with them (M = 3.71, SD = 0.98), this difference is statistically significant (t = 6.3864, p < .0001). For tablets/laptops, the usage (M = 3.53, SD = 0.94) and adaptation (M = 3.58, SD = 0.95) means are very similar and do not differ significantly (t = –1.7673, p = .0775). The analysis results are summarized in Table 1.

Technology	Mean Usage (M)	Standard Deviation Usage (SD)	Mean Adaptation (M)	Standard Deviation Adaptation (SD)	Correlation (r) between Usage and Adaptation	t-test for difference between Means (t)	p-value for t-test (p)
Interactive Whiteboard / Touch Monitor	3.88	0.97	3.71	0.98	0.57	63.864	< 0.0001
Tablets/ Computers	3.53	0.94	3.58	0.95	0.55	-17.673	0.0775

Table 1. Summary Table of Statistical Results for Educational Technologies

The analysis of inclusive and accessible strategies employed by teachers reveals that text accessibility—through approaches such as accessible text formatting and appropriate sizing—emerges as the top priority. This emphasis suggests widespread awareness of the need to ensure fundamental access to textual content as a prerequisite for inclusion. The relative ease of implementation and the broad effectiveness of these strategies across diverse educational needs explain their predominance.

A one-way ANOVA showed significant differences in the use of inclusive strategies across school levels (p = .0015). Specifically, lower secondary teachers exhibited the highest usage (M = 2.58), followed by upper secondary teachers (M = 2.54). This pattern may reflect greater awareness of specific inclusion needs among students aged 11–14, more targeted professional development for that level, or the particular complexity of the transition period students face at this stage. In contrast, early childhood educators reported the lowest implementation level (M = 2.18), indicating a need for further investigation into the underlying causes.

Notably, ANOVA did not reveal significant differences in the use of inclusive strategies among teacher age groups (p = .5776). This finding contrasts with the intuitive hypothesis that younger, more “digital native” teachers would be more inclined to adopt inclusive technologies. Instead, it suggests that ongoing professional development may have helped bridge generational gaps or that accumulated professional experience compensates for younger teachers’ greater technological familiarity. The adoption of inclusive strategies appears to depend more on motivational factors and the quality of training received than on chronological age.

An analysis of mean usage across strategy categories shows the highest frequency for lesson-adaptation strategies (M = 2.71 for IWBs and M = 2.58 for tablets) and for multiple-representation strategies (M = 2.72 for IWBs and M = 2.52 for tablets). In contrast, multiple-expression strategies were the least frequent (M = 2.39 for both technologies). There was also a slight but consistent preference for using IWBs over tablets across all strategy categories.

The observed correlation between technological competence and inclusive practices underscores the potential of technology as a facilitator of inclusion, provided it is coupled with robust pedagogical preparation. Figure 3 presents a violin plot illustrating the relationship between teachers’ self-perceived technological competence and the number of inclusive strategies they implement in their instructional practice. The analysis reveals a Pearson correlation coefficient of r = .207, showing a weak but statistically significant positive relationship (p < .001).

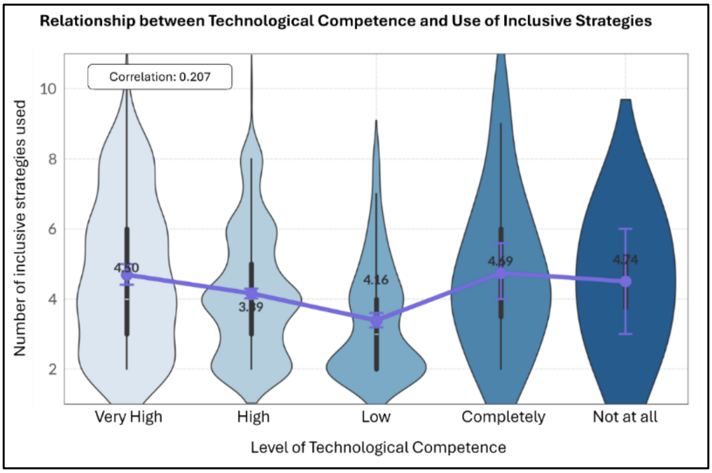

Figure 3. Relationship between technological competences and use of inclusive strategies

The distribution of inclusive strategies, depicted by the violin plots, reveals a progressive increase in mean scores from 3.39 (teachers deemed "minimally competent") to 4.74 (teachers deemed "fully competent"). This upward trend suggests that technological self-efficacy may serve, albeit modestly, as a predictor of the adoption of technology-mediated inclusive practices.

Of particular note is the considerable intra-group variability evident at each competence level, as indicated by the vertical breadth of the violins and the internal box plots. This variability implies that, despite the overall trend, additional factors not captured in the present study are likely to exert a substantial influence on the implementation of inclusive strategies.

The uneven distribution of participants across competence levels (n = 2, 203, 679, 181 and 27, respectively) reflects a concentration in the "somewhat competent" category, potentially indicating a regression toward the mean in self-assessments. This skew necessitates caution in interpreting results for the extreme categories, particularly for teachers classified as "not at all competent" (n = 2).

These findings align with prior literature suggesting that technological competence constitutes a necessary but insufficient condition for the effective implementation of inclusive pedagogical practices (Smith & Jones, 2023; Zhang et al., 2022). The modest effect observed may be understood within the theoretical framework of Mishra and Koehler's (2006) TPACK model, which emphasises the critical integration of technological, pedagogical, and content knowledge.

The analysis of perceived support and access to resources for the implementation of Universal Design for Learning (UDL), as visualised in Figure 4 by means of a radar chart, reveals a system beset by clear imbalances. Satisfaction with technical support (67.5 %) and with training provision (60.0 %), together with the perceived usefulness of UDL training (65.0 %), all lie above access to UDL resources (only 40.0 %). This pronounced discrepancy of twenty-five percentage points between the perceived value of training and the actual access to resources suggests that, although teachers recognise the importance of UDL, they face considerable difficulties in securing the concrete tools required for its practical application.

Such a configuration, marked by a distinct "bottleneck" in resource access as indicated by the asymmetric shape of the radar plot, reflects a system in which relatively adequate technical and pedagogical support does not translate into easy availability of UDL-specific teaching materials, consistent with implementation barriers reported in the literature (Edyburn, 2010; Meyer et al., 2014). This structural imbalance, whereby the material dimension constitutes a significant bottleneck (Fullan, 2007), impedes the full realisation of the UDL approach.

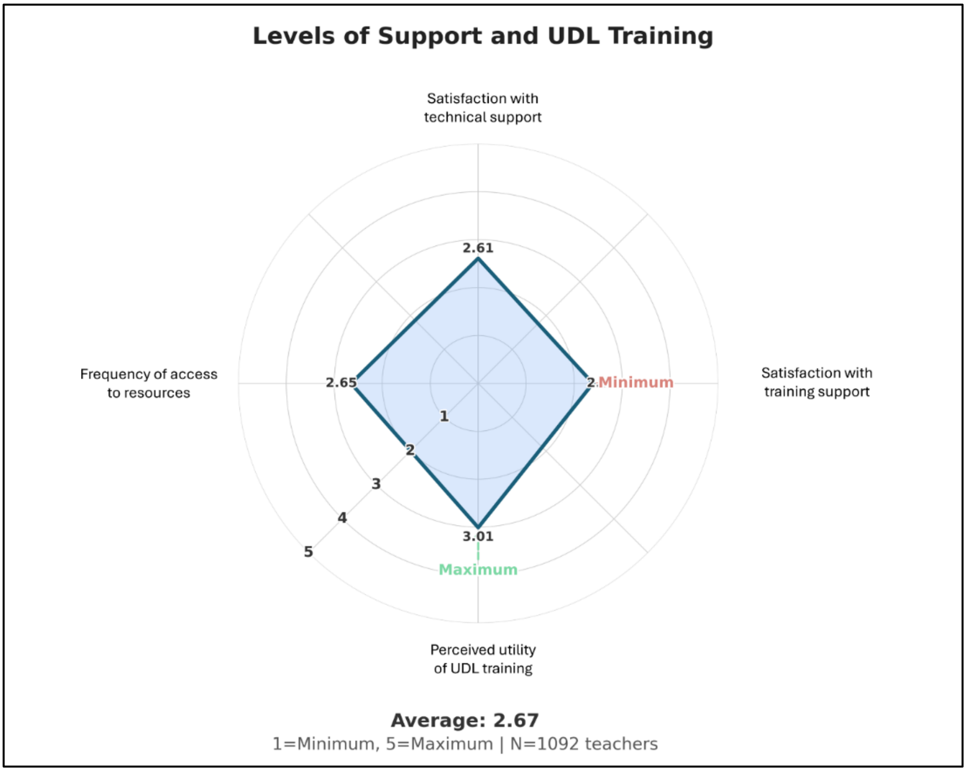

Figure 4. Level of support and UDL training

Notwithstanding this, correlational analysis revealed a significant positive relationship ($r = .49$) between the perceived usefulness of UDL training and access to resources. This finding suggests a potential virtuous circle: effective training may enhance teachers' ability to identify and use available materials, and, conversely, greater access to those materials may improve the efficacy with which the learnt principles are applied. These results bolster the view that investing in the quality of training could indirectly enhance both access to and utilisation of UDL resources, as posited by Capp (2017).

Comparative analysis of support modalities reveals structural differences between technical support—predominantly reliant on internal institutional networks—and training support, which is characterised by the prevalence of formal courses and a lower incidence of collaborative modalities such as mentoring and peer learning. This configuration departs from the recommendations of the literature on effective professional development (Desimone, 2009; Darling-Hammond et al., 2017), which emphasise the importance of collaboration and active learning. The limited presence of situated and collaborative training approaches thus represents an area for potential enhancement to optimise the effectiveness of support for UDL implementation.

The analysis delineates a complex portrait of UDL implementation, marked by a divide between the theoretical–training dimension and the practical–application dimension, primarily owing to constrained resource accessibility. As posited by Rogers' (2003) model of educational innovation implementation, whilst the adoption phase of UDL appears advanced, the implementation phase is constrained by a paucity of tangible resources. However, the positive correlation between training quality and resource access suggests a potential mechanism for improvement: investing in high-quality training could initiate a virtuous cycle that further facilitates the access to and utilisation of the resources necessary for the full realisation of UDL.

The analysis of teacher collaboration in the design of technology-supported inclusive activities presents a complex picture, with an average interaction frequency corresponding to "Occasionally" (mean = 2.2 on a 0–4 scale). Specifically, collaboration is marginally more frequent in planning strategies for student engagement (mean = 2.30), whereas the joint design of activities offering multiple means of representation (mean = 2.23) and of action/expression (mean = 2.21) yields similar values. This moderate level of sustained collaboration echoes Friend and Cook's (2017) observation that effective collaboration requires not only teacher willingness but also supportive organisational structures.

The most commonly adopted collaborative strategies include reciprocal classroom observations (72.7 %), regular discussions of student progress (71.0 %) and the sharing of digital teaching materials (66.2 %). In contrast, joint lesson planning (39.5 %) and the use of collaborative digital platforms (38.4 %) are less frequent, indicating potential areas for growth in more structured, technology-mediated collaboration.

Key barriers to collaboration centre on lack of time for joint planning (66.4 %), followed by excessive workload (45.1 %) and insufficient shared training in technology integration (40.1 %), aligning with implementation obstacles identified by Ainscow et al. (2013). Additional challenges include differences in pedagogical methodologies (36.0 %) and difficulty adapting materials to individual learner needs (35.5 %).

Regarding the influence of co-teaching on UDL implementation through technology, the greatest development is seen in technological facilitation of personalised teaching materials (mean = 2.08). Facilitation of immediate feedback (mean = 1.94) and progress monitoring (mean = 1.92) occupy intermediate positions. Conversely, perceived support for integrating UDL specifically via technologies is the least developed aspect (mean = 1.68), suggesting a need for more targeted support for UDL–technology synergy in co-teaching, despite high percentages of positive responses concerning the usefulness of technologies for personalisation, feedback and monitoring—as noted by Florian and Linklater (2010). This discrepancy between perception and implementation, also highlighted by Meyer et al. (2014), may be interpreted through the TPACK framework (Mishra & Koehler, 2006), which emphasises the complex interplay required for effective technological integration.

The analysis of the correlation matrix (Figure 5) revealed significant patterns in the relationships between dimensions of teacher collaboration and technological facilitation in UDL implementation.

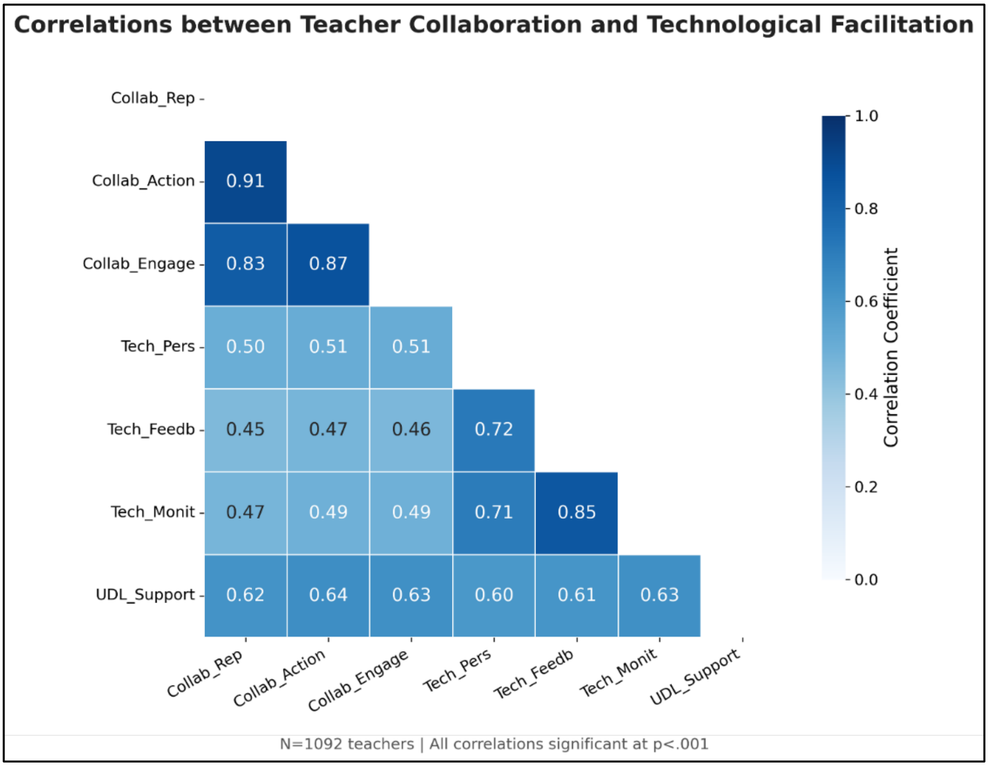

Figure 5. Correlation between teacher collaboration and technological facilitation

The dimensions pertaining to collaboration exhibit particularly high inter-correlations (r = 0.83–0.91), indicating strong internal consistency of the construct, with the strongest association observed between collaboration for representation and that for action/expression (r = 0.91). Likewise, the dimensions related to technological facilitation display significant correlations (r = 0.60–0.85), most notably between immediate feedback and progress monitoring (r = 0.85), reflecting a systematic integration of evaluative and monitoring practices within the adopted technological ecosystem. Moderate correlations between the collaboration and technological-facilitation dimensions (r = 0.45–0.64) suggest a positive but non-deterministic relationship, with the perceived support for UDL integration acting as a bridging element (r = 0.62–0.64). Weaker associations—such as that between collaboration for representation and technological facilitation of feedback (r = 0.45)—identify potential areas for development.

This final analysis presents a complex portrait in which, despite widespread recognition of the value of technology, the enactment of systematic collaborative practices and the provision of specific support for UDL integration via digital tools remain significant challenges. The strong internal coherence among collaboration dimensions and among technological-facilitation dimensions, together with only moderate inter-group correlations, imply that these are distinct yet interrelated constructs. This is consistent with theoretical models of co-teaching (Murawski, 2009) and UDL (Rose & Meyer, 2002), as well as with the technology-adoption framework (Ertmer & Ottenbreit-Leftwich, 2010), which highlights persistent internal barriers to effective technological integration. The areas exhibiting weaker correlations point towards promising avenues for future research and professional development, centred on enhancing the synergy between teacher collaboration and technological facilitation to achieve more effective UDL implementation.

4. Study limitations

No study is without limitations, and this research is no exception. Acknowledging these constraints is essential for a proper interpretation of the findings and for guiding subsequent investigations.

Nature of self-reported data

This study relies on self-reported data collected via a custom-designed online data collection instrument. While valuable for exploring participants' perceptions, experiences, and attitudes, self-reports are inherently subjective and susceptible to various biases. Respondents may provide socially desirable answers or misremember their actual classroom practices. For instance, self-assessed digital competence or the reported frequency of UDL strategy implementation may differ from teachers' real behaviors. Subsequent research might strengthen validity by integrating observational methods, objective performance measures, or qualitative approaches such as open-ended questions, interviews, and focus groups.

Generalizability and sample characteristics

Participants were exclusively enrolled in the fourth cycle of the 30-credit teacher certification courses (ex-art. 13) at e-Campus University. Although the sample size was substantial (N = 1,092), its specificity may limit generalizability. This cohort may share certain traits (e.g., motivation, digital awareness) not representative of the broader teaching population, and voluntary participation may have attracted those already inclined toward innovation. Future studies should recruit educators from diverse institutions, geographical areas, and career stages to enhance external validity.

Cross-sectional study design

The cross-sectional design, with data collected at a single point in time, provides a snapshot of current practices and perceptions but precludes causal inferences and temporal analysis. For example, while we found correlations between perceived UDL training effectiveness, resource access, and technology use, causal relationships cannot be established. Longitudinal research is needed to observe the evolution of UDL implementation, changes in digital competence, and the long-term impact of professional development on inclusive teaching practices.

Scope of the data collection instrument and depth of inquiry

Although the custom-designed instrument covered five main areas, its breadth limited in-depth exploration. Certain dimensions—such as strategies for overcoming resource constraints, contextual factors affecting co-teaching effectiveness, and the pedagogical reasoning behind specific UDL choices—were only partially addressed, mainly through open-ended prompts. Subsequent studies could focus more deeply on these topics, employing mixed-methods designs to combine rich qualitative insights with quantitative analysis.

Focus on perceived utility and reported implementation

This research centered on teachers' perceptions of UDL principles and their self-reported implementation. While such insights are valuable, the study did not directly assess the quality or effectiveness of UDL practices in terms of student learning outcomes. Future investigations could incorporate measures of student achievement, engagement, and feedback to provide a more comprehensive understanding of the impact of UDL-aligned instruction.

5. Conclusion

Universal Design for Learning (UDL) emerges here as an evolutionary, ecological and equitable framework for genuine inclusion, extending beyond mere integration (Malaguti et al., 2023). Building on this premise, the present work offers a critical overview of the best practices identified and the key areas for improvement, with the aim of providing concrete recommendations for both the ongoing professional development of teachers and the design of sustainable, inclusive educational interventions.

This investigation afforded the opportunity to gather the perspectives of a diverse cohort of teachers and to explore their pedagogical practices, as well as the application of UDL principles and the integration of digital technologies into their teaching. The study revealed a richly nuanced picture: while many teachers acknowledge the value of technology in promoting engagement and instructional differentiation, significant gaps remain in specialised training on UDL principles and in the resources available to ensure full accessibility.

The evidence generated by this analysis has important implications for both research and educational practice. From a research standpoint, our findings underscore the need for an integrated approach to studying UDL implementation that simultaneously considers technical support, teacher training, and resource accessibility.

From the perspective of educational practice, our results point to the necessity of a more balanced, holistic approach to supporting UDL adoption. In particular, there is a need to increase the availability and accessibility of UDL-specific resources, thereby bridging the gap between training and practical implementation; to develop training methods that explicitly combine theoretical knowledge acquisition with the ability to identify, access and deploy resources effectively; to diversify support modalities by incorporating collaborative, situated approaches such as mentoring and professional learning communities; and to adopt a systemic approach to UDL implementation that addresses technical, pedagogical and material support dimensions concurrently.

Translating inclusive intentions into daily practice demands tangible investments in both professional development and infrastructural support. Schools should therefore ensure that teachers have seamless access to high-quality UDL resources—such as openly licensed educational materials (OER) and embedded accessibility tools—and that these assets are housed within an intuitive digital environment. Equally crucial is the provision of situated, ongoing professional learning: in-class coaching and peer-review cycles enable mentors and colleagues to observe, model and refine UDL strategies in real time, whilst internal "design labs" offer collaborative workshops in which educators co-prototype, test and iterate inclusive lesson units. Finally, fostering dedicated collaborative teams—comprising curricular and support teachers, technologists and instructional designers—creates the multidisciplinary synergy required to co-create pilot and scale inclusive curricula. Policy makers, in turn, must underwrite these initiatives with clear guidelines and stable funding mechanisms to support the adoption of open-access platforms and accessibility-centred tools, thereby ensuring that UDL principles move from theory into sustainable classroom practice.

Focusing on best practices, it is evident that low-cost tools and peer collaboration (co-teaching) are particularly instrumental. The most salient challenges relate to unfamiliarity with advanced software and the lack of allotted time for joint planning. The work presented herein contributes an empirical foundation that bridges a knowledge gap, whilst highlighting the need for training pathways tailored to varying levels of digital competence and for more intuitive, adaptable technological platforms. To foster genuinely inclusive pedagogy, a systemic approach is imperative—one in which UDL principles, technologies and the teacher's role are synergistically integrated to cultivate resilient, sustainable learning pathways focused on maximising each student's potential.

Author contributions

The Authors collaboratively conceived the contribution. With regard to the drafting of the sections, Daniela Maggi was responsible for the first and fifth, while Antonio Balestra authored the second, third, and fourth.

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