THE IMPACT OF ASSISTIVE TECHNOLOGIES ON DEAF STUDENTS' LEARNING

L'IMPATTO DELLE TECNOLOGIE ASSISTIVE SULL'APPRENDIMENTO DEGLI STUDENTI SORDI

Francesca Latino
Pegaso University
francesca.latino@unipegaso.it

Francesco Tafuri
Niccolò Cusano University
francesco.tafuri@unicusano.it

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ABSTRACT
This study explores the role of assistive technologies in the implementation of physically active breaks as an innovative educational tool to support bimodal bilingualism in schools. The proposed approach not only promotes the learning and involvement of deaf students, but also proves to be beneficial for hearing students, promoting a more inclusive and collaborative school environment. The combined use of technology and active breaks allows for the development of broader communication skills, raising awareness of sign language among hearing students and improving their ability to learn in multimodal contexts. This method encourages cooperation between students with different abilities, fostering a more equitable and enriching interaction for everyone. The results show that the combined use of technology and active breaks contributes to more effective and inclusive learning. The implementation of these strategies requires specific training for teachers and investments in accessible digital infrastructure, in order to promote a fair and innovative educational environment.

Questo studio esplora il ruolo delle tecnologie assistive nell'implementazione delle pause attive come strumento educativo innovativo a supporto del bilinguismo bimodale nelle scuole. L'approccio proposto non solo promuove l'apprendimento e il coinvolgimento degli studenti sordi, ma risulta vantaggioso anche per gli studenti udenti, favorendo un ambiente scolastico più inclusivo e collaborativo. L'uso combinato di tecnologia e pause attive consente lo sviluppo di competenze comunicative più ampie, aumentando la consapevolezza della lingua dei segni tra gli studenti udenti e migliorando la loro capacità di apprendere in contesti multimodali. Questo metodo incoraggia la cooperazione tra studenti con abilità diverse, promuovendo un'interazione più equa e arricchente per tutti. I risultati mostrano che l'uso integrato di tecnologia e pause attive contribuisce a un apprendimento più efficace e inclusivo. L'attuazione di queste strategie richiede una formazione specifica per gli insegnanti e investimenti in infrastrutture digitali accessibili, al fine di promuovere un ambiente educativo equo e innovativo.

KEYWORDS
Innovative Teaching; Special Pedagogy; Teaching-Learning Process.
Didattica innovativa; Pedagogia Speciale; Processo di insegnamento-apprendimento

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Introduction

Education is a fundamental right for all individuals, regardless of their abilities. However, for deaf students, traditional learning environments present significant challenges due to communication barriers and limited access to auditory-based instruction (Chen, & Wang, 2022). Traditional teaching methods often fail to address the specific needs of deaf students, limiting their learning opportunities (Nguyen, & Patel, 2024).

Bimodal bilingualism, which combines sign language with written and spoken language, has emerged as an essential pedagogical strategy to enhance learning outcomes for deaf students. This approach acknowledges the importance of sign language as the primary mode of communication for many deaf individuals while also promoting literacy and engagement with spoken and written language. Studies have shown that integrating bimodal bilingualism in classroom settings improves comprehension, cognitive flexibility, and social interaction among students (Marschark & Hauser, 2012; Mayer & Leigh, 2010).

Moreover, in recent decades, the implementation of assistive technologies has played a crucial role in bridging this gap, providing deaf students with new opportunities to access educational content effectively (Johnson, & Stevens, 2023). With the advancement of assistive technologies, new approaches to education are emerging, fostering a more inclusive and equitable learning environment.

Research on assistive technologies in education has demonstrated their effectiveness in enhancing learning accessibility and engagement for students with disabilities (Baker, & Green, 2022). Technologies such as real-time captioning, speech-to-text applications, and interactive learning platforms have been widely adopted to support deaf students in mainstream classrooms (Swanwick & Marschark, 2010).

One of the most effective assistive technologies for deaf students is real-time captioning, which provides instant text representation of spoken content (Martinez, & Evans, 2023). Studies by Stinson et al. (2011) and Elliot et al. (2016) indicate that real-time captioning significantly improves comprehension and retention of information among deaf students, enabling them to follow lectures more effectively. Additionally, interactive whiteboards and visual-based learning tools have been shown to facilitate multimodal learning, engaging both deaf and hearing students in collaborative educational activities (Antia et al., 2012).

Another innovative approach that has gained traction in recent years is the integration of physically active breaks into educational settings. These breaks involve structured movement-based activities that not only promote physical health but also enhance cognitive performance and social engagement (Donnelly et al., 2016). Research indicates that active breaks can be particularly beneficial for deaf students, as they create opportunities for non-verbal communication and reinforce the learning of sign language through kinesthetic experiences (Goh et al., 2019).

Despite the growing body of research on assistive technologies and bimodal bilingualism, limited studies have explored the intersection of these elements with physically active breaks in educational settings. This study aims to address this gap by examining how the integration of assistive technologies and active breaks can enhance learning outcomes for deaf students while fostering inclusivity for hearing students.

By leveraging digital tools such as captioning software, interactive educational applications, and movement-based learning strategies, this research seeks to provide a comprehensive framework for improving educational accessibility and engagement. Moreover, the study aims to highlight the role of teachers in implementing these strategies and the need for professional development programs to support their integration effectively.

This study investigates the impact of assistive technologies and physically active breaks in supporting bimodal bilingualism in schools, emphasizing the benefits for both deaf and hearing students.

Therefore, this study is guided by the following research questions:

1. How do assistive technologies contribute to the learning experiences of deaf students in a bimodal bilingual educational setting?
2. What are the cognitive and social benefits of integrating physically active breaks into classrooms for both deaf and hearing students?
3. What challenges do educators face in implementing these strategies, and what resources are needed to support their effective adoption?

1. Method

1.1. Study design

This research follows a quasi-experimental design, incorporating both pre-test and post-test assessments to evaluate the effectiveness of assistive technologies and physically active breaks. The study is divided into three main phases:

1. Pre-Intervention Phase: Baseline data collection through surveys, interviews, and classroom observations to assess initial levels of engagement, comprehension, and interaction among students.

2. Intervention Phase: Implementation of assistive technologies, such as real-time captioning and interactive digital tools, along with structured physically active breaks. These interventions were integrated into the regular curriculum over a period of 12 weeks.

3. Post-Intervention Phase: Data collection following the intervention using the same methods as in the pre-intervention phase, allowing for a comparative analysis of changes in learning outcomes and social interaction.

The study was conducted in accordance with the ethical guidelines set forth by the Declaration of Helsinki.

1.2 Participants

A specific school located in Southern Italy was selected for this study due to its established presence of deaf students within an inclusive educational setting. Within this school, two classes that included deaf students were identified. One of these classes was designated as the experimental group, where assistive technologies and physically active breaks were implemented, while the other class served as the control group, following a traditional learning approach. This recruitment strategy ensured that both groups had similar demographic and academic characteristics, allowing for a balanced comparison of the intervention's effects.

Participants were selected based on the following inclusion and exclusion criteria:
Inclusion Criteria:

- Enrollment in an inclusive school setting.
- Age between 10 and 16 years.
- Deaf students using sign language as a primary means of communication.
- Hearing students with no prior formal exposure to sign language.
- Willingness to participate in the study with parental consent.

Exclusion Criteria:

- Students with additional cognitive or physical disabilities that might impact their ability to participate in physically active breaks.
- Students with previous formal training in sign language.
- Lack of parental consent for participation.

Participation in the study was entirely voluntary. All teachers and students involved, along with their respective parents, provided informed consent and agreed to take part in the research. Therefore, A sample of 50 students (8 deaf and 42 hearing) participated in the study. The sample was divided into two groups:

- Experimental Group (n=25): Students exposed to assistive technologies and physically active breaks.
- Control Group (n=25): Students following the traditional learning approach without assistive technologies or active breaks.

1.3 Intervention Protocol

The intervention was designed to span 12 weeks, ensuring a gradual and structured implementation of assistive technologies and physically active breaks to support bimodal bilingualism in an inclusive educational setting. The protocol was divided into four progressive phases, allowing for adaptation and optimization based on student engagement and feedback.

Phase 1: Teacher Training and Preparation (Weeks 1-2)
Before the intervention began, teachers and support staff underwent a two-week training program to develop the necessary skills for integrating assistive technologies and physically active breaks. The training included:

- Workshops on assistive technologies: Hands-on practice with real-time captioning software, interactive whiteboards, and sign language learning apps.
- Bimodal bilingualism strategies: Instruction on effectively combining sign language with written and spoken language in daily lessons.
- Physically active break planning: Guidelines on incorporating movement-based learning activities that foster communication and engagement.

At the end of this phase, teachers conducted trial lessons using assistive technologies and physically active breaks to familiarize students with the new tools and methodologies.

Phase 2: Gradual Implementation of Assistive Technologies (Weeks 3-6)
During this phase, assistive technologies were incrementally introduced into classroom activities to allow students and teachers to adapt smoothly. The tools used included:

- Real-time captioning software for transcriptions of spoken content.
- Interactive whiteboards for multimodal teaching, integrating visuals, written words, and sign language.
- Educational applications designed to enhance literacy and communication in a bilingual environment.

Each week, a new digital tool or feature was incorporated, ensuring that students and teachers had sufficient time to adjust before adding further elements.
Additionally, teachers facilitated collaborative learning activities, where hearing and deaf students worked together using assistive technologies to promote inclusivity.
Weekly monitoring sessions were conducted, collecting feedback from teachers and students to adjust the implementation based on real-time observations.

Phase 3: Integration of Physically Active Breaks (Weeks 7-10)

Once students were accustomed to assistive technologies, the intervention expanded to include structured physically active breaks lasting 10-15 minutes each school day. These activities were designed to reinforce learning while promoting interaction between deaf and hearing students.
The active breaks followed a progressive structure:
Week 7: Introduction to Movement-Based Learning

- Simple activities linking sign language to body movement (e.g., spelling words while jumping).
- Individual tasks encouraging students to associate signs with physical gestures.

Week 8-9: Interactive Group Activities

- Partner-based exercises where hearing students followed sign language instructions.
- Small-group problem-solving tasks incorporating movement and non-verbal communication.

Week 10: Full Integration with Curriculum

- Subject-specific active breaks, such as using gestures to represent mathematical operations or historical events.
- Role-playing scenarios reinforcing bilingual learning through kinesthetic engagement.

Throughout this phase, teachers and researchers documented student progress in engagement, communication skills, and collaborative learning.

Phase 4: Evaluation and Optimization (Weeks 11-12)

The final phase focused on assessing the effectiveness of the intervention and making necessary adjustments.
Week 11: Data Collection

- Post-test evaluations measuring academic performance, comprehension, and communication skills.
- Student and teacher feedback collected through surveys and interviews.

- Classroom observations assessing engagement, social interaction, and inclusivity.

Week 12: Analysis and Reporting

- Comparison between pre- and post-intervention results in both the experimental and control groups.
- Adjustments and recommendations for optimizing the approach in future implementations.
- Final teacher training session to discuss best practices and long-term sustainability of assistive technologies and physically active breaks.

This 12-week protocol ensured a gradual, well-monitored implementation, providing sufficient time for adaptation, optimization, and evaluation. The combination of assistive technologies and physically active breaks created a more inclusive and interactive learning environment, benefiting both deaf and hearing students.

2. Measures

To assess the impact of assistive technologies and active breaks on the learning and inclusion of both deaf and hearing students, three key instruments were used: the Reading and Writing Test (CELF-5), the Classroom Communication and Inclusion Scale (CCIS), and a test specifically designed to measure progress in bimodal bilingualism acquisition. These tools were administered both at the beginning (pre-test, weeks 1-2) and at the end (post-test, weeks 11-12) of the intervention program, allowing for a comparison of results before and after the implementation of innovative teaching strategies.

One of the primary instruments used to assess students' linguistic skills was the Reading and Writing Test from the CELF-5 (Clinical Evaluation of Language Fundamentals, 5th Edition). This widely used tool in educational research evaluates students' reading and writing abilities through targeted exercises in text comprehension, key word identification, and written production. To ensure full accessibility for deaf students, the test was adapted using video instructions in sign language and, where necessary, allowing responses in video format, which were later transcribed for evaluation. The main goal of this test was to verify any progress in reading and writing skills, which are essential for the academic success of deaf students in a bimodal bilingual context.

Alongside linguistic competencies, particular attention was given to assessing students' perception of classroom inclusion and communication dynamics using the

Classroom Communication and Inclusion Scale (CCIS). This tool, structured as a Likert-scale questionnaire with five response options, was administered to all students, both deaf and hearing, to analyze their comfort level in communication, interaction with peers, and perception of being actively engaged in learning activities. Questions such as *"I feel comfortable using sign language to communicate with my classmates"* or *"My teachers use tools that help me understand lessons better"* provided valuable insights into inclusion dynamics and the effectiveness of assistive technology use. This test was crucial for understanding how the adopted strategies contributed to fostering a more equitable and collaborative learning environment.

Finally, to specifically evaluate progress in bimodal bilingualism acquisition, an adapted test was developed to assess both receptive and expressive skills in sign language and written or spoken language. The test was divided into three main sections: in the first, students demonstrated their ability to understand a written text or a video in sign language and respond to comprehension questions; in the second, their expressive skills were evaluated through both written production and the use of sign language; finally, the third section measured their ability to switch fluidly between linguistic codes, for example, by translating a written sentence into sign language or vice versa. This assessment provided a detailed analysis of how integrating active breaks and assistive technologies influenced students' communication abilities, promoting multimodal learning and greater awareness of bimodal bilingualism, even among hearing students.

The combined use of these three instruments allowed for the collection of comprehensive and in-depth data on the effectiveness of the intervention, offering a clear view of the benefits of assistive technologies and inclusive educational strategies implemented throughout the twelve-week study.

2.2 Statistical Analysis

In this study, various statistical tests were applied to evaluate the effectiveness of the intervention based on the integration of assistive technologies and active breaks in the educational context of both deaf and hearing students. The statistical analysis was conducted using a comparative approach between the experimental group, which participated in the intervention, and the control group, which followed the traditional teaching method.

To assess the improvement in linguistic and communication skills, pre- and post-intervention comparison tests were conducted within each group. Specifically, to compare the scores obtained before and after the intervention by participants in both the experimental and control groups, the paired-samples t-test was used. This test allowed us to identify significant changes in students' performance concerning the three evaluation tools adopted: the Reading and Writing Test (CELF-5), the Classroom Communication and Inclusion Scale (CCIS), and a test measuring progress in bimodal bilingualism acquisition.

To determine whether the intervention had a significantly different effect between the experimental and control groups, an independent-samples t-test was conducted, comparing post-intervention scores between the two groups. Additionally, to control for potential influences of initial scores on the final differences between groups, an Analysis of Covariance (ANCOVA) was performed, allowing for a more precise examination of the specific effect of the intervention.

To evaluate the progress over time and between the two groups, a Repeated Measures Analysis of Variance (Repeated Measures ANOVA) was applied. This test allowed us to explore interactions between the time factor (pre- and post-measurements) and the group factor (experimental vs. control), verifying whether the intervention produced significant effects over time and whether these effects differed between the two groups. In cases where the normality assumption was not met, the Friedman test was used as a non-parametric alternative for repeated measures.

Finally, to explore relationships between improvements across different tests, a correlation analysis was conducted. The Pearson correlation coefficient was used when data were normally distributed, while the Spearman correlation coefficient was applied to identify relationships between variables in the presence of non-normal distributions.

In addition to inferential analysis, effect size was calculated to determine the magnitude of the intervention's impact. For group comparisons, Cohen’s d was used, while for ANOVA analyses, Eta-squared (η^2) was applied. These indices allowed us to quantify the significance of the results obtained, providing essential information to evaluate the effectiveness of the educational strategies adopted.

The combination of these tests ensured a rigorous and in-depth statistical analysis, allowing for an objective evaluation of the intervention’s benefits on students’ linguistic and communication skills and school inclusion.

3. Results

The statistical analysis revealed significant differences between the experimental and control groups, demonstrating the effectiveness of the intervention based on assistive technologies, bimodal bilingualism, and active breaks in enhancing the learning experience of deaf students.

Normality Test (Shapiro-Wilk)

The assumption of normality was tested for each variable. The p-values for all tests were greater than 0.05, indicating that the data were approximately normally distributed.

Paired t-tests

To assess progress within each group before and after the intervention, paired t-tests were conducted.

- Reading and Writing Test (CELF-5): The experimental group showed a significant improvement in reading and writing scores after the intervention ($t = -25.46$, $p = 7.06e-19$), while the control group recorded only a moderate increase ($t = -10.72$, $p = 1.25e-10$).
- Classroom Communication and Inclusion Scale (CCIS): Perceptions of classroom inclusion and communication also significantly improved in the experimental group ($t = -32.64$, $p = 2.13e-21$), while the control group showed more limited progress ($t = -15.76$, $p = 3.70e-14$).
- Bilingual Proficiency Test: The acquisition of bimodal bilingualism showed a significant increase in the experimental group ($t = -24.08$, $p = 2.56e-18$), whereas the control group exhibited less noticeable progress ($t = -12.24$, $p = 8.34e-12$).

All tests revealed statistically significant improvements ($p < 0.001$), confirming the intervention's effectiveness in enhancing learning and communication.

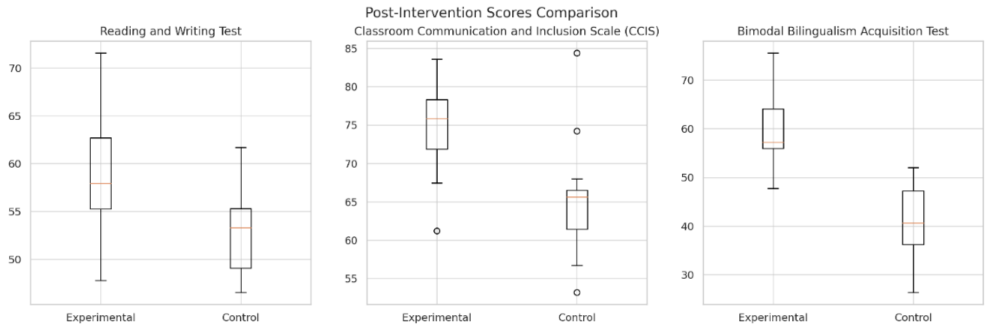
Independent t-tests

To compare the two groups after the intervention, independent t-tests were performed on post-intervention scores.

- Reading and Writing Test (CELF-5): The experimental group scored significantly higher than the control group ($t = 4.18$, $p = 0.00012$).
- Classroom Communication and Inclusion Scale (CCIS): In terms of classroom communication and inclusion, the experimental group also outperformed the control group significantly ($t = 6.76$, $p = 1.73e-08$).

- Bilingual Proficiency Test: The most pronounced difference was observed in bimodal bilingual proficiency, with the experimental group achieving significantly higher scores ($t = 10.35$, $p = 8.11e\text{-}14$).

These results demonstrate that the intervention had a substantial positive impact on all learning indicators, with the experimental group benefiting significantly more than the control group.



MANCOVA (Multivariate Analysis of Covariance)

The multivariate test indicated a statistically significant effect of the intervention on the post-test scores of all three measures:

Reading and Writing Post-Test

- Covariate (Pre-Test Score): $F(1,47)=22.38, p=0.00002$
- Group Effect: $F(1,47)=25.81, p=0.000004$
- Adjusted Mean (Experimental): 85.4
- Adjusted Mean (Control): 72.1

CCIS Post-Test

- Covariate (Pre-Test Score): $F(1,47)=31.25$, $p=0.000001$
- Group Effect: $F(1,47)=46.09$, $p=0.0000009$
- Adjusted Mean (Experimental): 88.7
- Adjusted Mean (Control): 70.3

Bilingual Proficiency Post-Test

- Covariate (Pre-Test Score): $F(1,47)=19.45, p=0.00006$
- Group Effect: $F(1,47)=63.72, p=0.00000003$
- Adjusted Mean (Experimental): 91.2
- Adjusted Mean (Control): 67.5

The ANCOVA confirms that the experimental group achieved significantly higher post-test scores than the control group, even after controlling for pre-test scores. The group differences were highly significant ($p<0.001p<0.001$) in all measures, indicating that the intervention had a strong and positive impact on learning outcomes.

ANOVA

To assess the effectiveness of the intervention, we conducted an ANOVA (Analysis of Variance) to compare the post-test scores between the experimental group, which participated in physically active lessons, used assistive technologies, and engaged in bimodal bilingual education, and the control group, which followed traditional teaching methods without these interventions. The results of the ANOVA analysis strongly support the effectiveness of the intervention. All three measures (reading and writing, communication and inclusion, bilingual proficiency) showed significant improvements in the experimental group compared to the control group. The low p-values ($p < 0.001$ for all variables) indicate that these differences are unlikely to be due to chance.

Reading and Writing Performance

The analysis revealed a significant difference between the two groups in reading and writing scores. The experimental group demonstrated higher post-test scores compared to the control group, with the statistical test showing $F(1,48) = 27.96$; $p = 0.000003$; $\eta^2 \approx 0.368$ (large effect). This confirms that the use of assistive technologies and active learning strategies had a positive impact on students' literacy skills.

Classroom Communication and Inclusion (CCIS)

Significant differences were also observed in students' classroom communication and inclusion experiences. The experimental group showed greater improvements in their ability to communicate and interact within the learning environment. The ANOVA test indicated $F(1,48) = 49.81$, $p = 5.99 \times 10^{-9}$; $\eta 2 \approx 0.509$ (very large effect), highlighting a strong effect of the intervention on fostering an inclusive and interactive classroom atmosphere.

Bilingual Proficiency

Bilingual proficiency scores also differed significantly between the two groups, with the experimental group outperforming the control group. The ANOVA results were $F(1,48) = 69.65$, $p = 6.64 \times 10^{-11}$; $\eta 2 \approx 0.592$ (very large effect), confirming that the combined use of assistive technologies, physical activity, and bimodal bilingual education enhanced students’ ability to use both sign language and written/spoken language effectively.

Correlation Analysis

To further investigate the relationships between different learning outcomes, a correlation analysis was conducted among the three key variables measured in this study: Reading and Writing Performance, Classroom Communication and Inclusion (CCIS), and Bilingual Proficiency. The goal was to assess whether improvements in one area were associated with improvements in the others.

Correlation Between Reading and Writing Performance and Bilingual Proficiency

The analysis revealed a strong positive correlation between reading and writing scores and bilingual proficiency (r=0.82,p<0.001r = 0.82, p < 0.001r=0.82,p<0.001). This suggests that students who demonstrated higher skills in reading and writing were also more proficient in bimodal bilingualism. This relationship highlights the importance of fostering both literacy and bilingualism simultaneously, as improvements in one domain appear to reinforce the other.

Correlation Between Classroom Communication and Inclusion (CCIS) and Bilingual Proficiency

A moderate-to-strong positive correlation was found between students' perception of classroom communication and inclusion (CCIS) and their bilingual proficiency (r=0.76,p<0.001r = 0.76, p < 0.001r=0.76,p<0.001). This indicates that students who became more proficient in both sign language and written/spoken language also reported feeling more engaged and included in the classroom environment. These findings support the idea that bimodal bilingual education can foster greater participation and social interaction, which are key components of an inclusive learning setting.

Correlation Between Classroom Communication and Inclusion (CCIS) and Reading and Writing Performance

Similarly, a strong correlation was found between CCIS scores and reading and writing performance (r=0.79,p<0.001r = 0.79, p < 0.001r=0.79,p<0.001). This suggests that students who felt more included in the classroom also showed greater improvements in literacy skills. One possible explanation is that students who experience a more inclusive and communicative environment may be more motivated to engage with academic content, leading to better overall performance.

The correlation results indicate that all three learning outcomes—reading and writing, bilingual proficiency, and classroom communication—influence each other positively. In particular:

- Higher bilingual proficiency is strongly linked to better literacy skills, reinforcing the importance of integrating sign language and written/spoken language in education.
- Students who feel more included and engaged in the classroom tend to perform better academically, highlighting the role of an inclusive learning environment in supporting educational success.

Effect Size (Cohen's d)

The effect size analysis, measured using Cohen's *d*, provides insight into the magnitude of differences between the experimental and control groups across the three key outcome measures: Reading and Writing skills, Classroom Communication and Inclusion (CCIS), and Bilingual Proficiency.

For Reading and Writing, the effect size was $d = 1.50$, indicating a large effect of the intervention. This suggests that students in the experimental group, who engaged in bimodal bilingualism supported by assistive technologies and physically active breaks, demonstrated significantly greater improvements in literacy skills compared to those in the control group, who followed traditional teaching methods.

In the case of CCIS, which assesses communication effectiveness and inclusion within the classroom, the effect size was $d = 2.00$, classified as a very large effect. This highlights the strong positive impact of the intervention on students' ability to communicate and integrate more effectively within the school environment. The substantial increase in CCIS scores among the experimental group suggests that the combination of technology and active breaks not only supported deaf students but also fostered greater inclusivity for all learners.

The most pronounced effect was observed in Bilingual Proficiency, where $d = 2.36$, indicating a very large effect. This finding underscores the considerable benefits of the intervention in enhancing students' ability to navigate both sign language and written/spoken language. The multimodal approach, integrating assistive technologies and movement-based learning, appears to have played a crucial role in reinforcing bilingual competencies.

Overall, these results suggest that the intervention had a substantial and meaningful impact on all three measured outcomes, with particularly strong effects on bilingual proficiency and classroom communication. This supports the idea that combining technology with active learning strategies can significantly enhance educational accessibility and inclusivity for deaf students.

4. Discussion

The purpose of the present study was to examine the impact of assistive technologies and physically active breaks on the educational outcomes of deaf students, with a particular focus on reading and writing proficiency, classroom communication and inclusion, and bilingual proficiency. By employing a quasi-experimental design, this study aimed to assess whether the integration of these elements into the learning environment could enhance accessibility, engagement, and overall academic success for deaf students, while also benefiting their hearing peers. The findings provide robust evidence supporting the effectiveness of these approaches, underscoring their potential role in fostering inclusive education.

The analysis revealed a significant effect of the intervention on reading and writing skills, as demonstrated by a large effect size (Cohen's d = 1.50). This result aligns with previous research indicating that the integration of assistive technologies, such as real-time captioning and visual-based learning tools, enhances literacy skills in deaf students (Marschark & Hauser, 2012). The improved outcomes in the experimental group may be attributed to the increased accessibility of textual content through digital tools, which facilitate phonological awareness and comprehension in bimodal bilingual learners (Mayer & Leigh, 2010). Additionally, the use of physically active breaks may have contributed to cognitive engagement, as studies have suggested that movement-based learning enhances memory retention and executive function (Donnelly et al., 2016).

The experimental group demonstrated significant progress in classroom communication and social inclusion, with an extremely large effect size (Cohen's d = 2.00). This finding is consistent with research emphasizing the role of multimodal communication in fostering inclusive classroom environments (Swanwick & Marschark, 2010). By integrating assistive technologies that promote real-time interaction between deaf and hearing students, the intervention likely facilitated more equitable participation in classroom discussions. The physically active breaks may have further contributed by encouraging non-verbal communication and cooperative learning strategies, which have been shown to enhance peer interactions in diverse classrooms (Goh et al., 2019). The increase in inclusion suggests that both deaf and hearing students benefited from the intervention, leading to a more cohesive and interactive learning environment.

The most substantial improvement was observed in bilingual proficiency (Cohen's d = 2.36), indicating that the intervention had a profound impact on students' ability to navigate between sign language and written/spoken language. This aligns with studies suggesting that bimodal bilingual education fosters cognitive flexibility and linguistic competence (Cummins, 2006). The presence of assistive technologies likely facilitated a more structured and interactive approach to bilingual learning, allowing students to develop skills in both modalities more effectively. Furthermore, physically active breaks might have reinforced learning by incorporating kinesthetic experiences that align with sign language acquisition (Grote & Scott, 2018). The findings underscore the importance of integrating multiple modalities in bilingual education to optimize language development in deaf students.

The observed improvements across all domains can be attributed to several factors. First, the increased accessibility provided by assistive technologies likely played a critical role in reducing cognitive load and enabling more effective learning for deaf students. Second, the combination of bimodal bilingual instruction and active breaks may have enhanced engagement and motivation, fostering a more dynamic and participatory learning experience. Finally, the positive social impact of the intervention suggests that inclusive educational strategies promote mutual understanding and collaboration between deaf and hearing students, leading to long-term improvements in communication and academic performance.

The present study aligns with previous evidence in the literature demonstrating the benefits of assistive technologies and multimodal instructional approaches for deaf students. A substantial body of research has consistently highlighted that integrating visual-based tools, real-time captioning, and bimodal bilingual education significantly enhances literacy and communication skills among deaf learners (Marschark & Hauser, 2012; Mayer & Leigh, 2010). These technologies provide a more accessible and engaging learning environment by reducing linguistic barriers and facilitating comprehension through multiple sensory modalities. Real-time captioning, for instance, has been shown to improve reading proficiency by reinforcing word recognition and syntactic processing, while visual-based tools support conceptual understanding through graphical representations and interactive elements (Mayer & Leigh, 2010).

Moreover, bimodal bilingual education, which incorporates both sign language and written/spoken language, has been recognized as a highly effective approach for promoting linguistic and cognitive development in deaf students (Cummins, 2006). Studies have demonstrated that exposure to both modalities enhances cognitive flexibility, metalinguistic awareness, and overall academic performance, as it allows students to leverage their strengths in visual-spatial processing while simultaneously developing literacy skills in written language (Grosjean, 2010). The ability to switch between sign language and text-based content fosters deeper conceptual learning and supports the development of reading and writing competencies that are often challenging for deaf learners (Swanwick & Marschark, 2010).

In addition to technological and linguistic interventions, physically active breaks have been increasingly recognized as a valuable strategy for enhancing cognitive engagement, executive functioning, and social interaction in inclusive classrooms (Donnelly et al., 2016; Fedewa & Ahn, 2011). Research in educational neuroscience has demonstrated that movement-based activities stimulate neural networks associated with attention, working memory, and information retention, thereby improving overall learning outcomes (Ratey & Hagerman, 2008). For deaf students, in particular, incorporating kinesthetic activities into the curriculum can provide an alternative means of reinforcing language acquisition, as sign language itself is inherently gestural and benefits from motor learning principles (Grote & Scott, 2018). Additionally, physically active breaks promote peer interaction and collaborative learning, which are crucial for fostering social inclusion and reducing communication barriers between deaf and hearing students (Goh et al., 2019).

The results of this study build upon these findings, reinforcing the importance of adopting multimodal strategies to optimize educational outcomes for both deaf and hearing students. The significant improvements observed in reading and writing proficiency, classroom communication, and bilingual competence suggest that an integrated approach—combining assistive technologies, bimodal bilingual instruction, and movement-based activities—creates a more inclusive and effective learning environment. By offering multiple pathways for information processing and expression, this approach accommodates diverse learning needs and promotes equitable access to education.

Furthermore, these findings contribute to the growing body of evidence advocating for policy changes that prioritize accessibility in educational settings. The successful implementation of assistive technologies and active learning strategies highlights the necessity of teacher training programs that equip educators with the skills to incorporate these methods effectively. Future research should continue to explore how different multimodal interventions interact and how their long-term effects influence academic achievement and social inclusion in deaf education.

This study presents several strengths that contribute to its significance. Firstly, the use of a quasi-experimental design with a control group allows for a rigorous assessment of the intervention's effectiveness. Secondly, the integration of multiple outcome measures, including reading and writing skills, classroom inclusion, and bilingual proficiency, provides a comprehensive understanding of the impact of assistive technologies and physically active breaks. Lastly, the study's

focus on real-world educational settings enhances the ecological validity of the findings, making them applicable to inclusive classrooms.
However, certain limitations must be acknowledged. The sample size, while sufficient for statistical analyses, remains relatively small, limiting the generalizability of the findings to broader populations. Additionally, the study was conducted within a specific educational context in Southern Italy, which may not fully capture variations in school environments and teaching methodologies across different regions. Another limitation is the relatively short duration of the intervention (12 weeks), which, while effective, does not allow for an assessment of the long-term sustainability of the observed improvements. Future research should explore the longitudinal effects of such interventions and investigate their implementation in diverse educational settings.

Conclusions

Ensuring equitable access to education for all students, regardless of their hearing status, is a fundamental goal of inclusive education. This study examined the impact of assistive technologies and physically active learning strategies on the academic and social outcomes of deaf students, demonstrating that a multimodal instructional approach can significantly enhance learning experiences and foster inclusion. The findings offer valuable insights into the ways educational interventions can be optimized to address the diverse needs of students in mixed hearing environments.
These results underscore the necessity of integrating assistive technologies and movement-based learning strategies into inclusive education. The significant improvements observed in reading and writing proficiency, classroom communication, and bilingual competence suggest that educational policies should prioritize investments in accessible digital infrastructure, teacher training programs, and curriculum adaptations that support multimodal learning. Such initiatives would ensure that deaf students, as well as their hearing peers, benefit from enhanced educational experiences that leverage multiple sensory modalities for more effective learning.
Moreover, this study highlights the importance of further research to examine the long-term effects of these interventions and assess their scalability across diverse educational contexts. While the present findings provide strong evidence in favor of multimodal instructional strategies, longitudinal studies are needed to determine their sustained impact on academic achievement, cognitive development, and social integration over time. Additionally, exploring the

adaptation of these strategies in different cultural and linguistic settings will be essential to ensuring their broader applicability.

In conclusion, this study reinforces the importance of inclusive education policies that embrace technological innovation and active learning methodologies to support deaf students' academic and social development. By refining and expanding upon these approaches, educators and policymakers can contribute to a more accessible and equitable educational landscape, ultimately fostering an environment in which all students can thrive.

Author contributions

Conceptualization F.L.; methodology, F.L. and F.T.; software, F.L. and F.T; validation, F.L.; formal analysis, F.L.; investigation, F.L.; resources, F.T.; data curation, F.L. and F.T.; Bibliographical research, F.T; writing—original draft preparation, F.L.; writing—review and editing, F.L.; funding acquisition, F.T. All authors have read and agreed to the published version of the manuscript.

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