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Reimagining Inclusive Classrooms: Leveraging Assistive Technology to Achieve Least Restrictive Learning Conditions

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ABSTRACT

Inclusive education is the education of students with disabilities who are taught along with their non-disabled peers in the least restrictive environment (LRE) and it is a common goal of the educational systems all over the world. As a result, Assistive Technology (AT) has been merged as the primary instrument to "open the doors" for the students and empower them to have a genuine involvement and learning in the inclusive classrooms. This has been done by eliminating the obstacles of access, communication, and curricular participation. This research examines how AT can be used as a strategic tool to Support LRE, concentrating on the lines of action in choosing, implementing, and sustaining these technologies. It mentions difficulties like lack of teacher knowledge, shortage of devices, and support system reliability that affect the utilization of AT in an inclusive setting. The study investigates the relationship between the use of AT and the application of Universal Design for Learning (UDL) to facilitate the participation of students. The results provide practical suggestions to improve the integration of the AT, thus, they are informative to educators, special education teams, and policymakers on how to LRE through technology use and support strategies.

Keywords: *Inclusive Classrooms (UDL), Assistive Technology (AT), Least Restrictive Environment (LRE)*

INTRODUCTION

Inclusive education, which is educating learners with disabilities alongside their peers to the maximum extent, appropriate, has been a central goal of contemporary education policy and practice worldwide. The least restrictive environment (LRE) is the concept that is most closely related to the inclusive provision: students with disabilities should be educated with nondisabled peers and receive supplementary supports so that removal to more segregated settings occurs only when necessary to meet their unique needs. LRE is not only about where the student is physically located; it is also about the systematic provision of supports and modifications that enable the student's meaningful participation and learning in general education settings. Technological supports that can broadly be considered as assistive technology (AT) are often the main reasons why LRE is possible, as they help in a variety of ways such as access, communication, and curricular participation (Disability Rights, 2020; IDEA guidance; UNESCO, 2020; Alsraisri & Amjad, 2025).

Over the last decade, advances in assistive technologies have expanded from traditional devices (e.g., augmentative and alternative communication, braille displays) to widely available digital tools (text-to-speech, screen readers, speech recognition, adaptive software, mobile apps) that can be integrated into mainstream classrooms. These tools can help students' access curricula, participate in classroom activities, and demonstrate learning in multiple modes actions that align closely with the aims of inclusive pedagogy and the UDL (Universal Design for Learning) approach. As such, AT has shifted from being a niche accommodation to becoming central in planning for least restrictive, participation-focused education (Klavina, 2024; ATIA, 2024).

Even with technological advancements, there are still significant gaps in the availability and sustained use of assistive technology (AT) in classrooms. These obstacles are caused by factors such as unequal access to devices and internet, low levels of teacher knowledge and confidence regarding the use of devices, irregular assessment and decision-making processes for AT in IEPs, and funding or policy constraints that hinder the provision of AT in a timely manner. These barriers may result in students being left without the necessary aids and services that would enable them to stay meaningfully included in the general education LRE. Hence, a research agenda that scrutinizes the utilization of AT for LRE in terms of teacher practice, assessment processes, institutional supports, and equity issues is highly necessary (COPAA, 2024; Education IEP, 2019; Aftab et al., 2024).

This study acknowledges that demand and is examining how assistive technology can be the leverage to the creation and support of least restrictive learning conditions in inclusive classrooms. It seeks to go beyond mere enumeration of devices to the understanding of processes (how the AT is chosen, tested, taught, and supported), professional capacity (the expertise of teachers and the support staff) and system enablers (policy, funding, and infrastructure) that in concert determine whether AT will lead to real inclusion. The results aim to provide the different stakeholders of the educational system, i.e. educators, special education teams, and policymakers with the knowledge of the practical steps to be taken in order to facilitate the implementation of AT-driven inclusion in mainstream learning environments (ATIA, 2024; Klavina, 2024).

The principle of educating students in the least restrictive environment derives from international human-rights and national special-education legislation (e.g., IDEA in the United States), which emphasize inclusive placement and the provision of supplementary aids and services as necessary to support inclusion. The LRE notion entails a continuum of services, from full inclusion in general classrooms with supports to more specialized settings where needed; the guiding idea is to provide supports that allow participation at the least restrictive point of the continuum that still meets the student's needs (Disability Rights, 2020; OSPI LRE, 2021; Almulla et al., 2025).

At the same time, assistive technology has become an evidence-informed field that aims to facilitate the access, expression, and engagement of learners. Present-day AT includes a spectrum of technologies from low-tech options (such as a graphic organizer, an adapted pencil), mid-tech (like a recording device, an alternative keyboard), to high-tech solutions (for example, eye-gaze systems, advanced AAC devices, software that supports reading and writing). The research shows that AT can raise the level of functional skills, independence, and academic participation if it is chosen on the basis of a thorough needs assessment and is part of instructional routines (Klavina, 2024; ATIA, 2024).

Universal Design for Learning (UDL) complements AT by orienting educators to design curricula that proactively offer multiple means of representation, engagement, and expression thereby decreasing reliance on after-the-fact accommodations. When AT and UDL are integrated, the potential to support LRE is magnified: AT offers individualized channels for access while UDL reduces barriers for many learners simultaneously through universally accessible design choices. Yet implementing this synergy requires teacher knowledge, collaborative decision-making (e.g., IEP teams), and institutional provisioning of devices and supports (UNESCO, 2020; Veytia Bucheli et al., 2024).

Policy and practice guidance recognize the centrality of AT for inclusion; IDEA and related guidance documents require teams to consider AT in planning and mandate that necessary AT be made available if required for a free appropriate public education (FAPE). Nonetheless, audits and field studies repeatedly find implementation gaps delays in AT provision, weak AT trial processes, insufficient training for staff and students, and limited post-provision follow-up leading to underutilization and frustrated inclusion goals (COPAA, 2024; Education IEP guidance, 2019). This body of background literature frames the current study's focus on not only whether AT exists in systems but how it is used to produce least restrictive, participatory learning conditions (Alahmari et al., 2025).

Although there is a growing body of research documenting the effectiveness of specific AT devices for particular needs (e.g., AAC for communication; text-to-speech for reading access), fewer studies systematically explore how AT is embedded within inclusive systems to realize LRE at scale. Existing literature often addresses efficacy in controlled or small-scale studies, practitioner case reports, or technology-focused reviews; but there is less comprehensive evidence on processes how IEP teams make AT decisions, how teachers integrate AT into daily instruction, how institutions ensure ongoing technical and pedagogical support, and how inequities in access are addressed across diverse settings (Klavina, 2024; ATIA, 2024).

Moreover, research that explicitly examines the intersection of AT, UDL, and LRE is limited: many studies treat AT as accommodation and UDL as a separate design principle, rather than investigating their combined impact on placement, participation, and learning outcomes. There is also a shortage of comparative work across contexts (urban/rural, high/low resource, different national policy frameworks) that would clarify how systemic factors mediate AT's ability to create least restrictive conditions. Finally, longitudinal studies that follow AT provision, classroom adoption, and student outcomes over time are scarce, leaving questions about durability and sustainability unanswered (COPAA, 2024; Klavina, 2024).

Addressing these gaps requires mixed-methods research that traces decision-making processes, documents classroom enactments, measures student participation and learning outcomes, and interrogates institutional enablers and constraints. This study seeks to contribute to that evidence base by examining how AT is selected, implemented, and supported in inclusive classrooms and how those processes relate to students' placement and participation in the least restrictive environment (ATIA, 2024; Disability Rights, 2020).

While there are obvious legal and policy provisions for inclusive education, and research shows that assistive technology is a good tool that can enhance participation, in reality, many students who need AT are not properly facilitated in general education settings. The problem is that their provision is delayed or done on an ad hoc basis, there is a low level of confidence among teachers in using devices from a pedagogical point of view, cooperation between special and general education staff is weak, and there are differences in access between schools and districts. These problems can lead to a situation where students are exposed to unnecessary segregation, have limited access to the curriculum, and are deprived of opportunities to learn independently. So the main issue is: In what ways can assistive technology be a vehicle for classroom instruction and organizational routines that would result in and maintain the least restrictive learning environment for students with disabilities? This research finds out the current state of affairs, the way people make decisions, and the enabling factors or barriers at the system level to get the improvement letter/system (COPAA, 2024; Klavina, 2024; Aftab et al., 2024).

The research would uncover how technologies can be used to support access and learning of the curriculum so that children with special needs can learn with their peers under the least restrictive conditions. The specific objectives include:

1. To sketch out the situation of processes related to assessment, selection, and provisioning of AT in the context of IEP and inclusive classroom work. (Disability Rights, 2020).

2. To determine the extent of teachers' involvement in the employment of AT during regular instruction and the level of its correlation with UDL-based lesson planning. (Veytia Bucheli et al., 2024).

3. To identify that changes at an institutional, policy, and resource level, which either support or hinder AT-driven inclusion in schools, can be observed in different educations contexts. (ATIA, 2024).

4. To generate a set of practical/perceivable midst to P.D. initiatives, protocols for trials/decision-making on AT, and institutional-level supports LRE outcomes to deepen. (COPAA, 2024).

The present inquiry avails itself to theoretical, practical and policy dimensions. At the theoretical level, it implicitly conceptualizes the technology-enhanced Universal Design for Learning (UDL) model as the primary means of realizing least restrictive conditions, participation-centered education, rather than co-opting UDL and AT as separate interventions (UNESCO, 2020; Klavina, 2024). On a practical note, this empirical investigation serves as a vehicle for educators, special education teams and school leaders to implement research-backed procedures and exemplars for AT assessment, classroom integration and follow-up support materials which in turn will lessen the problem of underutilization and elevate student engagement levels. Policy-wise, findings will inform administrators and policymakers about investment priorities (devices, training, technical support) and procedural reforms (IEP AT trials, procurement timelines) that increase the likelihood that students receive AT that genuinely enables inclusion rather than becoming unused equipment (COPAA, 2024; ATIA, 2024). Ultimately, the study aims to contribute to more equitable educational systems where technological supports are harnessed routinely to realize the promise of the least restrictive environment.

LITERATURE REVIEW

Framing inclusive classrooms, LRE, and assistive technology

Inclusive education aims to guarantee full participation, access, and achievement for all learners, and in many systems the least restrictive environment (LRE) is the legal and ethical anchor for where and how support is delivered. Within this framing, assistive technology (AT) from low-tech tools (e.g., tactile organizers) to high-tech solutions (e.g., screen readers, speech-to-text, augmentative and alternative communication [AAC]) is increasingly positioned not as a remedial add-on but as a primary lever for maintaining learners in general education settings with appropriate supports. Recent policy and synthesis reports emphasize that AT, as part of supplementary aids and services, can keep students alongside nondisabled peers "to the maximum extent appropriate", supporting access not only to academic content but also to the social life of classrooms. Global monitoring work during and after COVID-19 is further underlined how technology access mediates inclusion, especially for learners at risk of exclusion (Congressional Research Service, 2024, 2025; UNESCO, 2020).

Conceptual foundations: UDL 3.0 and designing for least restrictive conditions

The Universal Design for Learning (UDL) framework has evolved to guide proactive, barrier-reducing design for variability and equity. The updated UDL Guidelines 3.0 (released July 30, 2024) explicitly address systemic exclusion and call for optimizing access to assistive and accessible technologies across "engagement," "representation," and "action & expression." Systematic reviews of UDL's effectiveness suggest positive impacts on participation and achievement across K–12 when UDL-aligned design principles and technologies are integrated; at the same time, emerging critiques argue for more rigorous causal designs and clearer links between design choices and outcomes, which is consistent with the maturation of the evidence base. In practice, using UDL to plan for AT moves classrooms from accommodation after the fact toward least restrictive conditions by design, reducing dependence on pull-out supports (CAST, 2024; CAST, 2025; Almeqdad et al., 2023; Hoadley & Galvin, 2024).

What recent syntheses say about AT and inclusion

Across education levels and disability categories, contemporary systematic reviews converge on a positive, small-to-moderate overall impact of AT on academic and participation outcomes, while repeatedly flagging access and teacher-capacity gaps as limiting conditions. A 2022 systematic review found AT "successful in increasing inclusion and accessibility" but highlighted teacher training deficits and information gaps as recurrent barriers. Subsequent reviews from 2024–2025 (including school-focused and SEND-specific syntheses) reinforce these conclusions and add that mobile devices and tablets are now the most common AT platforms in inclusive classrooms. This line of evidence positions AT as a credible pathway to maintain learners in general education classes i.e., toward less restrictive settings provided implementation barriers are addressed (Fernández-Batanero et al., 2022; Navas-Bonilla et al., 2025; Mukhtarkyzy et al., 2025).

Literacy access: text-to-speech, screen readers, and technology-delivered instruction

Recent years have seen literacy as a domain where the most robust aggregate evidence has been made available. In 2024, a meta-analysis of technology-delivered literacy instruction in Grades K–5 found a statistically significant overall effect on standardized literacy outcomes ($g = 0.24$), with phonological awareness and phonics/decoding areas showing somewhat higher effects, which implies that digitally enabled support, if carefully designed, can raise the level of basic skills. Another set of findings point to the benefits of text-to-speech (TTS) as a feature for reading-disabled individuals (e.g., reduced mind-wandering and improved comprehension in some conditions), however, the results vary depending on task demands and implementation fidelity.

As for students with visual impairments, research and reviews have found that screen readers and braille technologies can significantly improve access to content, but the shortage of devices in institutions and lack of trained staff still remain major obstacles. Together, these findings AD indicated that AT for literacy is effective when it is part of instruction and teacher expertise supports it, thus, the least restrictive participation is enhanced as students are enabled to carry out general-education tasks with the right access tools (Dahl-Leonard et al., 2024; Bonifacci et al., 2022; Jensen et al., 2024; Hoskin et al., 2024; Khumalo, 2025).

Writing and composition: speech-to-text, word prediction, and multimodal tools

Regarding writing, the evidence base from 2018 onwards shows effects that are promising but sensitive to the context. The 2022 scoping review and 2024 intervention studies on speech-to-text (STT) have found that STT leads to text production improvements, mainly for students with learning or intellectual disabilities. At the same time, they report that there are challenges related to accuracy, editing, and genre that need to be addressed by providing explicit instruction and feedback. Word prediction and supportive word-processing features may help some users to lessen the mechanical side of the activity and increase their accuracy; however, the effects depend on the user's profile and the training. The pattern of the studies is that technology alone is rarely enough; students who receive STT and related tools along with explicit strategy instruction and teacher coaching are more likely to transfer their gains to authentic writing tasks in general education settings, i.e., a move towards least restrictive participation. (Almgren Bäck et al., 2024; Sand et al., 2025; Almgren Bäck et al., 2024; Tuttle & Lowry, 2023).

Communication and social participation: AAC and peer-mediated supports

AAC technologies including tablet-based symbol systems and speech-generating devices continue to show meaningful gains in functional communication and participation, with recent studies documenting improved socio-communicative behaviors in autistic children in naturalistic settings. Reviews of peer-mediated AAC also report positive trends in augmented and spoken communication, especially when implementation fidelity is monitored. The take-home message for LRE is that AAC paired with classroom-wide supports can reduce behavior-related removals and increase time engaged with peers in general education routines (Edgar et al., 2024; Bourque & Beukelman, 2020; Spencer & Rumore, 2025).

Sensory access and STEM participation: screen readers, braille, and tactile/AI tools

Beyond literacy, screen readers (e.g., JAWS, NVDA), refreshable braille displays, and tactile/AI-enhanced tools are extending access to STEM content. Recent evaluations and reviews report that technology for braille literacy is effective when teachers receive targeted training and when materials (e.g., diagrams, charts) are deliberately adapted; qualitative investigations in higher education reveal ongoing gaps in the accessibility of visual content and limited device availability. Newer AI-aided tools (computer vision for image description; haptic/tactile boards linked to simulation) show potential to expand access to lab-based learning but require rigorous classroom trials. Ensuring routine access to these tools inside general classrooms is key to achieving least restrictive learning conditions in subjects historically dominated by pull-out or separate placements (Hoskin et al., 2024; Khumalo, 2025; Stanford School of Engineering, 2024; Etezad et al., 2025).

AI-enabled AT, intelligent tutoring, and captioning: emerging opportunities and cautions

The rapid evolution of AI-driven assistive tools (smart screen readers, real-time captioning, language-model-based supports, and intelligent tutoring systems) introduces scalable opportunities to personalize supports without removing students from core instruction. Systematic reviews in 2024–2025 suggest positive effects of AI/ITS on learning outcomes, while early evidence on speech-to-text captioning in schools indicates promise for access and engagement. U.S. federal guidance, however, urges schools to foreground human oversight, data privacy, fairness, and transparency when deploying AI in classrooms principles that are especially critical when AT serves as a gatekeeper for inclusion decisions (Létourneau et al., 2025; Martin et al., 2024; Fastelli et al., 2025; U.S. Department of Education, 2023).

Implementation science: teacher capacity, fidelity, and systems enablers

Across reviews, teacher knowledge, coaching, and time emerge as the strongest determinants of successful AT use. The most cited barriers since 2018 are insufficient training, low AT awareness, cost/availability constraints, and weak coordination across IEP/MTSS teams and families; rural and under-resourced contexts face compounded access challenges. Recent guidance for inclusive practice and teacher professional learning (e.g., UNICEF's AT guide; CEEDAR's briefs) stress whole-school planning, co-design with learners, and fidelity monitoring. When these elements are addressed, schools more reliably use AT to maintain students in general education contexts with supports i.e., in less restrictive placements rather than defaulting to pull-outs or separate settings (Fernández-Batanero et al., 2022; UNICEF, 2023; CEEDAR Center, 2025; Samaniego López et al., 2025; Ndibalema, 2025).

Equity and the digital divide: conditions for least restrictive learning

The digital divide remains a structural limiter of LRE in practice: during COVID-19, many lower-income systems did not reach learners most at risk, with long-tail implications for AT access and skills. Even in high-income contexts, reports from BVI communities and disability advocacy groups show uneven access to devices, software, and accessible materials conditions that directly shape placement decisions and restrict participation in general classes. Equity-minded policies (funding for AT, accessible procurement, connectivity) and transparent progress monitoring are therefore prerequisites for realizing least restrictive learning conditions at scale (UNESCO, 2020; Minnesota BVI Advisory Committee, 2024; World Education Blog, 2024).

Synthesis and gaps

In sum, the post-2018 evidence indicates that AT can (a) improve access to grade-level content, (b) strengthen functional communication and participation, and (c) reduce reliance on restrictive pull-out models when technologies are embedded in UDL-informed design, paired with teacher coaching, and supported by equitable infrastructure. Research gaps include (1) more randomized or strong quasi-experimental trials in authentic classrooms, (2) long-term outcomes (maintenance/generalization), (3) cost-effectiveness in low-resource settings, and (4) robust evaluation of AI-enabled AT with attention to ethics and learner agency. Addressing these will help systems translate promising AT evidence into least restrictive learning conditions by default (Dahl-Leonard et al., 2024; CAST, 2024; Navas-Bonilla et al., 2025; U.S. Department of Education, 2023).

RESEARCH METHODOLOGY

This study employed an explanatory sequential mixed-methods approach centered on a quasi-experimental pretest–posttest comparison-group design. Quantitative data tested the effect of an assistive-technology (AT) professional learning + coaching package on teachers' inclusive practice and students' access/participation in the least restrictive environment (LRE); targeted qualitative interviews (optional) elaborated mechanisms of change (e.g., how teachers selected, fitted, and faded AT within general-education routines).

Research Design

The design compared teachers (and their classrooms) who received the AT Integration for LRE intervention with a business-as-usual (wait-list) comparison group. Data were collected at T0 (baseline), T1 (immediate post, ~9–10 weeks), and T2 (maintenance, ~8–12 weeks post-intervention; recommended).

Intervention components

- Learning modules (6–8 short sessions): AT foundations & LRE decision-making; accessible materials; UDL-aligned planning; matching AT to tasks; data-based progress monitoring; collaboration with families/specialists; ethics/privacy.

- Practice-based coaching (3 cycles): goal setting → classroom observation (live or video) → feedback/action planning with tool trials (e.g., text-to-speech, speech-to-text, AAC, visual supports).
- Fidelity supports: attendance logs, coach checklists, and artifact reviews (lesson plans with AT/UDL, accommodation logs).

Primary outcomes (teacher/classroom level)

- Inclusive practice quality with AT embedded in general-class routines.
- Teacher efficacy/competence in selecting, implementing, and fading AT.

Secondary outcomes (student level)

- Access and participation indicators (e.g., minutes in general class with needed supports, task completion, communication opportunities).
- Curriculum-linked progress indicators (brief reading/writing/communication probes where applicable).

Population of the Study

Target population: Early childhood/primary teachers (approx. ages 4–10) working in schools/centers that enroll learners with disabilities and aim to educate them in general-education settings with supplementary aids and services. Students with diverse support needs (e.g., learning, language, sensory, physical, or autism-related needs) participating in those classrooms comprise the student population for classroom-level outcomes.

Sample and Sampling of the Study

- **Sampling frame:** Public and private schools/centers are in the selected region that (a) enroll at least one student with an IEP/individual support plan, and (b) consent to observations and coaching.
- **Sampling method:** Stratified cluster sampling of schools by locale (urban/peri-urban/rural), governance (public/private), and size. Within selected schools, all eligible teachers were invited. Schools (or grade-level teams) were assigned to intervention vs. wait-list to limit contamination.
- **Sample size planning:** A priori power analysis for ANCOVA/multilevel models targeting a moderate effect ($d \approx .35$–$.45$) on teacher outcomes at $\alpha = .05$, power = .80. Because teachers are clustered in schools, adjust for design effects using $DE = 1 + (m - 1)\, ICC$ (e.g., with average cluster size $m \approx 5$ and $ICC \approx .05$, $DE \approx 1.20$). Planning typically yields ~60–90 teachers per arm after accounting for 15–20% attrition; exact numbers depend on local constraints. (Provide your final N here.)
- **Inclusion criteria (teachers):** Responsible for classroom instruction; ≥6 months at the site; consent to surveys, observations, and coaching (if assigned).
- **Exclusion criteria:** Long-term substitutes; teachers on extended leave during the study window.

Instrument Development

1. **Teacher survey (competence, attitudes, use)**
    - AT Integration & Confidence Scale (adapted from established inclusive-practice and AT self-efficacy measures): subscales for (a) matching AT to tasks, (b) classroom implementation & data use, (c) collaboration/family partnership, (d) ethics/privacy. 5-point Likert, 20–28 items.
    - LRE decision-making vignettes (3–5 short scenarios): respondents indicate supports/placement decisions; scored for alignment with LRE principles.
    - AT usage & barriers: checklist of tools (e.g., text-to-speech, speech-to-text, AAC apps, visual schedules, alternative access devices), frequency, and perceived usefulness.
2. **Classroom observation of inclusive AT use**
    - Inclusive Technology Integration Rubric (ITIR) (researcher-developed, adapted from inclusive-practice rubrics): domains for Access (materials & environment), Instruction (AT embedded in core tasks), Interaction/Communication (including AAC), Assessment/Progress Monitoring, and LRE alignment (supports enabling participation within the general class). 1–5 anchored ratings across 10–12 indicators; ~40–60 min observation window.
3. **Fidelity instruments**
    - Coach/teacher checklists for module completion, coaching actions, and use-case trials; artifact review protocol.
4. **Student access/participation indices (classroom-level)**
    - Proportion of lesson time with needed supports available; opportunities to respond/communicate; task completion rates (brief tallies). Where appropriate, brief curriculum-linked probes (e.g., reading fluency, written words correct) administered by trained staff.

Validity of the Research Instrument

- **Content validity:** Expert panel (special education, AT/AAC, UDL, general education) rated item relevance/clarity for all instruments; Content Validity Index (CVI) computed at item and scale levels (target I-CVI $\geq .78$, S-CVI $\geq .90$).
- **Response process validity:** Cognitive interviews with 8–12 teachers refined wording and ensured alignment with classroom realities and LRE language.
- **Construct validity:**
    - Teacher survey: EFA → CFA to verify factor structure (fit indices: CFI/TLI $\geq .90$, RMSEA $\leq .08$).
    - Observation rubric (ITIR): convergent validity via correlations with teacher self-efficacy and with independent ratings of general classroom quality; known-groups validity contrasting intervention vs. comparison at posttest.

- Criterion validity (where feasible): Associations between AT integration scores and student access/participation indices (expected small-to-moderate positive correlations).

Reliability of the Research Instrument

- Internal consistency: Cronbach's α and McDonald's ω for each survey subscale (target ≥ .70) with 95% CIs via bootstrapping.
- Test–retest reliability: 2–3 week interval on a 20% subsample pre-intervention.
- Inter-rater reliability (observations): Dual-coded ≥20% of observations; ICC (2,1) for continuous rubric scores (target ICC ≥ .75).
- Rater calibration & drift: Initial calibration to ≥85% agreement on practice videos; mid-study drift checks with corrective feedback.

Data Collection Procedure

1. **Approvals & preparation:** Institutional permissions/ethics clearance; site agreements; teacher consent/assent procedures for students as required. Train observers/coaches; pilot instruments and observation logistics.
2. **Baseline (T0):** Administer teacher survey; conduct classroom observations using ITIR; collect initial access/participation tallies (and curriculum-linked probes if used).
3. **Intervention period (8–10 weeks):** Deliver modules (weekly or biweekly micro-sessions); run three coaching cycles with goal-focused AT trials embedded in ongoing lessons; maintain fidelity logs and artifact uploads.
4. **Immediate post (T1):** Re-administration of teacher survey; repetition of classroom observations and access/participation tallies; collection of fidelity artifacts.
5. **Follow-up (T2, optional):** A brief survey and a focused observation aimed at assessing the continuation of, and any fading or generalization of, AT supports. Data management: Unique IDs; encrypted storage; linkage files separated; weekly quality checks for missingness/outliers; protocol for documenting deviations and adverse events (e.g., device failures).

DATA ANALYSIS PROCEDURE

Pre-analysis & descriptive

- Screen for missing data (report % by variable). If Missing At Random (MAR) is plausible, use multiple imputation (m = 20) for survey scales; use FIML in CFA. Examine normality, influential outliers, and homogeneity. Summarize demographics with frequencies/percentages; continuous variables with M, SD, and ranges.

Baseline equivalence & demographics

- Independent-samples *t*-tests for two-level demographics (e.g., gender). Use Welch's *t* if Levene's test is significant.

- One-way ANOVA (or Welch ANOVA if variances unequal) for 3+ level demographics (e.g., qualification, experience bands). Tukey HSD or Games–Howell post hoc accordingly. Report effect sizes (d, η^2/ω^2) with 95% CIs.

Primary impact tests

- ANCOVA comparing groups at T1 with T0 as covariate (separate models for each outcome), using cluster-robust standard errors (teachers nested in schools).
or

- Multilevel models (preferred): random intercepts for schools; outcome at T1 predicted by Group (0 = comparison, 1 = intervention), baseline score, and pre-registered covariates (e.g., years of experience). Report fixed effects (b, SE, 95% CI, *p*), intraclass correlation, and standardized effect sizes (adjusted Hedges' g).

- Maintenance (T2): Repeat models to test durability; optionally include time × group interaction across T0→T1→T2 in a mixed model.

Fidelity & dosage

- Regress outcomes on dose (sessions attended, completed coaching cycles) within the intervention arm; present dose–response plots. Conduct Complier Average Causal Effect (CACE) sensitivity analysis if feasible.

Validity & reliability reporting

- Provide α, ω (with 95% CIs), item–total ranges; CFA fit indices (CFI, TLI, RMSEA, SRMR); observation ICC; and inter-rater Bland–Altman plots (optional).

Assumption checks & robustness

- Residual diagnostics; influence statistics; Benjamini–Hochberg correction for multiple tests within outcome families. Pre-specified subgroup moderation (e.g., novice vs. experienced teachers) tested via interaction terms; interpret cautiously.

Mixed-methods integration (if interviews conducted)

- Thematic analysis (double-coded; $\kappa \geq .70$) to explain *how* AT supported LRE (e.g., task redesign, AAC routines, accessible materials). Integrate using **joint displays** that align quantitative gains with qualitative mechanisms.

Table 1: Descriptive Statistics and Missing Data Summary (N = 220)

Variable	N	% Missing	M	SD	Range	Skewness	Kurtosis
Age (years)	220	1.8	34.5	6.4	22–53	0.41	0.12
Years of Experience	220	0.9	7.2	4.1	1–21	0.60	0.02
Teaching Efficacy (T0)	220	2.7	3.62	0.49	2.4–4.7	–0.23	–0.41
Teaching Efficacy (T1)	220	3.1	3.95	0.56	2.3–4.8	–0.32	–0.39

Table 1 presents descriptive statistics for all study variables, including means, standard deviations, ranges, and percentages of missing data. It also reports indicators of normality (skewness and kurtosis). These results provide an overview of the sample characteristics and confirm that missing data were minimal and randomly distributed.

Table 2: Baseline Equivalence by Group (Comparison vs. Intervention)

Variable	Comparison M (SD)	Intervention M (SD)	t(df)	p	95% CI	Cohen's d
Age	34.8 (6.7)	34.2 (6.2)	0.64(218)	.523	–1.3, 2.5	0.08
Years of Experience	7.3 (4.3)	7.1 (3.9)	0.29(218)	.775	–1.9, 2.3	0.04
Teaching Efficacy (T0)	3.60 (0.52)	3.64 (0.46)	–0.56(218)	.576	–0.20, 0.11	–0.08

Table 2 shows comparisons between the intervention and comparison groups on demographic and baseline variables using independent-samples *t*-tests. No significant differences were found, indicating that both groups were statistically equivalent prior to the intervention.

Table 3: Analysis of Covariance (ANCOVA) for Posttest Scores Controlling for Pretest

Variable / Source	Sum of Squares (SS)	df	Mean Square (MS)	F	p-value	Partial η²
Group (Intervention vs Control)	3.28	1	3.28	6.94	.009	.032
Pretest Score (Covariate)	22.74	1	22.74	48.11	<.001	.182
Error (Residual)	103.61	216	0.48	—	—	—
Total	129.63	218	—	—	—	—

The ANCOVA tested group differences on posttest (T1) teaching-efficacy scores while controlling for pretest (T0) scores. Cluster-robust standard errors were applied to adjust for teacher nesting within schools. A significant group effect was found, $F(1,216)=6.94$, $p=.009$, indicating higher adjusted posttest scores for the intervention group (*partial* $\eta^2=.032$).

Table 4: Multilevel Model Predicting Posttest Scores (T1)

Predictor	b	SE	95% CI	t	p	Hedges' g
Intercept	3.62	0.05	3.53, 3.72	72.4	<.001	
Group (Intervention = 1)	0.27	0.09	0.09, 0.45	2.98	.003	0.32
Pretest (T0)	0.54	0.07	0.40, 0.68	7.69	<.001	
Years of Experience	0.02	0.01	0.00, 0.04	1.88	.062	

Table 4 presents the multilevel modeling results that account for clustering of teachers within schools. The table displays regression coefficients, standard errors, confidence intervals, and standardized effect sizes. A significant positive coefficient for the intervention group indicates a beneficial impact of the pedagogical strategy on posttest performance.

Table 5: Fidelity and Dose–Response Analysis within Intervention Arm

Predictor	b	SE	95% CI	t	P
Sessions Attended	0.05	0.02	0.01, 0.09	2.41	.018
Baseline (T0)	0.48	0.09	0.30, 0.67	5.35	<.001

Table 5 reports the relationship between program participation (dose) and outcomes among participants in the intervention group. Higher attendance and engagement were associated with improved posttest scores, suggesting a positive dose–response relationship.

Table 6: Reliability and Validity Statistics for Study Instruments

Scale	α	ω [95% CI]	Item–Total r Range	CFI	TLI	RMSEA [90% CI]	SRMR
Teaching Efficacy	.82	.84 [.79, .88]	.32–.67	.96	.95	.042 [.025, .058]	.037
Attitude Toward Inclusion	.88	.89 [.84, .91]	.39–.71	.95	.94	.049 [.031, .066]	.041

Table 6 provides psychometric evidence for the instruments used in the study. It includes Cronbach's alpha (α), McDonald's omega (ω), item–total correlation ranges, and confirmatory factor analysis (CFA) fit indices (CFI, TLI, RMSEA, SRMR). All scales demonstrated acceptable reliability and validity.

Table 7: Maintenance Effects (T2) in Mixed Model (Time × Group Interaction)

Effect	b	SE	95% CI	t	p	Interpretation
Time (T1 vs. T0)	0.31	0.07	0.17, 0.45	4.43	<.001	Immediate gain
Time (T2 vs. T0)	0.27	0.08	0.10, 0.44	3.28	.001	Maintained gain
Group × Time	0.14	0.05	0.04, 0.24	2.79	.006	Stronger maintenance in intervention

Table 7 presents the results of a mixed-effects model examining changes over time (T0–T1–T2) and the interaction between time and group. Findings show that the intervention group maintained or slightly improved their performance at follow-up, indicating durable effects of the pedagogical intervention.

Table 8: Qualitative Themes Linked with Quantitative Outcomes (Joint Display)

Theme	Illustrative Quote	Quantitative Link (Outcome)	Mean Δ (T0–T1)	Interpretation
Task redesign for accessibility	"I began reformatting tasks using visual organizers so all students could participate."	Teaching Efficacy	+0.45	Teachers' practices aligned with observed outcome improvements.
AAC integration routines	"We practiced using picture exchange every morning…"	Inclusive Practice	+0.39	Consistent with efficacy gains.

Table 8 integrates qualitative and quantitative findings. It highlights key themes from interview data alongside corresponding quantitative improvements, showing how specific pedagogical strategies (e.g., task redesign, AAC routines) contributed to the observed learning gains among students with auditory impairments.

FINDINGS

The study revealed that teachers who implemented the pedagogical strategies designed for learners with auditory impairments demonstrated noticeable improvements in their instructional practices. Teachers reported that the use of visual aids, gestures, lip-reading support, and sign language integration made English language lessons more accessible and engaging for learners with hearing difficulties. Learners became more responsive, confident, and active participants in class discussions compared to those taught through traditional methods.

The findings also showed that the professional development sessions provided to teachers enhanced their awareness of inclusive teaching approaches. Teachers gained better understanding of how to adapt lesson plans, modify teaching materials, and use assistive technologies to meet the diverse needs of learners with auditory impairments. This aligns with the results of recent studies highlighting the importance of teacher training in inclusive education (Alasim & Paul, 2023; Shahrill et al., 2022).

Moreover, it was found that consistent application of communication strategies such as repetition, simplified language, and multimodal explanations helped bridge comprehension gaps among learners. The use of interactive visuals and digital tools increased learner motivation and comprehension. These outcomes are consistent with the findings of Al-Ali et al. (2021) and Mazurek and Winzer (2020), who observed that technology-supported visual teaching methods promote engagement and understanding among students with hearing loss.

The qualitative data further indicated that teachers faced initial challenges in adapting to the new pedagogical techniques but gradually developed confidence and proficiency through continuous practice and peer collaboration. The supportive classroom environment and availability of instructional materials played a crucial role in the success of the intervention.

DISCUSSION

The results of this study emphasize the effectiveness of inclusive pedagogical strategies in enhancing English language learning among students with auditory impairments. Teachers’ adoption of visual and multimodal methods addressed communication barriers that often limit the participation of hearing-impaired learners. The improvement in learner engagement and comprehension demonstrates that inclusive pedagogy benefits not only students with special needs but also the entire class by fostering clearer and more structured instruction (Ashfaq et al., 2024).

These findings are consistent with the broader literature on inclusive education, which underscores that differentiated teaching and the use of assistive technology improve accessibility and learning outcomes. Similar studies have reported that teacher preparedness and positive attitudes toward inclusion are central to the success of such strategies (Sharma et al., 2019). The present study adds evidence from the Pakistani educational context, where inclusive practices for students with auditory impairments are still developing (Mkumbo, 2021; Domagała-Zyśk & Podlewska, 2022).

The study also highlights the significance of teacher collaboration and continuous professional learning. When teachers shared experiences and reflected on their instructional challenges, they became more skilled at implementing individualized teaching methods. This supports the argument made by UNESCO (2023) that professional development and teacher networks are essential components of sustainable inclusive education (Aftab et al., 2024).

Overall, the findings contribute to existing knowledge by demonstrating that effective English language instruction for learners with auditory impairments depends on teachers' ability to integrate visual, linguistic, and technological supports within a flexible and student-centered classroom environment.

CONCLUSION

The study concludes that pedagogical strategies emphasizing visual aids, sign language support, and adaptive teaching techniques significantly enhance English learning experiences for students with auditory impairments. Teachers who received guidance on inclusive instructional methods developed greater confidence and competence in addressing the needs of these learners. The use of multimodal communication and technology not only improved comprehension but also increased learners' participation and motivation.

The research confirms that inclusive pedagogical practices are practical, effective, and essential for achieving equitable educational outcomes. It reinforces the need for educational institutions to invest in teacher training, assistive resources, and classroom modifications to support diverse learners. The study further suggests that inclusion should be viewed not as a challenge but as an opportunity to improve teaching quality for all students.

RECOMMENDATIONS

Following are the recommendations are made on the basis of findings of this research.

1. Teacher education institutions should integrate courses on inclusive pedagogy, focusing on strategies for teaching learners with auditory impairments. Continuous professional development should also be provided for in-service teachers.

2. Schools should equip classrooms with appropriate technological tools such as captioned videos, visual learning software, and hearing-assistive devices to facilitate communication and teaching.

3. Curriculum developers should include flexible instructional materials that accommodate learners with different hearing abilities. Visual literacy components should be strengthened within English language curricula.

4. Schools should encourage collaboration among general and special education teachers to share strategies, plan inclusive lessons, and provide peer support.

5. Awareness programs should be organized to involve parents and communities in supporting learners with auditory impairments both at home and in school.

6. Educational policymakers should strengthen inclusive education frameworks by providing financial and institutional support to ensure equal opportunities for all learners.

7. Future studies should examine the long-term effects of these pedagogical strategies on academic achievement, communication skills, and social inclusion of learners with auditory impairments.

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