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Effects of a neuroscience-informed universal design for learning training on the development of inclusive teaching competencies: a quasi-experimental study

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Inclusive education has evolved from a legal mandate into a complex pedagogical endeavor requiring teachers to design for learner variability and engage in sustained collaboration. This study examined the impact of a neuroscience-informed Universal Design for Learning (UDL) professional development (PD) program on four competencies from the European Inclusive Teacher Profile: valuing learner diversity (mindset), supporting all learners (lesson design and implementation), working with others (co-teaching), and pursuing professional growth (self-efficacy). Fifty-one kindergarten and primary teachers from inclusive classrooms in southern Switzerland participated (experimental = 20; control = 31). Using established instruments, results showed that PD participants developed a more growth-oriented mindset sustained at follow-up, improved their capacity to design and deliver accessible lessons, and diversified co-teaching practices toward more collaborative models. Gains in self-efficacy were immediate but partially declined over time. Overall, findings highlight the potential of neuroscience-informed UDL to foster sustainable growth in inclusive teaching competence.

KEYWORDS

co-teaching, inclusive education, neuroscience-informed professional development, quasi-experimental design, teacher mindset, teacher self-efficacy, universal design for learning

1 Introduction

Over the last three decades, international policy frameworks have progressively steered education systems toward more inclusive models. Foundational documents such as, [UNESCO Salamanca Statement \(1994\)](#) and the [Organisation des Nations Unies \(United Nations\) \(2006\)](#) set forth the right of all students, including those with disabilities and other special educational needs, to participate in general education settings ([Balestra et al., 2022](#)). These normative advances, however, represent only one dimension of inclusion. The deeper challenge lies in transforming teaching practices, school structures, and professional culture. Inclusion requires moving beyond the traditional dichotomy between general and special education. Teachers face two interrelated demands: pedagogically, to design instruction responsive to the diverse

learning profiles within each classroom; and professionally, to engage in collaborative, interdisciplinary teamwork with colleagues and specialists. Within this context, teacher preparation and continuing professional development are pivotal for equipping both general and special teachers to value and leverage learner variability as an asset rather than a constraint.

2 Background

2.1 The European inclusive teacher profile

To provide a conceptual foundation for inclusive teacher education, the European Agency for Development in Special Needs Education (EADSNE, 2012) developed the *Profile of Inclusive Teachers* (PIT), designed as a reference for guiding initial and in-service training. This framework was subsequently expanded in the *Profile for Inclusive Professional Learning for Teachers* (EADSNE, 2022), which broadens the perspective to include all education professionals in professional learning processes for inclusion. Both frameworks, which are non-prescriptive, identify four core professional values that underpin effective inclusive teaching—valuing student diversity, supporting all students, working with others, and promoting personal and professional development. Each value is articulated in domains of competence applicable across grade levels and disciplines, emphasizing that inclusive expertise extends beyond technical strategies to encompass beliefs, professional identity, and interpersonal skills. A recent literature review by Rusconi and Squillaci (2023) proposes an operationalization of these four values into observable and measurable indicators for research and program evaluation. In this operationalization, valuing learner diversity corresponds to teachers' mindset, or beliefs about the fixed versus malleable nature of intelligence (Dweck, 2006, 2017); supporting all learners refers to the adoption of universal and flexible instructional approaches evident in daily lesson planning and delivery (Meyer et al., 2014); working with others is reflected in co-teaching practices and collaboration across roles (Friend and Cook, 2014); and personal and professional development manifests as teachers' self-efficacy, or perceived capability to manage and adapt instruction in diverse classrooms (Moradkhani et al., 2017; Tschannen-Moran et al., 1998). Together, these dimensions provide an integrated framework for examining how teacher learning experiences shape inclusive competence.

2.2 Universal Design for Learning

The Universal Design for Learning (UDL) framework (Rose and Meyer, 2006; Meyer et al., 2014) offers a proactive, scientifically grounded approach that aligns closely with the Inclusive Teacher Profile. Rooted in cognitive neuroscience and learning sciences, as well as in the principle of accessibility (Ébersold, 2017), UDL encourages the design of learning environments that anticipate and accommodate variability from the outset, rather than relying on retroactive accommodations once barriers appear (UNESCO et al., 2023). UDL rests on the premise that no "average" learner exists; variability is both systematic and predictable, influenced by context and individual differences (Meyer et al., 2014; Pape, 2018). Designing curricula for a hypothetical "average" student is therefore counterproductive, whereas

designing for variability fosters broader and more equitable participation and access.

The framework is grounded in neuroscientific evidence that identifies three primary brain networks involved in learning: the affective network, which regulates motivation and engagement; the recognition network, responsible for processing and understanding information; and the strategic network, which supports planning, action, and expression (Meyer et al., 2014). Based on this model, UDL proposes three guiding principles: providing multiple means of engagement to stimulate motivation, multiple means of representation to enhance access to knowledge, and multiple means of action and expression to enable all learners to demonstrate competence. The alignment between neuroscience and Universal Design for Learning (UDL) becomes particularly evident when functional brain networks are translated into instructional design principles. Variability within the recognition network supports the systematic use of multimodal representations to address differences in how learners perceive, process, and construct meaning (e.g., Masson, 2020; Meyer et al., 2014; Schunk, 2012). Evidence concerning the affective network highlights the central role of emotion, motivation, and self-regulation in sustaining learning over time, thereby providing a neuroscientific foundation for the principle of multiple means of engagement through autonomy, relevance, and psychologically safe classroom climates (e.g., Dehaene, 2020; Masson, 2020; Lim et al., 2019). Similarly, research on the strategic network, closely associated with executive functions, substantiates the need to provide varied opportunities for action and expression, including structured scaffolds, graduated supports, and flexible response modalities (e.g., Diamond, 2013; Zelazo et al., 2016; Morrison et al., 2010). From this perspective, UDL can be understood as a framework that translates neuroscientific insights into proactive curriculum design, intentionally addressing neurocognitive variability from the outset rather than through reactive adaptation. By integrating these principles, UDL indeed promotes a shift from a reactive to a proactive paradigm of inclusion, positioning learner variability as a resource rather than a barrier (Fovet, 2021; Capp, 2017; Navaitienė and Stasiūnaitienė, 2021). In this way, UDL not only reduces learning barriers to learning but also creates equitable and meaningful opportunities for all students to reach their full potential (Basham et al., 2018; Ewe and Galvin, 2023).

2.3 Neuroscience and the development of inclusive teaching competencies

A growing body of research has explored how cognitive neuroscience and UDL-based training can support the development of inclusive teaching competencies. Integrating neuroscience into teacher professional development has been shown to enhance teachers' understanding of learning processes (Schwartz et al., 2019), reduce the spread of neuromyths (Im et al., 2018; McMahan et al., 2019), and promote growth-oriented beliefs about intelligence and learning potential (Anderson et al., 2018; Ergas et al., 2018). Moreover, understanding the role of emotional and motivational factors in cognition fosters learner-centered practices that emphasize active, differentiated, and inclusive strategies (Tan et al., 2019; Schwartz et al., 2019). Neuroscience-informed training thus appears to influence primarily the first two PIT dimensions: valuing learner diversity and supporting all learners. Similarly, studies examining the effects of UDL-based training have identified significant improvements in teachers' capacity to recognize variability (Rusconi and Squillaci, 2023), to design

differentiated instruction, and to make lessons accessible to all learners (Spooner et al., 2007; Craig et al., 2019; Lee and Griffin, 2021). However, evidence remains limited or inconclusive for the remaining PIT dimensions: working with others and personal professional development. To date, few rigorous empirical studies have examined the effects of UDL training on co-teaching practices (Smith Canter et al., 2017), and findings related to teacher self-efficacy are mixed (Katz, 2015; Katz et al., 2019). This intersection between neuroscience and UDL aligns with the broader shift in teacher education toward evidence-based, cognitively informed inclusion (Dehaene, 2020; Immordino-Yang and Faeth, 2010). Such an approach not only bridges research and practice but also situates inclusive pedagogy within a neuroscientific perspective that recognizes variability as the core driver of learning.

Building on this body of evidence, the present study investigates the effects of a neuroscience-informed UDL professional development program on teachers working in inclusive kindergarten and primary classrooms in Southern Switzerland. Specifically, it examines changes across the four domains of the Inclusive Teacher Profile: teachers' mindsets, capacity to design and implement accessible lessons, co-teaching practices, and perceived self-efficacy.

2.4 Aims and research questions

The present study aims to examine the effects of a professional development program based on the UDL framework on the development of teachers' inclusive competencies. Specifically, it seeks to address the following Research Question: What are the effects of a UDL-based professional development program on the development of competencies among teachers working in inclusive educational contexts?

In order to answer this question, the following hypotheses (H) were formulated, each describing an expected outcome following participation in the UDL-based professional development program:

H1: Following a UDL-focused training, teachers adopt a more growth-oriented mindset regarding the development of students' intelligence.

H2: Following a UDL-focused training, teachers improve their ability to plan and implement accessible lessons.

H3: Following a UDL-focused training, teachers vary the way they organize co-teaching in the classroom.

H4: Following a UDL-focused training, teachers increase their sense of self-efficacy in managing heterogeneous classrooms.

3 Method

3.1 Research context

This study was conducted in southern Switzerland, within the Italian-speaking region of the Canton of Ticino. This canton has one of the lowest segregation rates in the country (Mainardi, 2023) and is progressively implementing inclusion-oriented educational policies promoted by the Department of Education, Culture and Sport

(DECS). These policies aim to foster the schooling of students with special educational needs within general education classrooms. To support inclusive education, in addition to small-group special classes, so-called "inclusive classes" have been established. These classes belong to regular schools but include students who receive intensive special education support. Each inclusive class is co-taught by a general education teacher and at least one special education teacher, who share responsibility for instructional planning and classroom management. In just over 10 years, the number of these classes has risen from three (one in nursery school and two in primary school) in 2014/15, to 92 (41 in preschool, 38 in primary school, and 16 in secondary school) in 2025/26 (Source: Special Education Section of the School Division, 2025). This organizational model offers a particularly fertile ground for examining how professional learning influences shared pedagogical responsibility and the practical enactment of UDL principles.

3.2 Research design

The study employed a quasi-experimental design structured into three main phases: a pilot phase, an experimental phase, and a follow-up phase. The pilot phase, conducted during 4 months (from January to May) aimed to test the data collection instruments and assess the feasibility of the research protocol, allowing for potential methodological adjustments prior to the full implementation of the intervention. The experimental phase took place during the academic year (from September to June) following a pre-test–post-test design with an experimental group (EG) and a comparison group (CG). This phase enabled the observation of the intervention's effects and comparison of outcomes between groups to identify changes attributable to the independent variable. Finally, the follow-up phase assessed the temporal stability of key variables considered significant. Conducted 3 months after the completion of the experimental phase, this data collection was carried out exclusively with the experimental group to examine the persistence of observed effects over time.

3.3 Participants

Participants were selected through convenience sampling. Teachers were invited to take part in the study and were allowed to voluntarily choose whether to join the treatment or comparison group.

The experimental phase sample included 51 teachers, representing approximately 45% of the total population of educators working in inclusive classrooms in the Canton of Ticino during the school year 2022–2023 (N = 113). The experimental group (EG) consisted of 20 teachers who completed the full training program, while the comparison group (CG) included 31 teachers who did not participate. Participation was voluntary, and therefore, the sample cannot be considered representative of the overall teaching population.

Table 1 summarizes the demographic characteristics of the sample. Participants included both general education teachers (n = 17) and special education teachers (n = 34), with the latter predominating, particularly within the experimental group (75%). Most of participants taught at the primary school level (59%), while the remaining 41% worked in kindergarten settings. The average age of teachers was 38.3 years in the experimental group and 40.7 years in the comparison group, and the overall mean teaching experience across participants was approximately 13 years. This distribution reflects the composition of inclusive classrooms in the region, where special educators are more

TABLE 1 Composition of the sample.

Variable	Sample <i>n</i> (%)	EG <i>n</i> (%)	CG <i>n</i> (%)
Professional role			
Specialised teacher	34 (67%)	15 (75%)	19 (61%)
Ordinary teacher	17 (33%)	5 (25%)	12 (39%)
School level			
Compulsory preschool	21 (41%)	8 (40%)	13 (42%)
Primary school	30 (59%)	12 (60%)	18 (58%)
Percentage of work			
≤50%	10 (20%)	3 (15%)	7 (22%)
51–90%	17 (33%)	5 (25%)	12 (39%)
90–100%	24 (47%)	12 (60%)	12 (39%)
Age			
≤30	13 (25%)	5 (25%)	8 (26%)
31–49	30 (59%)	14 (70%)	16 (52%)
≥50	8 (16%)	1 (5%)	7 (22%)
M	39.5	38.0	40.5
Years of experience			
≤3	7 (14%)	3 (15%)	4 (13%)
4–10	15 (29%)	5 (25%)	10 (32%)
≥10	29 (57%)	12 (60%)	17 (55%)
M	13.39	13.1	13.6
Years of experience in inclusive classrooms			
≤2	27 (53%)	11 (55%)	16 (52%)
≥3	24 (47%)	9 (45%)	15 (48%)
M	3.2	3	3.3
Academic graduation			
Regular teaching qualification	20 (39%)	5 (25%)	15 (48%)
Specialised teaching qualification	15 (29%)	10 (50%)	5 (16%)
Other university education	16 (31%)	5 (25%)	11 (35%)
Year of university graduation			
≤3	6 (12%)	3 (15%)	3 (10%)
4–10	12 (23%)	4 (20%)	8 (26%)
≥10	33 (65%)	13 (65%)	20 (64%)
Participation in the training by a colleague from the same class			
Yes	26 (51%)	16 (80%)	10 (32%)
No	25 (49%)	4 (20%)	21 (68%)
Participation in a previously certified course on UDL or neuroscience			
Yes	0 (0%)	0 (0%)	0 (0%)
No	51 (100%)	20 (100%)	31 (100%)
Participation in training between the pre-test phase and the post-test phase			
Yes	15 (29%)	7 (35%)	8 (26%)
No	36 (71%)	13 (65%)	23 (74%)

EG, experimental group; CG, comparison group.

frequently assigned to co-taught settings alongside general education teachers.

In line with previous research, sociodemographic factors such as teaching role and collaboration within the same class (Birman et al., 2000; Garet et al., 2001) may influence the effects of professional development, though the sample size did not allow subgroup analyses. Not all sections of the data collection were completed by every participant, leading to some missing responses. These cases were managed individually, as several questionnaires or materials were partially incomplete or unusable for statistical purposes. The final sample size therefore varied slightly across variables; however, preliminary checks confirmed that the experimental and comparison groups were comparable on all measured variables.

3.4 Instruments

To evaluate the four research hypotheses, multiple instruments were employed, each selected to correspond to a specific dimension of the European Inclusive Teacher Profile (EADSNE, 2012). All instruments were administered in Italian and, where necessary, adapted and pilot-tested to ensure clarity and consistency. To examine Hypothesis 1 (H1), teachers' beliefs about the nature of intelligence were assessed using the *Constructivist Conceptions of Intelligence Scale* (SCCI; Albanese and Fiorilli, 2003). The instrument consists of 29 items rated on a 6-point Likert scale (1 = strongly disagree to 6 = strongly agree). It measures teachers' endorsement of dynamic versus fixed conceptions of intelligence across three subdimensions: beliefs about the nature of intelligence, school failure, and educational inclusion. Although the scale has not undergone a full psychometric validation, it has been employed in both Swiss and Italian contexts, demonstrating acceptable reliability indices (Addimando, 2019). In line with previous research, analyses were conducted primarily using the total score, as it provides a more stable and interpretable indicator of teachers' overall mindset orientation.

To assess Hypothesis 2 (H2), teachers' ability to plan and implement accessible lessons was measured using the *Teacher Success Rubric* (TSR; Nelson et al., 2011), translated and adapted into Italian for this study. The TSR evaluates five domains - learning objectives, barriers, representation, engagement, and action/expression - on a four-point scale ranging from 1 (limited evidence) to 4 (consistent and comprehensive evidence). The analysis included both lesson plans (completed by all participants) and video-recorded lessons (completed by the experimental group only). Independent coders scored the materials, and interrater agreement was verified to ensure reliability of the ratings.

Given the absence of validated quantitative instruments in the literature, an *ad hoc* tool was developed for Hypothesis 3 (H3), based on the co-teaching typology proposed by Friend and Cook (2014). The *Weekly Co-Teaching Log* invited teachers to indicate, over a two-week period, the frequency with which they employed various co-teaching configurations: *one teach-one assist*, *one teach-one observe*, *team teaching*, *parallel teaching*, *alternative teaching* and *station teaching*. This instrument enabled systematic documentation of the presence and frequency of each configuration in daily practice, providing an overview of how co-teaching responsibilities were distributed and shared between professionals.

To test Hypothesis 4 (H4), teachers' perceived self-efficacy was assessed using the *Scala dell'Auto-Efficacia del Docente* (SAED; Biasi et al., 2014), the validated Italian version of the *Teacher Self-Efficacy*

Scale (Tschannen-Moran and Hoy, 2001). The instrument comprises 24 items measuring three subscales of teacher self-efficacy: student engagement, instructional strategies, and classroom management. Items are rated on a 9-point Likert scale (1 = not at all confident to 9 = very confident). The Italian version has demonstrated strong psychometric properties, with an overall Cronbach's alpha of 0.97, indicating high internal consistency.

Together, these instruments provided a multidimensional assessment of changes in teachers' conceptions, instructional practices, collaborative behaviors, and perceived competence, allowing for a comprehensive examination of the effects of the neuroscience-informed UDL professional development program.

3.5 Teacher training

The intervention consisted of a 20-h training program divided into five modules of 4 h each (16 h in person and 4 h online). The content was structured around three main thematic areas: (A) foundational paradigms, (B) neuroscience and learning, and (C) Universal Design for Learning (UDL). Rather than being treated as separate strands, these areas were explicitly integrated within each module, with neuroscientific constructs systematically translated into corresponding UDL design principles and then into concrete instructional planning practices. The online component was included to promote autonomy and motivation (McKenna et al., 2020; Merriam and Bierema, 2014; Youde, 2018), while the in-person sessions ensured progressive achievement of the training objectives. Printed and digital materials were made available to participants through an online learning platform. Table 2 presents the structure and content of the training modules. Detailed intervention protocols specifying the content and structure of each course are available upon request. Fidelity and effectiveness were monitored using three criteria: procedural consistency with planning, adherence to UDL guidelines, and participants' comprehension of content. Each module was observed by an evaluator and included pre- and post-assessment tasks, allowing monitoring of both training quality and participant learning outcomes.

4 Results

The experimental study examined the main variables and tested the research hypotheses by analyzing both between-group differences and changes over time. The results are presented below according to the four domains considered: teachers' mindset, lesson accessibility, co-teaching modalities, and perceived self-efficacy.

4.1 Teachers' conceptions and mindset

Teachers' beliefs about the nature of intelligence were assessed at three time points: before the training (pre-test), immediately after the training (post-test), and 3 months later (follow-up). Fifty participants completed this phase of the assessment. Preliminary analyses confirmed the acceptable internal consistency of the scale and the normal distribution of the data, allowing the use of parametric tests.

The results of the between-subjects and within-subjects ANOVAs for the SCCI are summarized in Table 3 and mean pre- and post-test scores for both groups are illustrated in Figure 1. Results from the repeated-measures ANOVA indicated significant differences between

TABLE 2 Structure and content of training modules.

Session	Thematic core	Time	Contents
Module 1			Basic Paradigms 1: Inclusion and accessibility
Session 1	A	2h	Basic Paradigms 2: Differentiation
Module 1			Neuroscience 1: Basic Knowledge
Session 2	B, C	2h	UDL 1: UDL Framework
Module 2			Neuroscience 2: Limbic System, Memory, and Consolidation
Session 3	B, C	2h	UDL 2: Affective Networks
Module 2			Neuroscience 3: Posterior cortex
Session 4	B, C	2h	UDL 3: Recognition networks
Module 3			Neuroscience 4: Frontal and prefrontal cortex, executive functions
Session 5	B, C	2h	UDL 4: Strategic networks
Module 3			Neuroscience 5: Positive and negative retroaction
Session 6	B, C	2h	UDL 5: Repetition and practice
Module 4			UDL 6: Planning with UDL
Asynchronous	C	4h	
Feedback from trainers			
Module 5			UDL 7: Planning with UDL
Session 7	C	2h	
Module 5			UDL 8: Training
Session 8	C	2h	

TABLE 3 ANOVA results for the SCCI scale.

Source	SS_type III	df	MS	F	p	η^2
Pre-Post test						
Between-subjects						
Group	4.2	1	4.17	24.24	<0.001	0.34
Within-subjects						
Time	0.236	1	0.236	5.10	0.029	0.10
Time * Group	0.207	1	0.207	4.46	0.040	0.09
Follow up^a						
Within-subjects						
Linear time	0.604	1	0.604	7.74	0.012	0.30

^aA repeated-measures ANOVA was conducted on the follow-up data across the three time points.

the experimental group. The experimental group (EG) began with slightly more growth-oriented conceptions than the comparison group (CG) and showed further improvement following the training, whereas the CG remained stable. Differences between the two groups were significant at both the pre-test and post-test, with a stronger effect observed at the latter stage.

Follow-up analyses confirmed the maintenance of training effects: scores for the EG continued to increase over time, with a large effect size ($\eta^2 = 0.30$). The results of the within-subjects ANOVA for the SCCI at follow-up are summarized in Table 3, and mean scores over time are illustrated in Figure 1. These sustained improvements suggest that neuroscience-informed training may strengthen conceptual change processes, supporting teachers in integrating growth-oriented beliefs into their instructional reasoning and decision-making.

4.2 Planning and implementation of accessible lessons

Teachers' ability to plan and implement accessible lessons was evaluated using two instruments: lesson plans and videotaped classroom sessions. Data were collected at two time points (pre- and post-training) and independently coded by two trained raters, achieving near-perfect interrater agreement across most dimensions. Given minor deviations from normality and the small sample size, nonparametric tests were used for data analysis. Differences between pre- and post-test scores were analyzed using a Wilcoxon signed-rank test for paired samples, while at the planning level, a Mann-Whitney U test was applied to the differences between group means to approximate the effects of a parametric test.

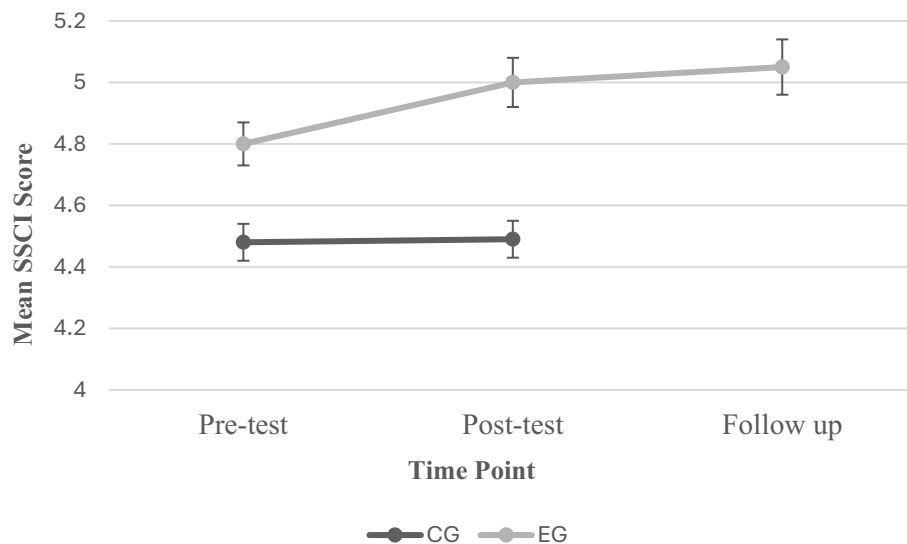


FIGURE 1 Mean SSCI scores at pre-test, post-test and follow up for both groups. Error bars represent standard error of the mean (SE). EG, Experimental group; CG, Comparison group.

TABLE 4 Non-Parametric test results for planning and implementation scores.

Variable	Time	Comparison	N	M	Mdn	Test	Statistic	p
Planning scores	Pre	EG vs. CG	42	2.35	2.20	Mann-Whitney	294.50	0.58
			30	2.06	1.80	U		
Planning scores	Post	EG vs. CG	42	3.28	3.30	Mann-Whitney	432.50	<0.001
			30	2.03	2.00	U		
Planning scores	Pre vs. Post	EG	20	2.35 3.28	2.20 3.30	Wilcoxon Z	-3.65	<0.001
	Pre vs. Post	CG	22	2.06 2.03	1.80 2.00	Wilcoxon Z	0.000	1.00
Implementation	Pre vs. Post	EG	18	2.23 3.28	2.20 3.40	Wilcoxon Z	-3.73	<0.001

Mean values are presented for descriptive purposes only. EG, experimental group; CG, comparison group. Mann-Whitney *U*-tests were used for between-group comparisons; Wilcoxon signed-rank tests were used for within-group comparisons.

4.2.1 Lesson planning

Forty-two teachers provided valid lesson-plan materials for analysis. At pre-test, no significant differences emerged between the experimental group (EG) and the comparison group (CG). At post-test, however, EG scores were significantly higher ($U = 432.50, p < 0.001$), indicating a clear effect of the training. Within-group analyses confirmed a significant improvement in the EG ($Z = -3.65, p < 0.001$), whereas CG scores remained stable (see Table 4 and Figure 2).

4.2.2 Lesson implementation

As shown in Table 4, analysis of the video-recorded lessons conducted exclusively with the EG revealed a significant improvement from pre- to post-training ($Z = -3.73, p < 0.001$). Eighteen teachers from the EG contributed valid video data for this analysis. Mean scores followed a pattern consistent with that observed in lesson planning, suggesting strong alignment between teachers' planned and enacted instructional practices (see Figure 2). Correlational analyses confirmed that lesson plan quality was a reliable indicator of observed classroom implementation, with positive associations at

both pre-test ($\rho = 0.63, p = 0.005$) and post-test ($\rho = 0.70, p = 0.001$). These findings indicate that improvements in teachers' capacity to design accessible lessons were reflected in their classroom practice. Overall, these findings confirm Hypothesis 2, showing that UDL-based professional development was associated with significant and consistent enhancement in teachers' ability to plan and implement accessible lessons.

4.3 Co-teaching practices

The analysis of co-teaching modalities was conducted using the *Weekly Co-Teaching Log* completed by participants, in which they reported the specific configurations adopted. Thirty-nine teachers contributed valid data for this measure. As the variables were nominal, data were analyzed using chi-square tests. Measurements were collected at two time points (pre- and post-training). At pre-test, significant differences emerged between the experimental group (EG) and the comparison group (CG) in the distribution of co-teaching modalities, $\chi^2(6, N = 1,860) = 55.26, p < 0.001$, which were confirmed at post-test, $\chi^2(6, N = 1,841) = 82.86, p < 0.001$. In both groups, the most frequently used configurations were *one-teach/one-assist* and *team teaching*, while *one-teach/one-observe* was the least frequently

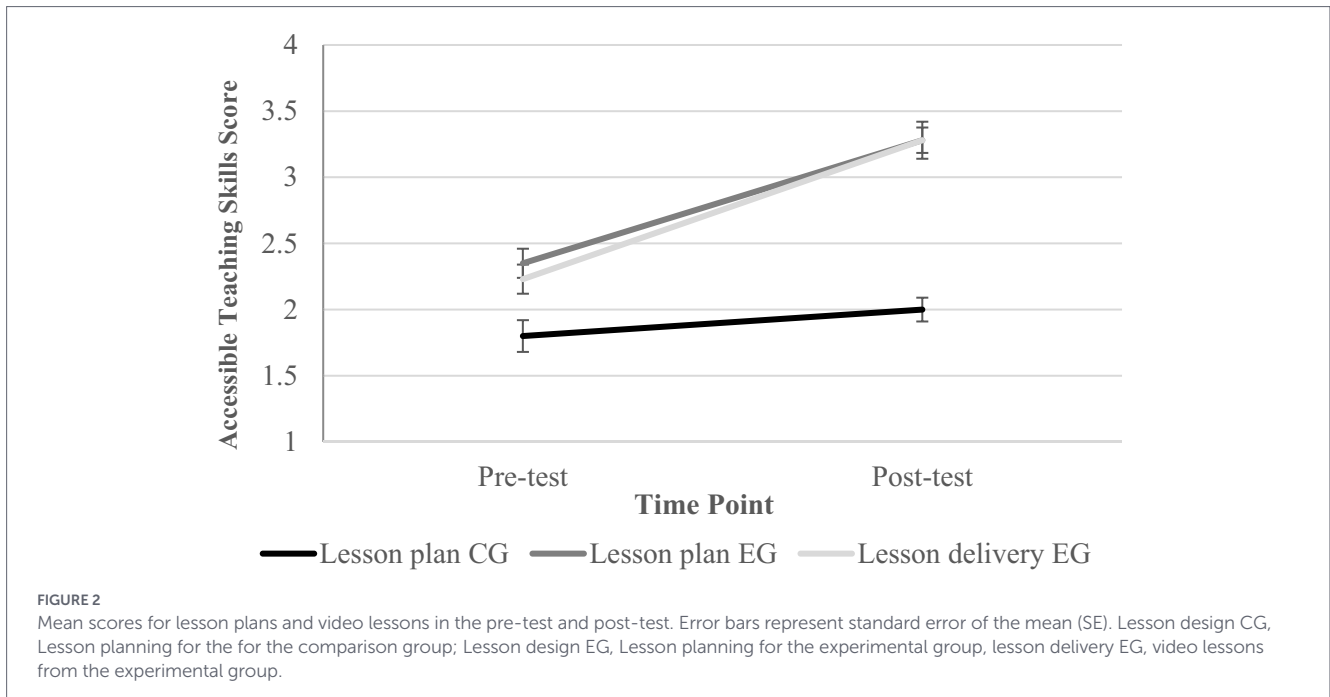


TABLE 5 Chi-square results for the evolution of co-teaching modalities.

Co-teaching models	CG				p	EG				p
	Pre-test		Post-test			Pre-test		Post-test		
	n	%	n	%		n	%	n	%	
					0.151					0.011
Observation	41	3.95	37	3.77		33	4.00	26	3.03	
Station	88	8.49	81	8.25		115	13.96	127	14.78	
Parallel	145	13.98	122	12.42		70	8.50	118	13.74	
Alternative	147	14.18	131	13.34		85	10.32	103	11.99	
Team	293	28.25	295	30.04		208	25.30	190	22.12	
Assistance	274	26.42	290	29.53		222	27.00	203	23.63	
Other	49	4.73	26	2.65		90	10.92	92	10.71	
	1,037	100	982	100		823	100	859	100	

EG, experimental group; CG, comparison group; Observe, one teach–one observe; Station, Station teaching; Parallel, Parallel teaching; Alternative, Alternative teaching; Team, Team teaching; Assistance, one teach–one assist; Other, Other co-teaching models.

employed. The “Other” category was often associated with independent student work or individual practice activities.

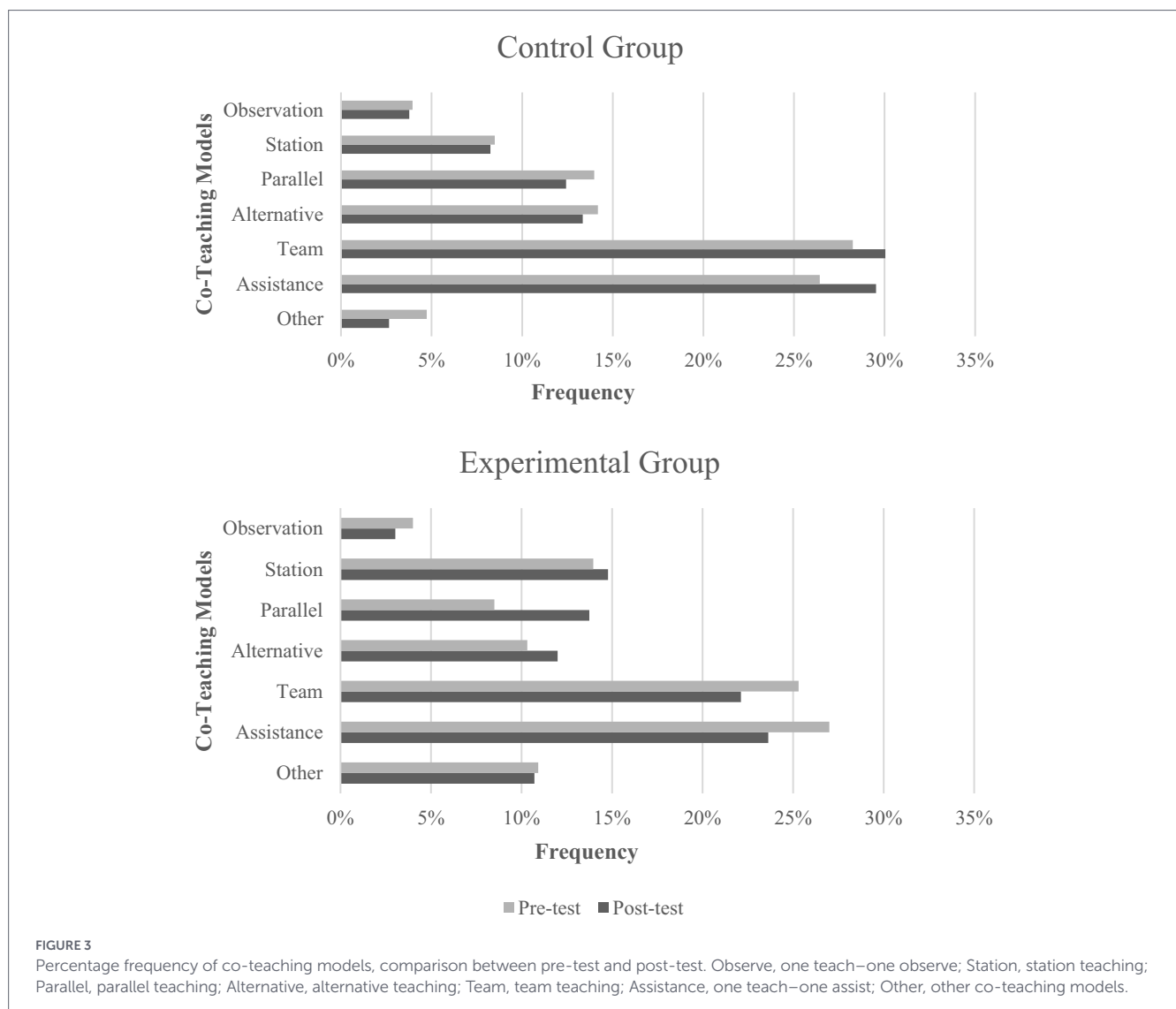
As shown in Table 5, no significant variations emerged in the CG between the pre- and post-training, $\chi^2(6, N = 2.02) = 9.42, p = 0.15$, indicating a largely stable distribution of co-teaching modalities over time (see Figure 3). In contrast, the EG showed a significant variation between the two time points, $\chi^2(6, N = 1,684) = 16.59, p = 0.011$. Specifically, the use of more traditional configurations, such as team teaching, assistance, and observation, tended to decrease, while more differentiated forms, including station, parallel, and alternative teaching, increased. The most pronounced change was observed in the growth of *parallel teaching* (see Figure 3).

These results confirm Hypothesis 3. The UDL-based training influenced the organization of co-teaching practices, promoting a

more diversified use of instructional configurations and reducing reliance on the most traditional models. Participation in the UDL-based training was associated with notable shifts in co-teaching organization, rather than implying direct causal influence.

4.4 Teacher self-efficacy

Teachers’ self-efficacy was measured using the Teacher Self-Efficacy Scale, in its Italian version, the Scala dell’Auto-Efficacia del Docente (SAED), administered at three time points: pre-test, post-test, and follow-up. Fifty teachers completed this phase of the assessment. Preliminary analyses confirmed good internal consistency for the overall scale ($\alpha = 0.91$) and its subscales. For the first two assessments, the assumptions of normality and homogeneity of variance were met,



allowing the use of parametric tests. The results of the between- and within-subjects ANOVAs for the SAED are summarized in Table 6, while Figure 4 illustrates the mean pre- and post-test scores for both groups.

At the pre-test, the comparison group (CG) reported higher mean scores than the experimental group (EG) on overall self-efficacy and on the subscales related to instructional strategies (CG $M = 6.94$, $SD = 0.61$; EG $M = 6.44$, $SD = 0.98$) and classroom management (CG $M = 6.98$, $SD = 0.62$; EG $M = 6.57$, $SD = 0.90$). At the post-test, the EG showed a substantial increase in scores across all dimensions, whereas the CG maintained stable or slightly lower values. Repeated-measures ANOVA confirmed significant main effects of time and a time \times group interaction for overall self-efficacy, $F(1, 48) = 9.68$, $p = 0.003$, $\eta^2 = 0.17$, as well as for the subscales of student engagement, $F(1, 48) = 8.89$, $p = 0.005$, $\eta^2 = 0.16$, and instructional strategies, $F(1, 48) = 10.02$, $p = 0.003$, $\eta^2 = 0.18$, confirming that the observed improvement in the EG was attributable to the training.

As shown in Table 7 and Figure 4, follow-up results indicated a decrease in teachers' self-efficacy scores relative to the post-test. Because the data at this stage violated the assumption of normality, nonparametric analyses were performed. Overall self-efficacy stabilized at intermediate levels ($M = 6.84$), while the subscale related to

student engagement retained a significant effect, $\chi^2(2) = 6.73$, $p = 0.035$; Wilcoxon $Z = -1.98$, $p = 0.048$, suggesting that only this dimension sustained improvement over time. In contrast, the other subscales and overall self-efficacy returned toward pre-test levels, indicating limited persistence of the training effects. In summary, the training had a positive impact on perceived self-efficacy, with clear improvements immediately after the intervention in the EG. However, only self-efficacy related to student engagement showed significant long-term persistence, whereas the other dimensions tended to regress toward baseline values. The initial between-group differences at pre-test also call for caution in interpreting the overall results.

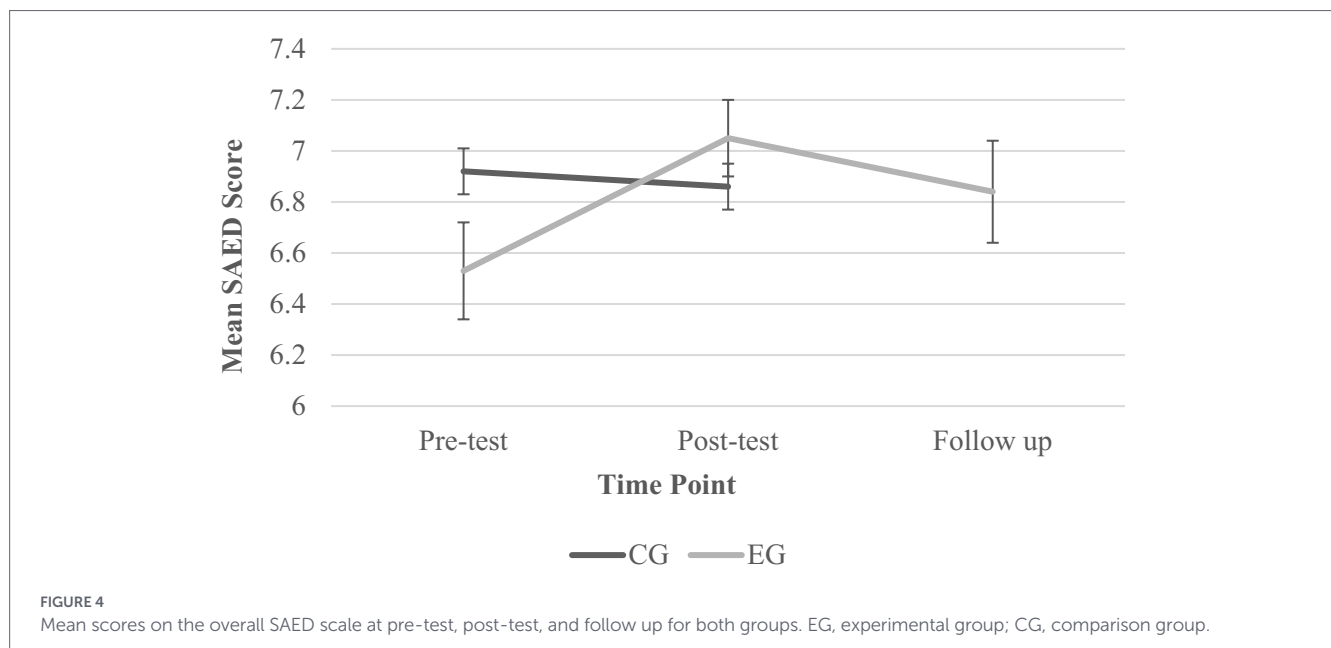
5 Discussion

This study aimed to examine the effects of professional development (PD) focused on UDL and neuroscience on the development of teachers' competencies in inclusive classrooms in the Canton of Ticino. The research hypotheses, formulated around four variables reflecting the four components defined by the European Agency's *Profile of Inclusive Teachers* (EADSNE, 2012), explored the potential

TABLE 6 Two-way mixed ANOVA results for the SAED scale.

Dimension	SS_type III	df	MS	F	p	η^2
Between-subjects						
Overall	0.25	1	0.25	0.45	0.51	0.01
Involvement	0.04	1	0.04	0.07	0.80	0.00
Strategies	0.46	1	0.46	0.65	0.43	0.02
Management	0.54	1	0.54	0.82	0.37	0.02
Within-subjects						
Overall						
Time	1.24	1	1.24	5.90	0.019	0.11
Time * Group	2.04	1	2.04	9.68	0.003	0.17
Involvement						
Time	1.62	1	1.63	7.57	0.008	0.14
Time * Group	1.91	1	1.90	8.89	0.005	0.16
Strategies						
Time	1.78	1	1.78	5.64	0.022	0.11
Time * Group	3.16	1	3.16	10.02	0.003	0.18
Management						
Time	0.79	1	0.79	2.54	0.117	0.05
Time * Group	1.58	1	1.58	5.09	0.029	0.10

Overall, Overall scale; Involvement, Self-efficacy in student involvement; Strategies, Self-efficacy in teaching strategies; Management, Self-efficacy in classroom management.



effects of the training on teachers’ conceptions and mindset, their ability to plan and implement accessible lessons, their co-teaching practices, and their sense of self-efficacy. The findings provide converging evidence of the positive effects of the training across all four domains. However, the magnitude and durability of these effects differed depending on the specific competency examined and the methodological characteristics of the research design. These variations highlight both the promise and the complexity of translating UDL and neuroscience principles into sustained professional change. The

following sections discuss possible interpretations and implications of the findings for each variable.

5.1 Effects of the training on teachers’ conceptions and mindset

Participation in the UDL-based training was associated with changes in teachers’ conceptions of their students’ intellectual development, particularly in relation to beliefs about intelligence and

TABLE 7 Friedman test results for self-efficacy across three time points.

Dimension	Pre-test			Post-test			Follow-up			Chi	df	p
	N	M	Mdn	N	M	Mdn	N	M	Mdn			
Overall	20	6.54	6.56	20	7.05	7.02	20	6.84	7.06	4.89	2	0.087
Involvement	20	6.54	6.67	20	7.08	7.13	20	6.87	7.13	6.73	2	0.035
Strategies	20	6.44	6.50	20	7.08	7.06	20	6.92	7.19	5.01	2	0.082
Management	20	6.57	6.75	20	7.01	7.00	20	6.73	7.00	0.83	2	0.661

Average values are presented for descriptive purposes. Overall, Overall scale; Involvement, Self-efficacy in student involvement; Strategies, Self-efficacy in teaching strategies; Management, Self-efficacy in classroom management.

learner variability. The data show that teachers who participated in the UDL-based training adopted more dynamic conceptions of intelligence, with this growth-oriented mindset persisting and even strengthening over time. This pattern supports the theoretical assumption that exposure to UDL principles - anchored in the notions of learner variability and flexible pathways to competence- encourages teachers to move beyond static conceptions of ability. These findings corroborate prior research highlighting that integrating cognitive neuroscience and UDL principles in teacher education fosters the adoption of more dynamic, constructivist conceptions of intelligence (Lanterman and Applequist, 2018; Anderson et al., 2018; Ergas et al., 2018; Privitera, 2021; Rusconi and Squillaci, 2023). By linking the variability of learning processes to neural plasticity, the training may have reinforced teachers' belief in students' capacity for growth and adaptability, consistent with Dweck's (2006, 2017) incremental theory of intelligence. However, analyses revealed that the experimental group already showed higher pre-test scores, indicating a preexisting growth-oriented mindset. This baseline difference is consistent with previous studies showing that teachers who hold dynamic conceptions of intelligence are more likely to seek professional learning opportunities and to integrate innovative pedagogical approaches into their practice (Calderhead and Robson, 1991; Huang, 2023). Despite this limitation, the longitudinal persistence of mindset change suggests that the training provided a reinforcing context in which theoretical knowledge and practical experience converged.

The experiential implementation of UDL principles appears to have played a particularly important role in consolidating these changes. Hands-on engagement with inclusive lesson design and collaborative reflection likely strengthened teachers' belief in the plasticity of learning, as evidenced by the sustained increase in mindset scores at follow-up. This interpretation is consistent with prior evidence suggesting that direct engagement with inclusive instructional design deepens teachers' cognitive and emotional commitment to growth-oriented conceptions of learning (Cartwright and Hallar, 2018; Torabzadeh and Hashamdar, 2022). It is therefore plausible that the explicit neuroscientific grounding of the program—particularly its focus on neuroplasticity—played a key role in consolidating these results (Anderson et al., 2018).

In summary, these results confirm Hypothesis 1, highlighting the positive effects of neuroscience-informed UDL training on teachers' growth-oriented beliefs and suggesting potential spillover effects on other professional dimensions such as accessible lesson design, collaborative practices, and self-efficacy. Several studies indeed show that a growth mindset is positively associated, first, with pedagogical practices, as teachers who adopt a growth mindset tend to implement more effective and accessible instructional strategies (Chen, 2008)

and approaches consistent with the UDL framework (Griful-Freixenet et al., 2021); second, with co-teaching, as they demonstrate a greater propensity for effective forms of teacher collaboration (Addimando, 2019); and third, with self-efficacy, as teachers' growth mindset has been linked to higher levels of perceived self-efficacy and greater professional satisfaction (e.g., Tao et al., 2021; Zarrinabadi et al., 2023).

5.2 Effects of the training on the design and implementation of accessible lessons

Participation in the training was associated with significant and consistent improvements in the experimental group's ability to plan and implement accessible lessons, while the comparison group remained stable. These findings are in line with prior studies demonstrating that UDL-based professional development enhances teachers' capacity to translate inclusive principles into concrete instructional practices (e.g., Craig et al., 2019; Lee and Griffin, 2021; Navarro et al., 2021; Owiny et al., 2019; Scott et al., 2019; Unluol Unal et al., 2020). The results suggest a successful transfer from conceptual understanding to enacted professional practice, indicating that teachers were able to apply UDL guidelines effectively in lesson design and delivery. Among the factors that may have contributed to the effectiveness of the training are the embedded opportunities for active experimentation and reflective feedback, the explicit integration of UDL principles throughout the modules (Lancaster and Bain, 2010), and the alignment of program content with current inclusive education reforms in the Canton of Ticino (DECS, 2022, 2024). These features appear to have facilitated both cognitive assimilation and practical internalization of the UDL framework, supporting teachers in designing learning environments responsive to predictable learner variability.

In summary, the findings support Hypothesis 2 and indicate that UDL-based training can substantially strengthen teachers' ability to implement universal design principles and proactive differentiation strategies.

5.3 Effects of the training on co-teaching

Changes were also observed in co-teaching practices. Although the literature provides limited evidence on the specific effects of UDL-based professional development on collaborative teaching, this variable is particularly relevant within the inclusive education system in Ticino, where cooperation between general and special educators represents a core organizational model (Giovannini and Mainardi, 2019). The experimental group showed a statistically significant shift in its use of co-teaching modalities compared with the pre-test,

whereas the comparison group remained stable. In the experimental group, the frequency of interactive and differentiation-oriented configurations increased, including parallel, station, and alternative teaching, which assign both teachers active instructional roles (Friend and Cook, 2014). Conversely, the use of less differentiated formats, such as *one-teach/one-assist* and *one-teach/one-observe* decreased after training. This redistribution of co-teaching practices suggests enhanced awareness and a more balanced division of instructional responsibility between teaching partners. A notable contextual factor is that approximately 80% of the teacher pairs participated jointly in the professional development program (see Table 1), which may have supported the alignment of shared pedagogical understanding and facilitated the translation of training content into classroom practice.

Overall, the results suggest that participation in the UDL-based training led to a greater diversification of co-teaching methods and a shift toward more interactive and inclusive forms of shared instruction.

5.4 Effects of the training on teacher self-efficacy

The analysis of teachers' self-efficacy revealed a significant increase immediately after the training, followed by a decline at follow-up, with values returning close to pre-test levels. These findings suggest that the impact on self-efficacy was primarily short-term. The initial increase can be interpreted through Bandura's (1997) four sources of self-efficacy - mastery experiences, verbal persuasion, vicarious experiences, and physiological states - particularly the first three, which are most frequently activated in professional learning settings (Moradkhani et al., 2017). The decline observed at follow-up may reflect the inherently context-dependent and dynamic nature of teachers' self-efficacy beliefs, as changes in classroom composition or teaching partnerships (e.g., new students or colleagues) can influence teachers' perceived capability over time. Some dimensions, however, displayed greater temporal stability, notably those related to the management of student motivation and engagement. Overall, these findings suggest that short-term gains in self-efficacy may arise from immediate mastery and feedback experiences during the training but require sustained professional support to become durable.

Taken together, the four domains of the Inclusive Teacher Profile reveal a coherent pattern: cognitive and collaborative dimensions of competence appear more responsive to neuroscience-informed UDL training than affective-motivational dimensions, such as sustained self-efficacy. This differential responsiveness highlights the importance of iterative, practice-embedded professional learning cycles that integrate emotional regulation, reflection, and peer feedback as mechanisms for consolidating inclusive teaching expertise.

6 Limitations and future directions

The findings of this study should be interpreted in light of several limitations. First, the sample size was relatively small and limited to teachers working in inclusive classrooms in one Swiss canton, which restricts the generalizability of the results. In addition, the absence of randomized group assignments and the voluntary nature of participation may have introduced self-selection bias, as teachers with more positive attitudes toward inclusion or professional development may

have been more likely to enroll. Consequently, the results should be interpreted as indicative of descriptive changes rather than as evidence of causal effects.

Second, some measures relied on self-reported data or instruments with limited validation in Italian-speaking contexts. The restricted range of certain rating scales and the potential for divergent interpretations of co-teaching categories may also have influenced the findings. Moreover, the lack of classroom observational data for the comparison group limited the comparability of implementation outcomes, and the assumption that lesson plans accurately reflected classroom practices requires further empirical verification through systematic and triangulated observation.

Third, the follow-up period was relatively short, preventing conclusions about the long-term sustainability of the observed changes in mindset, instructional practices, and co-teaching dynamics.

Future studies should include larger and more diverse randomized samples, incorporate longitudinal measures, and use validated observational tools and performance-based measures to assess the persistence and transfer of training effects. Investigating how changes in teachers' beliefs, instructional practices, and collaborative dynamics relate to student engagement and learning outcomes would further illuminate the mechanisms through which inclusive professional learning enhances teaching quality and sustainability. Additionally, it would be valuable to explore statistical associations among various professional variables, to investigate, for example, whether growth-oriented beliefs function as protective factors against teacher burnout and professional disengagement, and to analyze how characteristics of teaching pairs (e.g., experience level, grade, or disciplinary background) influence the adoption of more differentiated and reciprocal co-teaching approaches.

7 Conclusions and implications for practice and research

This study examined the effects of neuroscience-informed UDL professional development on the four domains of the Profile of Inclusive Teachers (EADSNE, 2012). The results revealed significant and sustained improvements in teachers' growth-oriented mindsets, their capacity to design accessible lessons, and their use of more differentiated co-teaching practices, along with short-term gains in perceived self-efficacy. Taken together, these findings indicate that professional development integrating UDL and cognitive neuroscience can effectively foster inclusive teaching competencies. Such programs appear to promote teachers' ability to design equitable learning environments and to collaborate more strategically within diverse classrooms. However, the temporary nature of self-efficacy gains and the variability in long-term implementation emphasize the need for ongoing, context-sensitive professional learning ecosystems rather than isolated training episodes. Anchoring teachers' inclusive teaching training to the neuroscientific principles of variability and plasticity presents a robust and scalable principle for bridging the gap between cognitive science knowledge and the scientific referents of inclusive pedagogy achievements. Future professional development initiatives should prioritize longitudinal mentoring, reflective inquiry, and collaborative peer learning to consolidate adaptive expertise—ensuring that inclusive education is supported not only by conceptual change but also by enduring professional growth.

The findings of this study further inform educational policy, showing that when teachers are adequately supported, they can successfully design and sustain inclusive learning environments. This reinforces the sustainability and scalability of neuroscience-based professional development models grounded in UDL principles, highlighting their potential to strengthen educational systems and enhance the quality of learning opportunities for students with disabilities.

From a research perspective, it will be important to further investigate the longitudinal effects of such programs to better understand how inclusive teaching competencies are consolidated over time. Moreover, more robust and sensitive instruments are needed to evaluate the classroom implementation of UDL (Gäng-Pacífico and Rusconi, 2024; Rusconi and Gäng-Pacífico, 2024) principles and co-teaching practices, in order to more precisely document how these dimensions translate into effective learning experiences for all students.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by SUPSI Ethics Committee (Approval Code: Req-12952; Approval Date: 12 October 2022). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

LR: Formal analysis, Validation, Project administration, Data curation, Methodology, Conceptualization, Funding acquisition,

Writing – review & editing, Writing – original draft, Resources, Investigation. MS: Writing – review & editing, Validation, Methodology, Supervision. MM: Validation, Supervision, Writing – review & editing.

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