The Use of Assistive Technology in Teaching: A Systematic Review and Meta-Analysis

Giusi Antonia Toto[1,*], Luigi Traetta[1], Ciro Esposito[1], Valentina Berardinetti[1], Guendalina Peconio[1], Salvatore Iuso[1], and Annamaria Petito[2]

[1]Department of Humanities, University of Foggia, Foggia, Italy
[2]Department of Clinical and Experimental Medicine, University of Foggia, Foggia, Italy
Email: giusi.toto@unifg.it (G.A.T.); luigi.traetta@unifg.it (L.T.); ciro.esposito@unifg.it (C.E.); valentina.berardinetti@unifg.it (V.B.); guendalina.peconio@unifg.it (G.P.); salvatore.iuso@unifg.it (S.I.); annamaria.petito@unifg.it (A.P.)
*Corresponding author

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***Abstract*—Assistive Technology (AT) is increasingly used in inclusive education to support students with disabilities, yet evidence on its overall effectiveness has not been well-synthesized. To address this gap, we conducted a systematic review and meta-analysis, following Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines, to evaluate how AT influences student performance and learning outcomes. A total of 33 peer-reviewed studies were included. The meta-analysis showed that AT for students with hearing impairments had a statistically significant effect, with an overall effect size of $Z = 1.12$ and a 95% Confidence Interval (CI) of −0.76 to −0.31. AT interventions for students with learning disabilities also showed significant positive effects ($Z = 2.91$, 95% CI: −1.46 to −0.28). In addition to the meta-analysis, we reviewed qualitative findings from studies with data not suitable for quantitative synthesis. Overall, 87% (29 of 33) of the included studies reported that AT improved educational experiences or outcomes for students. However, 13% (4 studies) found little to no effect. The review highlights several ongoing challenges that limit AT's impact in schools, such as inadequate teacher training, limited infrastructure, and uncertain teacher attitudes toward using AT in the classroom. Despite these barriers, the evidence suggests that AT is both available and feasible to implement in school settings, and that student performance can improve when AT tools are tailored to individual learning needs. The findings emphasize the importance of evidence-based policies to support teacher capacitation, improve access to AT, and ensure that AT is effectively integrated into inclusive education.**

***Keywords*—assistive technologies, instruction, education, inclusion**

I. Introduction

Technology integration has become paramount in today's rapidly evolving educational landscape, opening doors to innovative approaches that cater to diverse learning needs. One such paradigm that has gained significant traction is Assistive Technology (AT) in teaching, a dynamic field that endeavors to bridge the learning gap for individuals with disabilities. AT in teaching encompasses various tools, strategies, and devices designed to support students with disabilities in various educational settings [1]. These technologies aim to minimize barriers to learning, thereby promoting equal access, participation, and success for all learners.

In last years, the availability of increasingly powerful computers and various forms of technology has led to a proliferation of options for AT [2]. Providing inclusive education for students with disabilities is frequently impractical unless they have access to appropriate AT, as the obstacles to their education are frequently related to the environment [3]. Studies underline lack of environment where to improve AT [4] and this is particularly evidenced in third world development communities because of their socioeconomical limitation such as poverty [5, 6].

While several systematic reviews and meta-analyses have explored the role of AT in education, our study presents a more recent and focused analysis by incorporating the latest research from 2018 to 2023. Unlike previous reviews, which have primarily examined general AT effectiveness [7] or specific disability groups [7], our study uniquely integrates both systematic review and meta-analysis methodologies to provide a comprehensive, data-driven evaluation of AT's impact across diverse learning disabilities. Additionally, we address limitations in prior studies by considering teacher perceptions, infrastructure readiness, and AT's feasibility in real-world educational settings. This study, therefore, offers a timely and critical perspective that contributes to the ongoing discourse on inclusive education policies and evidence-based AT implementation.

II. Rationale

The use of AT has become a significant procedure in the face of "inclusive education". Experimental studies have elaborated their effectiveness in terms of improvement in "Quality of Life (QOL)" indicators. However, even if inclusive education has made significant steps, a lot different challenges remain. These include inadequate teacher training, limited accessible resources, attitudinal barriers, and infrastructural gaps. Furthermore, there is limited quantitative data regarding the utilization of AT in the education sector. We conducted a systematic review and meta-analysis to assess the scope of assistive technology in education, highlighting various types of assistive technology, the problems they address, and the impact they have on fostering inclusive and effective learning environments. The World Health Organization (WHO) forum defines AT as: "Assistive products that maintain or improve an individual's functioning and independence, thereby promoting their well-being". AT empowers individuals to lead healthy, productive, independent, and dignified lives, enabling their engagement in education, the workforce, and civic activities. AT diminishes the reliance on formal health and support services, long-term care, and the efforts of caregivers [8]. Kind of this formal definition is too linked with medical models to define AT, which stress the concept about

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overcome obstacles and improve strength [9]. Hersh and Johnson [10] underline the fact that AT can be better understood in terms of accessibility to different context for people with disability. Actually, on the opposite side, deprived of AT, individuals frequently face exclusion, isolation, and economic hardships, amplifying the repercussions of illness and disability on the individual, their family, and society.

Inclusive education is a paradigm shift that seeks to provide equitable access and opportunities for quality education to all learners, regardless of their diverse backgrounds, abilities, or disabilities. It represents a departure from traditional educational models that segregate students based on their differences. The present-day landscape of inclusive education reflects substantial progress, even if with challenges yet to be fully addressed. Many countries have adopted policies and frameworks that promote inclusive practices, striving to ensure that learners with disabilities receive education in mainstream settings alongside their non-disabled peers. While inclusive education has made significant step, challenges remain. These include inadequate teacher training, limited accessible resources, attitudinal barriers, and infrastructural gaps [11]. Students can benefit from inclusive education in the following ways: (1) accessible learning materials, (2) customized learning, (3) communication aids, and (4) interactive learning platforms.

In practical terms, inclusive education entails modifying teaching methods, curriculum, and classroom environments to accommodate various learning needs. It recognizes that learners with disabilities, varying learning paces, linguistic backgrounds, or socio-economic contexts enrich the educational tapestry. In this inclusive milieu, educators undergo continuous professional development to adapt their pedagogical approaches, recognizing that flexibility and tailored support are fundamental.

Assistive technology enhances inclusive education and this is particularly evident in developing country [11] where there is lack of coordination between government and instructional policies.

The integration of AT in teaching has transformative implications for creating inclusive educational environments. By addressing barriers to learning, AT empowers students with disabilities to actively participate in class discussions, complete assignments, and engage with educational content on par with their peers. Moreover, AT fosters self-reliance and independence, promoting a sense of accomplishment and reducing reliance on external assistance. Creating inclusive learning environments for students at all educational levels is an issue at the forefront of discourse today. In countries like the United States, there are also legal requirements for inclusion at the postsecondary level, as mandated by the Americans with Disabilities Act of 1990 (42 U.S.C. § 12101). Therefore, it is important to investigate all aspects of inclusive learning environments, including how AT can serve the needs of adolescent and adult learners—our focus in this paper.

AT options have proliferated in recent years, due to the greater availability of ever more powerful computers and other forms of technology [12]. Survey studies like Alper and Raharinirina [13] have documented the use of several types of AT accommodations for higher education students with LD: text-to-speech and voice recognition software, outlining programs, and various word-processing-based accommodations.

AT encompasses a wide range of applications that can directly or indirectly impact the level of learning ability in students, as well as improve its provision to deserving population. A few ATs are mentioned in our review. It is important to identify the problem they cater for and the solution they provide to tackle the problem.

1) Text-to-Speech Software: Difficulties faced by visually impaired or dyslexic students in accessing written content with the help of text-to-speech software converts text-based content into synthesized speech, enabling students to listen to their study materials, thus enhancing comprehension and retention.
2) Screen Readers: Visual impairment hindering the interaction with digital interfaces. Using screen readers audibly conveys the content on screens, making digital platforms, documents, and applications accessible to visually impaired learners.
3) Speech Recognition Software: Motor impairments or writing difficulties affecting traditional text-based communication by speech recognition software converts spoken words into written text, facilitating students' ability to express themselves in written form.
4) Captioning and Transcription Tools: Hearing-impaired students facing challenges in comprehending audiovisual content via captioning and transcription tools provide text-based representations of spoken content, ensuring that audiovisual materials are accessible to all learners.
5) Interactive Learning Apps: Diverse learning styles and cognitive differences among students via interactive learning apps offer customized learning experiences, adapting to individual learning preferences and pacing.
6) Electronic Braille Displays: Visual impairment hinders access to Braille content in digital formats using Electronic Braille displays convert digital text into tactile Braille, allowing visually impaired students to access and read digital content.
7) Mind-Mapping Software: Difficulties in organizing and presenting thoughts for students with cognitive challenges can take assistance from a mind-mapping software that helps students visually organize ideas, enhancing comprehension, and aiding in project planning.
8) Alternative Input Devices: Motor impairments prevent traditional keyboard or mouse use. This can be addressed by an alternative input device, such as eye-tracking systems or sip-and-puff devices, enable students to interact with computers and devices through non-traditional means.

III. Materials and Methods

In the current study, we analyzed the use of AT in the field of education. We found primary studies that assessed one of the impacts or implications of AT for students [13, 14], such as devising a speech-recognition software for those who have their hearing impaired, Picture Exchange Communication System (PECS) for emotional recognition in people with complex learning disorders, for example, Autism Spectrum Disorder (ASD) and Asperger Syndrome. The current study aims to analyze the impact of AT on student performance, overall improvement in quality of life as an adjourn to improvement in quality of education via AT. It will also compare the need for AT with its provision, teachers' perspective, and prospects of AT in education.

The aim of this study is to offer insights into the utilization of AT in educational environments, with the goal of facilitating the efficient provision of AT devices and services for students with special educational needs and disabilities. The objectives of the current study are: (1) to assess the scope of assistive technology in the field of teacher involved in AT training programs, (2) to compare the effectiveness of AT in inclusive education with non-AT interventions, (3) to identify the barriers to AT and its provision to the targeted populations, (4) to enhance the efficient provision of AT devices and services for students with special educational needs.

We established the eligibility criteria for studies based on 5 dimensions: Population, Intervention, Comparison, Outcome, and Study (PICOS) design framework, in accordance with the guidelines recommended by the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA).

We included studies where AT was taken into application. We employed the definition of assistive technology as outlined in the Technology-Related Assistance for Individuals with Disabilities Act of 1988, a commonly referenced concept in the literature: "Any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified or customized, that increases, maintains, or improves functional capabilities of individuals with disabilities".

In conducting the meta-analysis, we assessed heterogeneity using both statistical and visual methods to ensure the robustness of our findings. Heterogeneity was quantified using the I^2 statistic, which indicates the proportion of total variation across studies that is due to heterogeneity rather than chance. Following Cochrane guidelines, we interpreted I^2 values as follows: low (0%–40%), moderate (30%–60%), substantial (50%–90%), and considerable (75%–100%). In cases where substantial heterogeneity ($I^2 > 50\%$) was detected, we employed a random-effects model to account for between-study variability, as opposed to a fixed-effects model, which assumes a single true effect size across studies.

Additionally, to further explore sources of heterogeneity, we performed subgroup analyses based on disability type (e.g., hearing impairment vs. learning disabilities) and study design (randomized controlled trials vs. observational studies). We also conducted a sensitivity analysis by sequentially removing studies with high risk of bias to evaluate their impact on the overall effect size. Funnel plots and Egger's regression tests were used to assess publication bias, ensuring that our results were not unduly influenced by selective reporting. These methodological choices allowed us to rigorously control for heterogeneity while maintaining the integrity of the meta-analysis findings.

In order to follow objectives, we located the student population who experience some or any type of Neurodevelopmental disorders, such as Learning Disability (LD) or those who qualify for inclusive education needs. The concept of Neurodevelopmental disorders refers to developmental deficits which may vary from a very specific limitations in learning or cognitive function to global impairments in social skills or intelligence.

Our goal was to locate AT interventions for students with LD in secondary and post-secondary settings; therefore, we searched for studies that primarily included participants who were in Grade 9 or higher or who were 14 years or older.

To be as comprehensive as possible, we included peer reviewed, published studies as well as Ph.D. theses that were available on-line. We included both quantitative and qualitative work. We focused on research published in English, but we did not restrict our search procedure by language, meaning a study in potentially any language could have been included if the English-language papers cited it, or if it was indexed in the search engines we used by English keywords.

In summary inclusion criteria were as follows: (1) peer-reviewed studies or independent reports between 2018 and 2023, (2) studies with abstract and free full-text available, (3) study designs or study protocols that included pre- and post-intervention scores for the analysis, (4) studies that focused on students at secondary or post-secondary levels, (5) only study with quantitative/qualitative study design were included.

Studies where the term disorders took place into keywords were not included. The term does not include learning problems that are primarily the result of visual, hearing, or motor disabilities, of mental retardation, of emotional disturbance, or of environmental, cultural, or economic disadvantage. We did not favor a specific definition and included studies with participants with "learning disabilities" or "learning difficulties" in general, alongside papers where participants had a specific disability usually considered to fall under Learning Disabilities (LDs), like dyslexia. Studies of participants with attention deficits or autism spectrum conditions but no concurrent LDs were not included. Studies where the term "learning disability" was used in a different way, e.g., to refer to general intellectual impairment, were not included. Studies were participants of multiple disabilities were grouped together were likewise not included, unless at least two thirds of the group had a diagnosis of LD. LD frequently co-occurs with other conditions, and thus we did not want to exclude studies with participants who also have further diagnoses. Considering the rapid advancements in assistive technologies, we've opted to exclude studies predating the period between 2018 and 2023.

We restricted our inclusion criteria to studies published between 2018 and 2023 to ensure that our systematic review and meta-analysis reflect the most recent advancements in AT. The field of AT has undergone significant developments in recent years, particularly in areas such as artificial intelligence-driven learning tools, adaptive software, and real-time accessibility solutions. Older studies, while valuable, may not capture the latest technological innovations, implementation methodologies, or shifts in educational policy that influence AT adoption in schools. Moreover, many previous systematic reviews have already covered older research extensively. By focusing on recent literature, our study aims to provide an updated, evidence-based perspective on AT's current effectiveness and challenges in inclusive education.

Other exclusion criteria were linked to most recent studies, study design that were not related to neurodevelopmental issues: (1) study protocols with neither qualitative data, (2) prototype design studies that aimed at developing a new device or interface, (3) case reports and other review studies were also excluded, (4) disorders that are associated with emotional and environmental barriers were not included.

We searched a number of digital databases for relevant literature. These included: PubMed, Google Scholar (multiple methods), Science Direct, Embase, and MedLine. Independent journals and other reporting sources were also included. The "Disability and Rehabilitation: Assistive Technology", "International Journal of Education and Development using Information and Communication Technology (IJEDICT)", "International Journal of Education and Management Engineering", "International Journal of Environmental Research and Public Health", and other independent journals and reports were the source of literature other than databases.

We found a total of 33 studies that were eligible for the inclusion criteria and cover the terms: (("self-help devices"[MeSH Terms] AND "self-help devices"[MeSH Terms] AND "education"[MeSH Terms] AND "teaching"[MeSH Terms]) OR (("self-help devices"[MeSH Terms] OR ("self-help"[All Fields] AND "devices"[All Fields]) OR "self-help devices"[All Fields] OR ("assistive"[All Fields] AND "technology"[All Fields]) OR "assistive technology"[All Fields]) AND ("education"[MeSH Subheading] OR "education"[All Fields] OR "teaching"[All Fields] OR "teaching"[MeSH Terms] OR "teaches"[All Fields] OR "teach"[All Fields] OR "teachings"[All Fields] OR "teaching s"[All Fields]))) AND ((ffrft[Filter]) AND (fha[Filter]) AND (2018:2023[pdat])). Additionally, we inspected the reference lists of the studies selected for the systematic review and the meta-analysis.

A group of 4 researchers searched for literature in peer-reviewed journals and publications in accordance with the inclusion criteria. After a thorough selection of the literature, peer-reviewed journals with a strong impact factor were explored to reduce the risk of publication bias. All selected studies were uploaded to Rayyan.ai screening software, for primary and secondary screening of the literature. The first step was to detect any duplicate studies to prevent predictability in screening. A total of n = 122 duplicates were detected and removed from the original literature search. After excluding another 227 records via automation, a total of n = 74 records were deemed eligible for primary screening. 4 researchers worked as collaborators to "include" or "exclude" eligible studies based on the inclusion and exclusion criteria. A total of 50 studies (n = 381) were considered for the final review and analysis. Studies that did not pass the eligibility for screening were put under "exclusion" or "dispute". We created a team of 4 researchers for study selection, the "disputed" records were forwarded to Principal Investigator (PI) to serve as "tiebreaker" before final inclusion. Exclusion reasons were put forward before excluding a study from literature. Studies were excluded because of (1) wrong population target; (2) study design was not assimilable to quantitave/qualitative research; (3) study measured outcomes not related to this study objective; or (4) we found a high risk of bias. Sometimes, it was a combined effect of multiple reasons for exclusion.

There is sufficient literature published on the impact, effectiveness, nomenclature, barriers, and implications of AT. The quantitative analysis was extracted from studies that identified a problem, presented an AT-enhanced solution, and verified better patient or individual outcomes. It is important to note that we considered the data analysis validated for one of the several outcomes measured in our study.

The total sample size for the selected literature (n = 33) was scrutinized after secondary screening protocol was completed. We used the PRISMA standards to create a PRISMA FLOW DIAGRAM procedure to selected studies from journals and other independent resources (if the reports were available). The PRISMA flow diagram is given in Fig. 1.

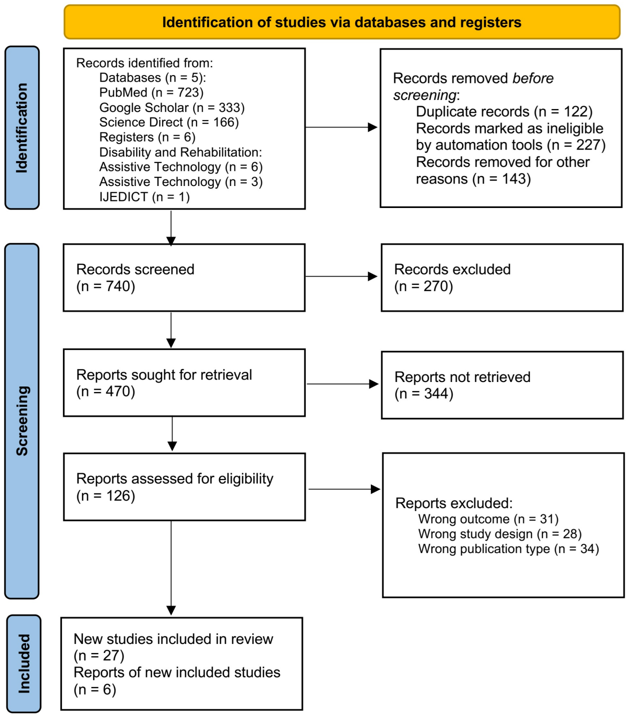

Fig. 1. PRISMA for the selected studies from journals and other independent resources.

After the study selection process was complete, we tabulated the study interventions one-by-one against the study population and the outcomes studied. Only the relevant themes of the outcome were mentioned in the synthesis table.

To mitigate bias in the analysis, we took several measures, including (1) choosing research of high quality and conducting a comprehensive literature review, (2) removing the double standard applied to peer review and informed consent in clinical research and practice, (3) mandating that peer reviewers disclose any conflicts of interest, and (4) substituting standard review articles with meta-analyses. Systematic reviews and narrative reviews were frequently excluded from the literature to maintain the standards of the study. These guidelines detect and remove bias in the study protocol in accordance with Silverman and Smith [15] stages of removing publication bias. All the studies chosen for the meta-analysis were found to have a "low" overall risk of bias. A "traffic light" figure was plotted using this data for randomization. A summary of the Risk of Bias (ROB) was also mentioned for collaborator convenience (Fig. 2).

Intention-to-treat

Uniq Study ID		Experimental	Comparator	Outcome	Weight	D1	D2	D3	D4	D5	Overall
1	Hannah Pimmerton et al. 2023	Assistive Technology	No Assistive Technology	QOL	1	+	+	!	!	+	+
2	Jareen Meinzen-Derr et al. 2021	Assistive Technology	No Assistive Technology	QOL	1	!	+	+	!		+
3	Vijaya K. Gothwal et al. 2018	Assistive Technology	No Assistive Technology	QOL	1	+	+	!	!	+	!
4	Sarah Ko & Linda S. Petty 2020	Assistive Technology	No Assistive Technology	QOL	1	+	+	!	+	+	+
5	Shawn P. Gilroy et al. 2018	Assistive Technology	No Assistive Technology	QOL	1	+	+	!	+	+	!
6	Paul G. Lacava et al. 2016	Assistive Technology	No Assistive Technology	QOL	1	+	+	+	!	+	!

+ Low risk
! Some concerns
- High risk

Fig. 2. A summary of the Risk of Bias (ROB) was also mentioned for collaborator convenience.

- For systematic review: All the studies selected for quality assessment were analyzed for publication bias. All the studies were manually checked for intervention characteristics, population demographics, and outcome domains. All the studies eligible for the analysis were independently selected based on the Cochrane criteria for ROB. We calculated the ROB via the Cochrane Risk-of-Bias (version 2019) online tool [16]. According to the Cochrane protocol, the risk of bias algorithm assessed 5 domains of potential risk of bias. These domains were as follows: (1) Bias arising from randomization procedures; (2) divergence from the intended intervention; (3) absence of outcome data; (4) measurement of the outcome; (5) choice of the reported result. Two researchers decoded all relevant data for risk-assessment.
- For meta-analysis: We sought digital/ online tools for risk-of-bias assessment of the studies selected for the meta-analysis. Cochrane Risk-of-Bias (version 3.5.1) online tool was used to assess 7 domains of risk occurring in the primary studies [ROBv2 Tool]. The risk-of-bias domains that were analyzed for the meta-analysis were as follows: (1) Generating random sequences (potential bias in participant selection), (2) concealing allocation (potential bias in participant selection), (3) ensuring blinding of participants and personnel (potential bias in performance), (4) ensuring blinding of outcome assessment (potential bias in detection), (5) handling incomplete outcome data (potential bias due to attrition), (6) reporting selectively (potential reporting bias), (7) considering other sources of bias. Continuous data was extracted for the statistical meta from 4 out of 13 primary studies. This data measured similar outcomes: substance use and externalizing symptoms. We created a "forest plot" using Review Manager (RevMan version 5.4) for the meta-analysis. Meta-analysis of 4 primary studies was done [16–18]. All the researchers collected comparable and pool-able data for the analytical tool. All the data was available in the form of continuous variables. The data for the meta-analysis is provided in the results section of our study.

IV. Result and Discussion

The systematic analysis encompassed a total sample of 27 studies published in peer-reviewed journals, along with 6 technical reports and 2 study protocols and 7 of these studies used randomization, and 2 used a (quasi)-experimental design to construct a matched comparison group. 1 study used constant-comparative methods, 1 used linear regression analysis, and 4 used mixed-methods approach as well. Sample sizes ranged from as small as $n = 8$ to as large as $n = 11{,}787$. Follow-up data collection time points ranged from 2 weeks to 24 months (2 years). We also reviewed the studies for the systematic review for studies which had unquantifiable data. 87% (29/33) of the studies supported the use of AT for education. However, 13% (4/33) studies revealed little to no effect on student performance on student outcomes.

Our meta-analysis confirms the positive impact of AT in inclusive education, as evidenced by the statistically significant effect sizes observed in the studies reviewed. Specifically, the meta-analysis for AT-based hearing impairment solutions yielded an overall effect size of $Z = 1.12$, Confidence Interval (CI) = 95% (−0.76, −0.31), while the analysis for non-specific learning disabilities demonstrated a significant effect with $Z = 2.91$, CI = 95% (−1.46, −0.28). These findings align with previous systematic reviews [2, 7] that have documented the efficacy of AT interventions in improving student engagement and academic outcomes. Furthermore, our review highlights that 87% of the included studies reported a positive impact of AT, reinforcing its role as an effective educational support tool. However, the remaining 13% of studies reported minimal or no effect, which may be attributed to factors such as limited teacher training and inadequate infrastructure. These findings provide strong empirical evidence supporting the integration of AT in educational settings while also highlighting areas for further investigation.

We tabulated the study outcomes against the variable of interest for all sample sizes. For all the studies selected for the systematic review, the ROB was calculated to be "low", so it does not interfere with the findings of the final analysis.

Effect sizes for combined outcomes were computed by assessing the impact of AT as a continuous variable across four studies, focusing on selected domains of study. The outcomes of each individual study were averaged, and Cohen's d was then calculated using weighted averages across all the studies. Combined outcomes favored the use of assistive technology (Experimental Group) indicating a positive overall impact on quality of life in students with hearing impairment, and those with other learning disabilities (median = 342); the effect size was small per Cohen's conventions and statistically significant.

- For first comparison group: two studies [17, 18] were selected for comparison because of (1) quantitative data was present for analysis and (2) similar outcomes were measured. In the initial comparison group, a language intervention using technology was implemented for children with hearing impairments. The experimental group underwent computerized speech training, whereas the control group did not receive any such intervention.

Forest plot for the 2 studies was plotted using continuous data. A random-effects model was selected to calculate the deviation and differences in the Mean (M) and Standard Deviation (SD) using the Standard Mean difference (SMD) scale. We calculated the CI (95%) on the horizontal axis; while the ‘point estimation’ was represented by green squares on the plot. The total sample size (n = 33) changed significantly in the experimental groups. The central vertical line refers to a state of “no effect”. The forest plot presented a concise overview of quantitative data from each study and offered an estimated overall quantitative value representing the combined effects across all studies. The overall effect size was calculated in terms of Cohen’s d which was found to be $d = 1.12$, CI = 95% (−0.76, −0.31). The individual effect size was found to be significant for both the studies. The heterogeneity was calculated to be: $Tau^2 = 2.49$; $Chi^2 = 18.33$, $df = 1$ ($p < 0.0001$); $I^2 = 95\%$. The individual effects of all the studies favored the experimental group. SMD was found to be SMD = −2.45, with a CI of 95% (−3.28, −1.62) for the study conducted [17]; whereas SMD was −0.16 with CI (−0.80, 0.49) [18]. The current study conformed to the analysis laid down by another meta-analysis [2]. On the other hand, all the other studies favored the use of assistve technology. The forest plot for the meta-analysis is given in Fig. 3.

	Favours AT			Favours Non-AT				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Jareen Meinzen-Der 2021	2.65	2.45	20	8.07	1.86	21	49.3%	-2.45 [-3.28, -1.62]	2021
Hannah Pimperton 2023	6.47	2.61	19	6.83	1.76	18	50.7%	-0.16 [-0.80, 0.49]	2023
Total (95% CI)			**39**			**39**	**100.0%**	**-1.29 [-3.54, 0.96]**	

Heterogeneity: Tau² = 2.49; Chi² = 18.33, df = 1 (P < 0.0001); I² = 95%
Test for overall effect: Z = 1.12 (P = 0.26)

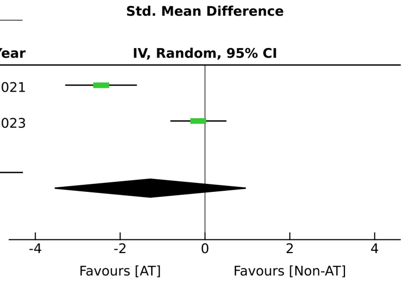

Fig. 3. The forest plot for the meta-analysis.

- For the second comparison group: two studies [16, 17]. compared the outcomes of QOL in students with non-specific LDs. In one study, the effectiveness of assistive technology in instructing emotion recognition to children with Asperger Syndrome was examined, while in another intervention (Pilot Study), a PECS was developed for facial recognition to enhance emotional regulation.

Forest plot for the 2 studies was plotted using continuous data. A similar random-effects model was selected to calculate the deviation and differences in the M and SD using the SMD scale. This forest plot summarized quantitative data about each study and provided an estimated overall quantitative value for all the combined effects. The overall effect size was calculated in terms of Cohen’s d which was found to be $d = 2.91$, CI = 95% (−1.46, −0.28). The individual effect size was found to be significant for both the studies. The heterogeneity was calculated for be $Chi^2 = 0.56$, $df = 1$ ($p < 0.045$) and $I^2 = 16\%$. The individual effects of all the studies favored the experimental group. SMD was found to be SMD = –0.56, with a CI of 95% (−1.56, 0.45) for the study conducted by Lacava *et al.* [19] whereas SMD was −1.03 with CI = 95% (−1.75, −0.31). The forest plot for the meta-analysis is given in the figure below (Fig. 4).

	Favours AT			Favours Non-AT				Std. Mean Difference	
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	Year
Paul G. Lacava 2016	29.875	5.167	8	32.75	4.559	8	34.0%	-0.56 [-1.56, 0.45]	2016
Shawn P. Gilroy 2018	37.32	9.74	17	48.88	12.02	17	66.0%	-1.03 [-1.75, -0.31]	2018
Jareen Meinzen-Der 2021	0	0	0	0	0	0	0.0%	-3.65 [-4.68, -2.62]	2021
Hannah Pimperton 2023	0	0	0	0	0	0	0.0%	-0.16 [-0.80, 0.49]	2023
Total (95% CI)			**25**			**25**	**100.0%**	**-0.87 [-1.46, -0.28]**	

Heterogeneity: Tau² = 0.00; Chi² = 0.56, df = 1 (P = 0.45); I² = 0%
Test for overall effect: Z = 2.91 (P = 0.004)

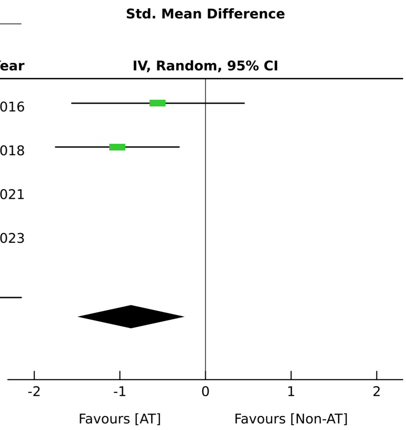

Fig. 4. The forest plot for the meta-analysis.

The reported Cohen’s d values and confidence intervals provide a meaningful measure of AT’s effectiveness in educational settings. In our meta-analysis, we observed an effect size of $d = 1.12$ (CI = 95% [−0.76, −0.31]) for AT interventions targeting hearing-impaired students and $d = 2.91$ (CI = 95% [−1.46, −0.28]) for those addressing learning disabilities. These values indicate a strong practical impact, as per Cohen’s conventional benchmarks (small:

$d = 0.2$, medium: $d = 0.5$, large: $d = 0.8$). The findings from this study are noteworthy, indicating that AT, such as smartphone and tablet applications, could provide children with reading impairments an equitable learning environment in school compared to their peers without reading difficulties [19]. Such technology could potentially enhance the process of acquiring information, subsequently boosting motivation to learn and fostering an increased interest in reading activities. AT has shown broader benefits for its users by helping them avoid the stigma often associated with leaving the classroom for special education services.

To better understand the practical implications of these effect sizes, it is essential to translate them into concrete educational outcomes. A Cohen's d of 1.12 for hearing-impaired students represents a large effect, suggesting substantial improvements in areas such as phonological awareness or reading comprehension. In practical terms, this might correspond to a shift from the 25th to the 75th percentile in performance—indicating significant academic gains, increased classroom participation, and greater autonomy in learning activities.

Likewise, the effect size of $d = 2.91$ for students with learning disabilities indicates an exceptionally strong effect. This may reflect meaningful improvements in emotional recognition, communication skills, or executive functioning, depending on the specific intervention used. In a classroom context, this can lead to enhanced student engagement, better peer interaction, and more consistent academic performance.

These findings underline not only the statistical relevance of AT interventions but also their tangible impact on educational practice, supporting their integration into inclusive teaching strategies and policy development.

While the utilization and efficacy of AT in Inclusive Education (IE) are widely acknowledged, there exist barriers and constraints in its implementation. Silverman and Smith [15] emphasized that when the need for AT is not identified early or adequately, education systems must be prepared to collaborate with other agencies to identify, assess, and provide the required AT. This provision should extend beyond educational use to support comprehensive and inclusive access. The study also underscored the critical role education systems play in identifying AT needs in students across all educational levels at an early stage.

Systematic reviews often lack sufficient quantitative data on AT interventions due to challenges such as difficulty in matching appropriate sample sizes and the varying needs of students with learning disabilities. The diversity in students' learning profiles, the individualized nature of AT interventions, and the complexity of measuring long-term outcomes make it challenging to standardize data across studies. Additionally, differences in how AT is implemented across educational settings further complicate the collection of consistent and comparable quantitative data.

A prior study, conducted in 2017, conducted an extensive meta-analysis on assistive technology interventions designed for adolescents and adults with learning disabilities. The study by Gilroy *et al.* [20] carefully considered student demographics, aiding in the identification of targeted interventions for students experiencing specific LDs. The research explored various interactive interventions to discern the outcomes for students utilizing AT.

Among these interventions, there were interventions specifically targeting word processing that emphasized various features of word processors, such as spell check or grammar check. The use of word processing appeared to result in improved writing outcomes, frequently with substantial effect sizes. Four studies employing a similar outcome metric, error rates, demonstrated a significant positive effect in the meta-analysis. Studies focusing on speech-to-text interventions were fewer and exhibited considerable heterogeneity, despite using the same software. Despite the variations, these studies tended to report positive effects, suggesting the need for further exploration of this type of AT and its availability for students.

The ultimate analysis further suggested that contemporary word processors, with all their features activated, should be utilized as a control condition in future studies. This would serve as a baseline against which other AT interventions can be measured, similar to the "treatment gold standard" in medical intervention trials. While Dragon software is utilized for speech-to-text analysis, there were fewer and, overall, quite diverse studies, preventing the production of a meta-analysis due to insufficient information. Nevertheless, the studies tended to report positive effects. This meta-analysis is akin to the current study, where various outcomes were examined to evaluate the use of AT in education. Our investigation incorporated PECS, computerized speech-training, mobile applications, and mind-mapping software to reveal student performance outcomes. The overall combined effect in our studies also supported the practicality and suitability of AT for both teachers and students requiring secondary forms of care, as well as those previously diagnosed with a learning disability.

AT is more commonly utilized for non-educational needs and requirements of people who experience clinical and non-clinical issues. It ranges from speech-training in the deaf to augmented wheelchair training [1] for people with disabilities. In the research conducted by Meinzen-Derr *et al.* [21], the investigators designed and assessed a computerized speechreading training program through a randomized controlled trial. The primary objectives were to ascertain (1) the feasibility of training speechreading in deaf children and (2) whether speechreading training leads to enhancements in phonological and reading skills. 66 deaf children aged 5 to 7 were randomly assigned to either speechreading or math training groups. Each training program consisted of daily 10-minute sessions, four days a week, over a period of 12 weeks, approximately equivalent to three months. Children were initially assessed for cognition level and literacy status. The study found statistically significant gains in the speechreading training group on one of the secondary outcome measures of speechreading, i.e., vocabulary production, audiovisual speech production, phonological awareness, and letter-sound knowledge. However, the primary outcome (speech-reading) revealed a weak association. According to the study proposed by Meinzen-Derr *et al.* [21], the overall effect size ($Z = 1.26$, $p < 0.0001$) was found to be significiant when AT was employed as an intervention to help deaf children. We deduced that speech-training is a trainable skill in deaf children, however broader literacy programs and long commitment regimens are required to produced significant results. The comparative study carried out by Meinzen-Derr *et al.* [21] pointed out that children who are Deaf or Hard of Hearing (DHH) frequently experience persistent delays in abstract language development, even with early identification and interventions. To address this issue, the Technology-Assisted Language Intervention (TALI) was created. TALI integrates augmentative and alternative communication technology into a speech-language therapy model with the aim of supporting language learning in this particular population. The study objective was to evaluate the effect of TALI on spoken language skill of students with DHH. Children aged 3 to 12 years with mild to profound bilateral hearing loss were enrolled in a single-blind randomized controlled trial. The experimental group was provided TALI and the control group received Treatment as Usual (TAU). As a result, children in the TALI group, compared with those in the TAU group, had significantly greater increases in the length of phrases they used to express themselves. The finding conforms to our data. The conclusive evaluation in this study serves the purpose of alleviating enduring language delays, with the ultimate objective of enhancing lifelong outcomes and fostering independence across various environments.

The remaining two Refs. [15, 18] focused on the evaluation of emotional recognition and overall performance.

In the study by Higgins *et al.* [18], the effectiveness of a free and open-source app for instructing social and communicative behavior in children with ASD was compared to conventional methods using picture cards. Picture card approach is an alternative form of Augmented and Alternative Communication (AAC) [22]. This study indicated that high-tech and low-tech AAC approaches resulted in significant improvements in communication, which highlights the need for AT in education. Similarly, another Randomized Controlled Trial (RCT) conducted by Biggs *et al.* [23] assessed the implications of using an emotional recognition software for students and its impact on their overall performance. The research endorses the utilization of mind mapping software in education, highlighting several advantages for students, including (1) Individual use by high-functioning students to learn Emotion Recognition (ER) skills, (2) applicability in various contexts, such as classroom or home settings, (3) potential use by students with Autism Spectrum Condition (ASC) and their typically developing peers for fostering relationships, through activities like collaborative games or joint exploration of emotions, (4) incorporation into therapeutic settings, such as speech-language or counseling sessions, as well as individual or group social skills sessions, (5) consideration for teachers, counselors, and mentors to address specific issues, like aiding students in understanding peer emotional reactions, (6) adaptability for students with cognitive impairments to assist in social skill instruction, (7) structured routines can be established around the use of mind mapping software, aiding students with difficulties in organization, time management, and adherence to routines. For instance, creating a schedule can indicate when the computer may be used, and timers can signify the remaining time.

A study conducted by Adebayo and Ayorinde [24] and another by Gothwal *et al.* [25] hypothesized that students with low vision have better performance outcomes when tablets and computers are made feasible. The feasibility and ease of access to AT was the primary outcome studied in this trial. Mobile devices, like tablet computers, have gained widespread popularity as mainstream tools and are also integrated into some educational settings. However, there is a lack of sufficient quantitative data on the use of tablets and computers to support students with low vision. To address this gap, a randomized multicenter pilot trial was carried out in school environments in the UK and India. This study aligns with findings from Carvalho *et al.* [26], indicating that irrespective of geographical location, children and young individuals with low vision reported using tablet computers daily at school and found them easily accessible.

The subject of inclusive education is often studied along AT. The interdependence and incorporation of AT in inclusive classrooms have subtle implications and the need-for-application is ever-increasing. Zilz and Pang [27] developed a study that evaluated the application of AT in inclusive education, and the ease-of-access to AT, and barriers and limitations in these settings. Researchers studying school-aged children have universally concluded that the integration of AT would be advantageous for children with disabilities. However, there is a consensus among these researchers that teachers lack the necessary preparation to effectively incorporate advanced technology into the classroom. Additionally, the study suggests that preschool-aged children with physical disabilities may be too young to independently utilize advanced technology [28]. The study outlines the following indications for the use of AT in these settings:

1) Students with severe disabilities often experience limited interactions with same-age peers. AT can serve as a tool to enhance the quality and quantity of these interactions among young students.
2) To sustain a rehabilitation program, student commitment is essential, fostering the development of recreational skills that can subsequently translate into classroom skills through engaging and entertaining activities.

Earlier investigations, such as those conducted by Lindeblad *et al.* [7] and Mortenson *et al.* [8], have employed mobile applications tailored for students with reading and writing challenges to evaluate the integration of AT within the classroom. One of the most profound implications of assistive technology is its ability to promote inclusivity within educational environments. Traditionally, individuals with learning disabilities have faced numerous barriers to accessing educational materials and participating fully in classroom activities. However, assistive technology serves as a catalyst for inclusion by providing equitable access to learning resources and leveling the playing field for all students. Specifically, reading and writing applications, equipped with Text-To-Speech (TTS) and Speech-To-Text (STT) functionalities, were designed to serve as AT for students with reading difficulties. The outcomes demonstrated variations in how teachers perceived the use of these apps for text-based interactions, influencing student motivation and autonomy in learning through text. These findings suggest that students facing reading challenges can effectively leverage AT for both assimilating text (i.e., reading) and expressing text (i.e., writing). The qualitative assessment in this research focused on evaluating the following aspects: (1) differences in the capability to comprehend and convey information, (2) development of written language skills, (3) variations in motivation and autonomy, (4) the requirement for supportive assistance, and (5) the competence of teachers. The study's findings led to the conclusion that AT holds the potential to enhance participation in regular education settings. A comparable research design, a pilot RCT, was employed to investigate the potential transfer effects on reading ability in children facing reading difficulties following a systematic intervention that aimed to train and compensate for reading deficiencies using applications on smartphones and tablets [7]. The study demonstrated that the use of AT can lead to sustained positive effects on reading ability even one year after the interventions concluded. This implies that the reading proficiency of children facing difficulties can potentially follow a more typical trajectory of skill development, thanks to the integration of assistive technology into educational settings which has been shown to yield positive outcomes for students with learning disabilities.

The findings from this study indicate that the benefits of AT in education significantly outweigh its challenges, particularly in enhancing accessibility, engagement, and learning outcomes for students with disabilities. Our meta-analysis demonstrated that AT interventions led to measurable improvements in student performance, particularly in hearing-impaired students ($Z = 1.12$, CI = 95% [−0.76, −0.31]) and those with learning disabilities ($Z = 2.91$, CI = 95% [−1.46, −0.28]). These results align with previous studies that highlight AT's effectiveness in fostering independence and reducing educational barriers [2, 18]. However, despite these benefits, certain challenges persist. The primary obstacles include insufficient teacher training, limited accessibility of AT resources, and attitudinal barriers toward technology adoption in classrooms. Our review found that 13% of studies reported little to no effect of AT on student outcomes, largely due to inadequate implementation strategies and lack of educator preparedness. Additionally, infrastructure limitations—especially in developing countries—pose a barrier to equitable AT access [29, 30]. While these challenges exist, they are largely surmountable through strategic policy interventions and improved teacher training programs. Investing in professional development, increasing institutional support for AT integration, and refining accessibility policies can significantly enhance AT's impact. Thus, the collective evidence suggests that the advantages of AT far outweigh its limitations, provided that appropriate implementation strategies are in place.

The results of this study highlight the transformative potential of AT in real-world classrooms, reinforcing its role in fostering inclusive education. By improving accessibility, AT allows students with disabilities to engage more effectively in learning, enhancing their academic performance and fostering greater independence. The significant effect sizes observed in our meta-analysis indicate that AT not only assists students but actively contributes to better educational outcomes, particularly for those with hearing impairments and learning disabilities. From a policy perspective, these results advocate for stronger initiatives to enhance AT accessibility in schools. Aligning with inclusive education frameworks, investing in AT not only ensures compliance with accessibility mandates but also contributes to long-term educational benefits, including reduced dropout rates and improved student self-sufficiency. While financial and logistical barriers persist, the evidence suggests that the benefits of AT outweigh these challenges, reinforcing its value as a fundamental tool in modern educational settings.

Although the current study conformed to previous studies and provided a quantitative analysis for the variables under study, the study had certain limitations. First, we did not check for within-group effect sizes for different sample sizes. The student samples were not analyzed based on the demographic data; we assumed that age, gender, and ethnicity were not the moderators for our final analysis. Multiple studies have shown that changing the demographic data for studies can alter the results. Moreover, many assistive devices used in an experimental study had little to no impact on overall performance. It is crucial to generate quantitative summaries of the effectiveness of AT in adolescent and adult populations. This evidence-based approach can be employed to advocate for enhanced and higher-quality support in secondary and postsecondary education.

The journey through the landscape of AT in education is one marked by both promising advancements and persistent challenges. As highlighted in the comprehensive review, AT has emerged as a beacon of inclusivity, offering equitable learning opportunities for students with reading impairments, speech and hearing difficulties, autism spectrum disorder, and low vision, among other disabilities. From sophisticated speech-to-text software to user-friendly tablet applications, AT has demonstrated its transformative potential in enhancing academic performance, social interactions, and emotional recognition skills among diverse student populations. However, amid the optimism, lies the sobering reality of implementation barriers and insufficient quantitative data to guide tailored interventions. The meta-analyses conducted shed light on the effectiveness of specific AT interventions, such as word processing and speech-training programs, yet gaps persist in understanding the nuanced needs of individual learners. While contemporary word processors set a benchmark for future studies, there remains a call for standardized evaluation frameworks akin to medical intervention trials. Moreover, the pivotal role of educators in facilitating AT integration cannot be overstated. As the frontline ambassadors of inclusive education, teachers require adequate training and support to harness the full potential of AT tools within the classroom. Preschool settings, too, present unique challenges and opportunities, underscoring the importance of early intervention and tailored approaches to suit the developmental needs of young learners with disabilities.

V. Conclusion

Looking ahead, the future of AT in education lies in collaborative efforts to bridge the gap between research and practice. Multidisciplinary partnerships between educators, technologists, healthcare professionals, and policymakers are essential to drive innovation, address implementation barriers, and ensure equitable access to AT for all learners.

By harnessing the power of technology as a catalyst for inclusivity, we can pave the way towards a more diverse, accessible, and empowering educational landscape for generations to come. The future of inclusive education is intricately bound to the advancement of assistive technology. As technology evolves, so too will the tools and solutions tailored to diverse learning needs. This symbiotic relationship holds the promise of a more inclusive, equitable, and empowering educational landscape. However, achieving this vision requires ongoing research, development, and collaboration among educators, technologists, policymakers, and stakeholders from diverse backgrounds. In addition to technological advancements, fostering a culture of inclusivity within educational institutions is essential. This involves promoting awareness, understanding, and acceptance of diverse learning styles and abilities. Educators must be equipped with the knowledge and resources to effectively integrate assistive technology into their teaching practices, ensuring that all students have equal opportunities to succeed. Furthermore, addressing systemic barriers to access is critical for realizing the full potential of assistive technology in education. This includes ensuring affordability, availability, and usability of assistive devices and software for students, educators, and families. Collaborative efforts between governments, educational institutions, and industry stakeholders are necessary to develop policies and initiatives that promote equitable access to assistive technology resources. Moreover, ongoing research and development efforts should prioritize the creation of innovative solutions that address the evolving needs of learners with disabilities. This may involve leveraging emerging technologies such as artificial intelligence, virtual reality, and augmented reality to create immersive and interactive learning experiences. Additionally, interdisciplinary collaborations between researchers, engineers, psychologists, and educators can lead to the development of more effective assistive technology interventions and strategies.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, LT and GAT; methodology, formal analysis, writing—original draft preparation, writing—review and editing, supervision, project administration, GAT; software, VB; validation, GAT, CE and SI; investigation, GP; resources, data curation, SI; visualization, AP; all authors had approved the final version.

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