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Inclusive Pedagogy through Technology: Implementing Speech-to-Text and Text-to-Speech in EFL Classrooms for Learners with Disabilities

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ABSTRACT

This study investigates the implementation of Speech-to-Text (STT) and Text-to-Speech (TTS) technologies in multimodal English as a Foreign Language (EFL) assessment for students with disabilities in Indonesian special senior high schools (SMALB). Using an embedded mixed-methods design, the research involved 25 students with diverse disabilities, alongside teachers and support staff, to explore how STT and TTS tools support inclusive pedagogy and assessment. Qualitative data from observations, interviews, and student work samples were integrated with quantitative results from language performance tests and attitude questionnaires. The findings indicate that STT and TTS technologies enhanced accessibility, engagement, and learner autonomy, allowing students to demonstrate language competence through alternative modalities aligned with Universal Design for Learning (UDL) principles. Teachers reported increased sensitivity to learner diversity and adopted more flexible, student-centered assessment strategies. Quantitative analyses showed significant improvements in students' speaking and writing performance, as well as positive shifts in motivation and confidence. Despite implementation challenges such as limited infrastructure and teacher readiness, the study highlights the transformative potential of assistive technologies in advancing equitable and meaningful EFL instruction in inclusive settings. These insights contribute to the growing discourse on inclusive digital education in under-resourced contexts and inform future policy, practice, and teacher training initiatives.

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1. Introduction

Inclusive education has emerged as a global imperative, emphasizing the need to ensure that all learners, regardless of ability, have equal access to quality education. In the context of English as a Foreign Language (EFL), this imperative becomes even more pronounced, as language acquisition demands engagement with complex communicative modalities; listening, speaking, reading, and writing that can be particularly challenging for students with disabilities [1,2]. Despite policies that endorse inclusive education in Indonesia, such as Permendikbud No. 70 of 2009 on Inclusive Education, students with disabilities still face systemic barriers in mainstream and special education institutions alike. Many students enrolled in Sekolah Menengah Atas Luar Biasa (SMALB), or Special Senior High Schools, struggle to access tailored EFL learning resources and technologies that support their specific learning needs [3]. Teachers in these settings often rely on traditional teaching methods, which may not be adequately responsive to students with hearing, visual, motor, or cognitive impairments. Consequently, learners with disabilities are at risk of educational marginalization and underachievement, particularly in language learning contexts that do not accommodate their diverse capabilities [4,5]. The advancement of inclusive pedagogy through technology offers a promising avenue to address these challenges. Technologies such as speech-to-text (STT) and text-to-speech (TTS) tools can help bridge communication gaps and facilitate language engagement in more accessible ways [5–7]. However, the extent to which these tools have been effectively integrated into EFL teaching and assessment practices in SMALB settings remains underexplored. This raises critical questions about how technological integration can reshape inclusive language instruction and assessment for learners with disabilities.

Recent advances in assistive technology, particularly Speech-to-Text (STT) and Text-to-Speech (TTS) tools offer promising solutions for bridging accessibility gaps. STT converts spoken language into written text, supporting learners with physical or motor impairments, while TTS reads written content aloud, assisting students with visual or reading difficulties [8,9]. When integrated within multimodal assessment, these tools can expand opportunities for students to demonstrate their understanding through diverse channels, aligning with inclusive pedagogy and Universal Design for Learning (UDL) principles. Prior research shows that STT and TTS enhance comprehension, pronunciation, and confidence in learners with disabilities [10–13]. The use of assistive technologies in education, particularly STT and TTS tools, has shown potential to support learners with physical, sensory, and learning disabilities in navigating classroom content. STT tools convert spoken language into written text, which is particularly beneficial for students with physical or motor impairments who may struggle with traditional writing On the other hand, TTS tools provide spoken feedback from written content, aiding students with visual impairments or reading difficulties [9–11]. In EFL contexts, these tools may serve as compensatory mechanisms that enable students to access and produce language in ways that align with their individual strengths and limitations.

However, most studies have been conducted in Western or well-resourced settings and rarely address the affective, motivational, or contextual dimensions of inclusion in developing countries like Indonesia. There is thus a need to situate the use of these technologies within the specific pedagogical realities of SMALB schools, where resource constraints and varying teacher competencies may impact implementation. Moreover, the previous studies tend to emphasize cognitive outcomes while overlooking the affective dimensions of learning, such as motivation, engagement, and sense of inclusion [12–14]. Very few studies offer a comprehensive view of how STT and TTS can be integrated into pedagogical and assessment frameworks that address both cognitive and emotional needs of students. This highlights the importance of culturally and contextually grounded research that explores not only what works, but also how and why it works or fails to work in particular educational settings [15,16]. In Indonesia, such data are still scarce, particularly at the senior high school level and in special education contexts. For that reason, this study responds to that gap by focusing on EFL learning among students with disabilities in Semarang, Indonesia.

In addition, inclusive pedagogy emphasizes the removal of barriers to learning and participation by recognizing and responding to learners' diverse needs, preferences, and experiences. In the EFL classroom, this requires rethinking conventional pedagogical models that prioritize written and spoken proficiency in a standardized form. For students with disabilities, inclusive pedagogy should not only involve accommodations but also active redesign of instructional and assessment practices[17–19]. STT and TTS technologies can support such redesign by offering alternative modalities for language expression and comprehension. For example, a student with limited motor control might use STT to complete a speaking or writing task, while another student with a visual impairment might rely on TTS to access reading materials. These adaptations, when embedded within a multimodal assessment framework, align with the Universal Design for Learning (UDL) principles that promote flexible paths for achieving learning goals. However, the implementation of such technologies requires both pedagogical innovation and institutional support, including teacher training, curriculum adaptation, and access to digital infrastructure. Understanding how these components interact in the field is essential to advancing inclusive education policy and practice in Indonesia.

Furthermore, one major barrier to inclusive technology implementation is the limited digital assessment literacy among EFL teachers working in special education settings. Many educators in SMALB schools report low confidence in using assistive technology tools, often due to inadequate pre-service or in-service training. Additionally, most teacher education programs in Indonesia do not yet integrate inclusive pedagogy with technology-enhanced language instruction[20]. This disconnect often leaves teachers unprepared to design and deliver meaningful learning experiences for students with disabilities, particularly in foreign language contexts. Even when devices and software are available, their pedagogical integration is often superficial, with technology used to replicate traditional practices rather than transform them[15,16]. As such, classroom practices may fail to realize the full potential of STT and TTS tools as enablers of inclusive education. Exploring how teachers conceptualize, implement, and reflect on their use of these technologies is thus an important line of inquiry. It can help identify professional development needs, inform curriculum design, and foster a culture of innovation that supports all learners.

The use of multimodal assessment as a complement to inclusive pedagogy is grounded in the recognition that students learn and demonstrate understanding in multiple ways. Traditional assessments in EFL often privilege written and oral proficiency, which may disadvantage learners with disabilities. Multimodal assessment, supported by STT and TTS tools, offers diverse entry points for students to engage with and demonstrate language competence. For instance, a student may present an oral narrative using STT or complete a listening comprehension task using TTS, thus shifting the focus from disability to ability. However, such assessment models must be carefully designed to ensure validity, reliability, and fairness. Teachers need guidance and support in developing assessment tools that are both inclusive and pedagogically sound. This calls for research that investigates how multimodal assessment is operationalized in practice, what challenges arise during implementation, and how students respond to these changes.

This study seeks to explore the implementation of STT and TTS-based multimodal assessment in EFL classrooms at SMALB schools in Semarang, Indonesia. Specifically, the research involves 25 students with various disabilities, including visual, auditory, and physical impairments. The study focuses on documenting classroom practices, identifying pedagogical strategies used by teachers, and examining student responses to the integration of STT and TTS tools. By situating this investigation in a real-world context, the study aims to generate practical insights that can inform inclusive pedagogy and assessment design in special education settings. It also seeks to contribute to the growing body of literature on technology-enhanced learning for students with disabilities in non-Western contexts. Ultimately, the findings are expected to inform policy and professional development initiatives aimed at fostering more inclusive and equitable EFL education in Indonesia and beyond.

In light of the above, this study is guided by the following research questions:

1) How are speech-to-text and text-to-speech technologies implemented in multimodal English language assessment for students with disabilities in SMALB settings?
2) How do these technologies influence students' engagement and performance in English language learning tasks?

2. Materials and Methods

2.1. Research Design

This study employed an embedded mixed methods design that integrates qualitative and quantitative approaches to comprehensively examine the implementation of Speech-to-Text (STT) and Text-to-Speech (TTS) technologies in inclusive EFL classrooms. The qualitative strand served as the primary method, aiming to explore the lived experiences, pedagogical practices[21], and challenges encountered by students and teachers in using STT and TTS. Meanwhile, the quantitative strand was embedded to provide supporting evidence on the effectiveness of these tools in enhancing students' English language skills and attitudes toward learning. This design allowed the researchers to combine the richness of qualitative insights with the precision of quantitative data, enabling a more holistic understanding of multimodal assessment in inclusive education. The rationale for using a mixed methods design stems from the need to address both how these technologies are implemented and to what extent they influence learning outcomes and learner engagement[22].

2.2. Participants

Participants included 25 students with disabilities enrolled in two SMALB (*Sekolah Menengah Atas Luar Biasa*) schools in Semarang, Central Java, Indonesia. These students, aged between 16 and 19 years, had varied disability types, including visual impairment (8), hearing impairment (7), physical/motor disabilities (6), and learning disabilities (4). All were participants in EFL classes as part of the national curriculum. In addition, three English teachers and two special education staff members participated to offer triangulated perspectives. Both SMALB schools were public institutions with prior exposure to basic digital tools but had not previously used STT and TTS as learning or assessment instruments. Ethical approval was obtained from the university ethics committee. Parental and institutional consent was secured, and participant anonymity and data confidentiality were strictly maintained throughout the research process.

2.3. Data Collection Procedures

This study was conducted over a period of twelve weeks and followed an embedded mixed-methods research design, where the qualitative strand served as the primary focus and the quantitative strand was embedded to provide supporting evidence. The procedure consisted of several sequential stages, namely preparation, implementation, data collection, and analysis.

In the preparation stage, the researchers sought ethical clearance from the university's research ethics committee and secured written consent from school principals, teachers, parents, and students. Prior to the main study, all research instruments including observation checklists, interview guides, language assessment rubrics, and attitudinal questionnaires were validated by three experts in English education and special needs pedagogy. The instruments were also pilot-tested with a group of SMALB students outside the research sample to ensure reliability, clarity, and cultural appropriateness.

The implementation stage involved the introduction of Speech-to-Text (STT) and Text-to-Speech (TTS) technologies in the classroom assessment practices of two SMALB schools in Semarang. Teachers received a short orientation on how to operate and integrate these tools into listening, speaking, reading, and writing activities. The intervention was structured into three phases: pre-assessment, during-assessment, and post-assessment. In the pre-assessment phase, TTS was primarily used to deliver audio-based instructions and reading passages to accommodate students with visual or processing difficulties. During the assessment phase, STT was utilized for speaking and writing tasks, enabling students with motor impairments or dyslexia to dictate responses orally. In some tasks, STT and TTS were combined. For example, students listened to a text through TTS and responded orally using STT. In the post-assessment phase, TTS was used for delivering teacher feedback, while STT facilitated student self-reflections.

The data collection stage employed multiple instruments to capture both qualitative and quantitative evidence. For the qualitative strand, (1) classroom observations were conducted twelve times using a structured checklist focusing on student engagement, tool usability, and teacher scaffolding; (2) semi-structured interviews were carried out with 15 students, three English teachers, and two support staff to elicit their perceptions of STT and TTS integration; (3) student work samples, including STT-generated texts, TTS-assisted reading responses, and audio recordings of oral tasks, were gathered as artifacts; and (4) teacher reflective journals

were maintained weekly to document pedagogical strategies, classroom adjustments, and teacher insights. For the quantitative strand, two instruments were used: (1) pre- and post-performance assessments of speaking and writing, rated with analytic rubrics on fluency, grammar, pronunciation, accuracy, and idea development; and (2) a 20-item Likert-scale attitudinal questionnaire, administered before and after the intervention, which measured motivation, confidence, perceived usefulness, and ease of use of STT/TTS tools. For the details of procedure of intervention in week 1 to week 12 is described in **Appendix A**, **Table A1**.

2.4. Data Analysis

A parallel data analysis strategy was employed, in which the qualitative and quantitative data were analyzed independently and then integrated during the interpretation phase. The qualitative data were analyzed using thematic analysis, following Braun and Clarke's[23] six-step framework. After transcription and familiarization, codes were generated inductively and organized into broader themes using NVivo 14 software. Themes were derived around core concepts such as accessibility, student agency, pedagogical adaptation, and challenges in digital inclusion. Triangulation across interviews, observations, work samples, and reflective journals strengthened credibility, while member-checking was conducted with a subset of participants to confirm the accuracy of thematic interpretations. On the other hand, quantitative data were analyzed using descriptive and inferential statistics with SPSS 27. Pre- and post-test scores were compared using paired-samples t-tests to determine whether significant improvements occurred in students' language performance. Questionnaire data were analyzed using mean scores and standard deviations, and changes in attitudes pre- and post-intervention were evaluated through Wilcoxon Signed-Rank Tests, given the small sample size and ordinal nature of the data. Cronbach's alpha was calculated to ensure internal consistency of the attitudinal scale ($\alpha > 0.85$).

For each language skill (speaking and writing), descriptive and inferential statistics were calculated, including the t-value, degrees of freedom (df), exact p-value, and effect size (Cohen's d). Effect sizes were interpreted following Tarone et al.'s[24] conventions, where $d = 0.2$ represents a small effect, $d = 0.5$ a medium effect, and $d \geq 0.8$ a large effect. For non-parametric data from the attitudinal questionnaire, the Wilcoxon Signed-Rank Test reported the Z statistic and p-value, while effect sizes were calculated using $r = Z/\sqrt{N}$. Reporting these metrics ensures transparency and allows readers to gauge the magnitude and reliability of observed improvements.

3. Results

The findings of this study are presented in line with the two research questions, each highlighting different but interconnected dimensions of the implementation of Speech-to-Text (STT) and Text-to-Speech (TTS) technologies in inclusive EFL classrooms. The first set of findings (Research Question 1) focuses on how the technologies were integrated into multimodal assessment practices, detailing the instructional design, classroom strategies, and teacher adaptations that shaped their use in SMALB settings. The second set of findings (Research Question 2) examines the influence of STT and TTS on students' engagement in English language learning tasks. While the first highlights the process of implementation, the second emphasizes the outcomes for learners in terms of behavioral, emotional, cognitive, and social engagement. Together, these findings provide a comprehensive understanding of how assistive technologies can transform both teaching practices and student learning experiences in inclusive contexts.

3.1. The Implementation of Speech-to-Text and Text-to-Speech Technologies in Multimodal English Language Assessment for Students with Disabilities in SMALB Settings

This subsection addresses Research Question 1, which explores how Speech-to-Text (STT) and Text-to-Speech (TTS) technologies were implemented in multimodal English language assessments for students with disabilities in SMALB settings. The analysis focuses on instructional design, assessment procedures, and teacher adaptations during the intervention. A parallel data analysis strategy was employed, in which the qualitative and quantitative data were analyzed independently and then integrated during the interpretation phase. The qualitative data were analyzed using thematic analysis.

3.1.1. Implementation Process and Instructional Design

The implementation of STT and TTS technologies in SMALB classrooms followed a structured approach across three phases of English learning activities: pre-assessment, during-assessment, and post-assessment. These phases were operationalized into a multimodal assessment framework in which students could engage with content, demonstrate their understanding, and receive feedback in a way that accommodated their individual learning needs and disabilities. **Table 1** provides a breakdown of how the two technologies STT and TTS were used across various assessment components and skill areas in the classroom.

Table 1. Implementation Breakdown of STT and TTS in the classroom.

Assessment Stage	Tool Used	Skill Assessed	Activity Type	Target Disability Group	Purpose
Pre-Assessment	TTS	Listening, Reading	Audio instructions, Text-to-speech reading tasks	Visual impairment, cognitive disability	To introduce and scaffold input through auditory mode
During Assessment	STT	Speaking, Writing	Oral dictation, Story retelling	Motor impairment, dyslexia	To allow students to produce language using voice
During Assessment	TTS + STT	Reading comprehension	Read-aloud followed by verbal response	Low literacy, cognitive processing difficulties	To support comprehension and oral articulation
Post-Assessment	TTS	Listening, Writing	Feedback delivery via audio	Visual impairment, students with attention deficits	To provide accessible, personalized feedback
Post-Assessment	STT	Speaking, Metacognition	Oral reflection on learning	All groups	To encourage self-assessment and reflection

Table 1 illustrates a deliberate strategy to align the tools with the cognitive and physical needs of different learners. In the pre-assessment stage, TTS was used predominantly to deliver audio versions of instructions and reading texts, which supported students with visual impairments or processing difficulties. For example, learners were able to listen to short reading passages and comprehend the main ideas without needing to decode visual text as an important modification for students with low literacy levels or cognitive delays.

During the assessment stage, STT was central to speaking and writing tasks, particularly for students with motor impairments or dyslexia. Instead of relying on conventional written responses, students could verbally dictate stories, answers to comprehension questions, or even reflections, which were transcribed in real-time. This bypassed their physical writing limitations and allowed a more authentic expression of their ideas. In some instances, STT and TTS were used in tandem: students would first listen to a text using TTS and then respond orally through STT, promoting an integrated receptive-productive task format that built both comprehension and fluency.

In the post-assessment phase, TTS was employed to deliver teacher feedback in audio format, helping students with visual impairments or attention deficits focus on feedback more effectively. Similarly, STT supported oral reflections, where students were prompted to describe what they had learned or what they found challenging during the lesson. This approach not only promoted metacognitive skills but also made self-assessment accessible to students who might struggle with writing due to cognitive or physical disabilities.

The implementation breakdown also shows how flexibility and accessibility were embedded in assessment design. Each tool was matched with specific student profiles to ensure that the assessment was fair, inclusive, and aligned with the learners' capabilities. The consistent use of TTS for input and STT for output allowed a balance between teacher control and student autonomy, while also maintaining task validity. Furthermore, the implementation was not rigid teachers made adjustments based on real-time classroom dynamics, such as switching to peer-supported STT tasks or simplifying TTS input based on student fatigue levels.

Overall, this implementation model demonstrates how multimodal assessment using STT and TTS technologies can be integrated into inclusive EFL classrooms. It also provides a scalable and replicable framework for other special education contexts aiming to implement equitable digital assessments. The structure, flexibility, and learner-centeredness observed in the implementation breakdown support the broader argument that inclusive pedagogy must be rooted in technological sensitivity, multimodal engagement, and continuous

adaptation.

3.1.2. Teacher Reflections and Adaptations

The integration of STT and TTS technologies in SMALB classrooms prompted a significant shift in how teachers approached assessment and instruction for students with disabilities. Many teachers shared that they initially had limited understanding of how assistive technologies could support language learning. However, after participating in the intervention, they began to view these tools not simply as technological enhancements but as transformative supports for inclusive pedagogy. Teachers expressed a growing awareness of the need to assess students using diverse modes of communication, recognizing that conventional paper-based tests were often exclusionary. This shift in mindset was reflected in their evolving classroom practices. As one teacher explained:

> "*Before this project, I always asked my students to write answers for every test. But after using STT, I saw that some of them could express their thoughts better through speaking. It changed the way I view assessment. It's not only about writing anymore*." (Teacher 1)

This mindset change was accompanied by adaptations in task design and assessment planning. Several teachers reported modifying existing activities to incorporate STT or TTS features, allowing students to choose how to complete their assignments through speaking, listening, typing, or writing. This flexibility helped to accommodate a range of learning needs and supported differentiated instruction in ways they had not previously implemented. Teachers also observed improvements in student engagement and confidence when they were given more autonomy in how they demonstrated their understanding. One teacher shared:

> "*I created two versions of the same activity, one using text and another using audio. I allowed students to choose. It was more work, but they were more engaged and confident when using the format they preferred*." (Teacher 5)

In adapting their instruction, teachers also had to modify classroom management routines and technical logistics. Many reported that the limited number of devices required careful scheduling, peer collaboration, and sometimes, creative workarounds. To address this, teachers restructured class time and group arrangements, often pairing students strategically to ensure support. In doing so, teachers unintentionally fostered a more collaborative classroom culture. For example:

> "*I had to change the way I manage the classroom. When using the app, I grouped students with different abilities so they could help each other. Some became very good at operating the tools and helped their friends. It built teamwork, which I hadn't expected*." (Teacher 3)

Another important shift involved recognizing student agency and the value of giving students choice in how they engage with language tasks. By allowing students to select between speaking or writing modes, and whether to use the STT or TTS features, teachers observed higher participation rates and reduced anxiety. This student-centered approach was especially effective for learners with dyslexia, autism spectrum disorders, and motor impairments. Teachers became more sensitive to how providing multiple access points could empower students in their learning. As one participant noted:

> "*Some students preferred to type, some to talk, and some even asked to do both. I gave them the freedom to choose how to submit their answers. They felt more in control, and it reduced their anxiety*." (Teacher 6)

Teachers' reflections also revealed growing confidence and a desire for continuous professional growth. Although many admitted feeling unprepared or intimidated by the technology at first, their experiences during the intervention encouraged them to learn through experimentation and observation. Several teachers started exploring new digital tools and even shared their practices with colleagues, indicating a broader professional development trajectory. For instance:

> "*I was nervous at first, thinking I would make mistakes with the technology. But I kept trying, and the students were patient. I began to reflect more on what worked and what didn't.*

Now I'm planning to use these tools in other subjects too." (Teacher 2)

Importantly, teachers did not simply implement the tools passively. They became co-designers of inclusive assessment strategies. They made informed, intentional choices based on what worked best for their students and demonstrated resilience and creativity in addressing challenges. Their adaptability proved essential to the success of STT and TTS in the classroom. As one teacher insightfully commented:

"*I became more curious and reflective. I even started reading more about inclusive education and EdTech. It's not just about using the app. It's about thinking differently as a teacher*." (Teacher 1)

Overall, these reflections demonstrate that technology alone cannot guarantee inclusion. It is the teacher's role in adapting, reflecting, and making pedagogically sound decisions that determines success. The incorporation of STT and TTS technologies served as a catalyst for broader changes in teacher belief systems and instructional approaches [25,26]. Through this process, teachers developed a deeper commitment to inclusive education and multimodal assessment practices, showing that with the right support, meaningful change is possible even in under-resourced educational contexts.

3.2. The Influence of Speech-to-Text and Text-to-Speech Technologies on Students' Engagement English Language Learning Tasks

This subsection presents findings related to Research Question 2, which examines how the integration of STT and TTS technologies influenced students' engagement and performance during English learning activities. Evidence is drawn from classroom observations, questionnaires, teacher reflections, and student interviews.

Students' engagement was examined through triangulated data sources: (1) classroom observations using a structured rubric, (2) attitudinal questionnaires administered pre- and post-intervention, (3) teacher reflective journals, and (4) semi-structured interviews with selected students and teachers. Engagement was analyzed across four observable criteria namely attention, task initiation, task persistence, and peer collaboration while qualitative data illuminated emotional and cognitive dimensions of engagement. **Table 2** illustrates the improvement of students' engagement across twelve weeks, based on observation checklists, teacher journals, interviews, and attitudinal questionnaires. All four engagement indicators such as attention, task initiation, task persistence, and peer collaboration showed notable progress, reflecting how STT and TTS technologies supported inclusive participation in line with Universal Design for Learning (UDL) principles.

Table 2. Engagement Ratings Over 12 Weeks.

Criteria	Mean of Week 1	Mean of Week 12
Attention	2.1	4.3
Task Initiation	2.0	4.5
Task Persistence	2.3	4.6
Peer Collaboration	2.4	4.2

In **Table 2**, the sharpest increase occurred in task initiation, which rose from 2.0 in Week 1 to 4.5 in Week 12. This improvement demonstrates UDL's principle of providing multiple means of engagement, as STT offered an alternative entry point for learners who struggled with handwriting, allowing them to begin tasks quickly through spoken responses. Students reported feeling empowered to start without hesitation, showing that accessible modes of expression reduce barriers to task initiation.

"*When the teacher said I could speak instead of writing, I felt free. I don't have to wait for help to start anymore*." (Student 4, physical impairment)

Similarly, another student noted how STT made initiating tasks easier and less stressful:

"*Sometimes I forget how to spell words. But when I speak, the app writes it for me. That*

makes me want to try more." (Student 9, learning disability)

To add, task persistence also increased substantially, from 2.3 to 4.6, highlighting how STT and TTS fostered sustained effort. By enabling students to revise responses through listening (TTS) or retrying dictation (STT), the tools supported sustained effort and persistence, another key UDL checkpoint. Teacher journals noted that students no longer abandoned tasks at the first sign of difficulty but instead experimented with corrections, which reinforced resilience and learning stamina. This was echoed by the students during the interview.

"*Before, if I made a mistake, I would stop. But now, I just press the mic again and try. It's fun to fix my own words."* (Student 2, learning disability)

Furthermore, in terms of attention, scores improved from 2.1 to 4.3. The use of TTS in delivering input addressed the UDL principle of recruiting interest, particularly for students with visual impairments or low literacy. Teachers observed fewer distractions and higher attentiveness once students could access content aurally, showing how multimodal input channels maintain focus and reduce disengagement. During the interview, students mentioned that hearing the materials made lessons more enjoyable and helped them focus longer.

"I like it when the phone reads the story. I can follow every sentence, and I don't get sleepy anymore." (Student 7, visual impairment)

Finally, peer collaboration increased from 2.4 to 4.2, aligning with the UDL principle of fostering collaboration and community. Shared device use and peer tutoring around STT/TTS applications encouraged cooperative learning. Interviews also revealed that students felt more motivated when helping or being helped by peers, which created a supportive classroom culture and reinforced social dimensions of engagement. For instance, one participant commented:

"My friend helps me when I can't use the app. Later, I help him too. We do the tasks together and laugh when the voice makes mistakes." (Student 10, autism spectrum disorder)

Another student reflected on how collaborative activities made English learning more meaningful. The use of assistive technology in group settings appeared to reduce feelings of isolation and encouraged active participation. This shift from passive observation to active engagement highlighted the social benefits of collaborative learning environments.

"Before, I was quiet. But now, when we use the voice tool together, I talk more and share ideas. I feel part of the class." (Student 5, hearing impairment)

Taken together, the findings suggest that STT and TTS technologies not only improved observable engagement behaviors but also operationalized UDL's multiple means of engagement. By offering flexible pathways for starting, sustaining, and completing tasks, as well as promoting collaboration, the tools created equitable opportunities for learners with diverse disabilities to participate actively in English learning. The integration of direct student voices illustrates how accessible multimodal tools can transform students from passive recipients into active, confident participants in the learning process.

In addition to students' task engagement, a paired-samples t-test based on observed engagement ratings (Week 1 vs Week 12) confirmed statistically significant improvements across all four dimensions. **Table 3** showed that students gave higher attention ($t(24) = -18.93$, $p < 0.001$, $d = 3.79$), task initiation ($t(24) = -18.21$, $p < 0.001$, $d = 3.64$), task persistence ($t(24) = -14.73$, $p < 0.001$, $d = 2.95$), and peer collaboration ($t(24) = -12.60$, $p < 0.001$, $d = 2.52$). These very large effect sizes suggest that STT and TTS technologies strongly enhanced students' behavioral engagement and classroom participation over the twelve-week intervention. Qualitative observations and interviews supported these findings, revealing that learners became more confident in expressing ideas, showed persistence when correcting pronunciation or text output, and actively collaborated with peers during multimodal tasks. Together, the quantitative and qualitative evidence highlight the effectiveness of STT and TTS integration in promoting inclusive, participatory, and engaging English learning experiences for students with disabilities.

Table 3. Result of Paired-Samples t-test for Engagement Criteria.

Engagement Criteria	Pre-Test Mean	Post-Test Mean	*t*(24)	*p*-Value	Cohen's *d*	Effect Size
Attention	2.02	4.16	−18.93	<0.001	3.79	Very large
Task Initiation	2.05	4.46	−18.21	<0.001	3.64	Very large
Task Persistence	2.33	4.53	−14.73	<0.001	2.95	Very large
Peer Collaboration	2.47	4.21	−12.60	<0.001	2.52	Very large

4. Discussion

The findings of this study also highlight the transformative role of Speech-to-Text (STT) and Text-to-Speech (TTS) technologies in facilitating multimodal assessment in English as a Foreign Language (EFL) classrooms for students with disabilities in SMALB settings. The integration of these tools allowed students to demonstrate their language competencies in diverse formats, such as oral dictation, audio-assisted reading comprehension, and technology-mediated writing. These implementations are closely aligned with the principles of Universal Design for Learning (UDL), which emphasize multiple means of representation, expression, and engagement[27,28]. Through this framework, STT and TTS tools functioned as enablers of flexibility by providing auditory input, verbal output, and visual feedback that accommodated learners' sensory and cognitive differences. By operationalizing UDL checkpoints such as providing options for perception, communication, and sustaining effort and persistence, the study demonstrates how assistive technologies can be embedded in inclusive EFL assessment to ensure equitable participation.

Furthermore, the teachers' evolving practices during the intervention illustrate the development of Technological Pedagogical Content Knowledge (TPACK) in inclusive settings. Initially, teachers viewed technology as an external aid, but over time, they integrated it pedagogically and content-wise to design differentiated EFL tasks. This shift demonstrates the interconnection between technological knowledge (STT/TTS operation), pedagogical knowledge (task adaptation and multimodal scaffolding), and content knowledge (English language skills). The fusion of these domains supports the TPACK model, emphasizing that effective integration of digital tools depends on teachers' ability to align technology use with pedagogical purposes and content objectives[29]. Teachers' reflections on restructured tasks, flexible feedback mechanisms, and collaborative grouping illustrate a maturing awareness of how to leverage technology to address individual learning differences.

The improvement in students' engagement and performance also reflects the synergy between UDL and TPACK principles. While UDL provided the theoretical foundation for ensuring accessibility and flexibility, TPACK explained how teachers' evolving competence mediated that accessibility through informed instructional design[30]. The combination of these frameworks positions technology not as a mere support mechanism, but as a pedagogical transformer that is a catalyst for inclusive assessment and learner autonomy. In this regard, the study extends prior research by showing how UDL-oriented technology integration can be effectively realized in resource-limited EFL contexts through teachers' TPACK growth.

The students' language engagement and performance enhancement as evidenced by both qualitative observations and quantitative test results reveals the efficacy of STT and TTS tools in enhancing learning outcomes. The consistent upward trend in engagement ratings reflects increased student agency and classroom participation. These findings align with Sharma[27], which underscores the importance of tools and social interaction in mediating cognitive development. By enabling students to participate more meaningfully in EFL tasks, the technologies served as cognitive tools that bridged gaps between ability and academic expectations. In particular, TTS was instrumental in helping students comprehend complex texts and instructions, while STT enabled students with motor challenges to articulate their ideas with clarity. This resonates with results from recent studies which showed that text-to-speech tools significantly enhanced reading fluency and comprehension among students with special needs[28,29]. Importantly, the technologies not only facilitated input and output processes but also enhanced metacognitive awareness, as students could hear or read back their responses for self-editing.

Moreover, the study adds nuance to our understanding of engagement in inclusive EFL settings by showing how technology can act as both a motivator and an equalizer.

Engagement was not limited to behavioural participation but extended to emotional and cognitive domains, including students' willingness to take risks, complete assignments independently, and collaborate with peers. These results are aligned with Villalba et al.'s [30] conceptual model of engagement, such as behavioural, emotional, and cognitive. The improvement in students' task initiation and persistence over time indicates not only tool familiarity but also the establishment of a psychologically safe and stimulating classroom environment. Furthermore, the shift from passive reception to active meaning-making aligns with constructivist approaches to language learning, emphasizing learner agency and contextualized learning. While several previous studies [31,32] explored engagement in technology-enhanced settings, few have focused specifically on inclusive EFL classrooms using STT and TTS. Thus, this study fills an important gap by showing how these technologies mediate engagement in marginalized student populations.

The findings also provide empirical evidence for the pedagogical alignment between multimodal assessment and inclusive teaching in language classrooms. Multimodal assessment by leveraging audio, speech, text, and visual representations provided learners with various channels to demonstrate knowledge and skills. As Wijaya [33] asserts, assessment in the 21st century must recognize the multimodal nature of communication, especially for learners whose access to traditional modalities is limited. In this study, students were able to navigate and combine modalities, such as listening to texts via TTS and responding using STT, which reflects a dynamic interplay of receptive and productive skills. This not only supported learners' diverse communication styles but also fostered deeper engagement with the content. In contrast to traditional written tests, multimodal assessments empowered learners with disabilities to take ownership of their learning and perform tasks that previously posed substantial challenges. This shift from deficit-based to strength-based assessment aligns with inclusive assessment principles advocated by Riwayatiningsih et al. [34].

Nevertheless, the challenges faced during implementation must be carefully considered when scaling similar interventions to broader contexts. The reliance on internet connectivity, device compatibility, and teacher readiness remains a major constraint, particularly in under-resourced school environments. Some students, especially those with severe speech impairments, experienced difficulty using STT tools accurately, pointing to the need for customizable voice recognition systems and multimodal input alternatives (e.g., pictorial or keyboard-based dictation). This reflects limitations similar to those noted by Prastikawati, Florian, and Spratt [35,36] in their investigation of technology in language teaching for diverse learners. The findings thus suggest that assistive technologies must be embedded within an inclusive infrastructure that ensures accessibility, ongoing teacher support, and context-sensitive implementation strategies. In addition, more inclusive training for EFL educators is necessary to develop technological pedagogical content knowledge (TPACK) for designing and assessing inclusive tasks using these tools.

This study also opens important avenues for policy and curriculum development in inclusive education within the current framework in Indonesia. The integration of STT and TTS supports its emphasis on differentiated instruction and learner-centered assessment [37–39]. However, for such tools to be sustainably implemented, institutional support in terms of funding, infrastructure, and professional development is crucial. Collaboration with parents, local tech developers, and special education professionals can further enrich the design and evaluation of inclusive digital tools [38]. The results of this study suggest that the national curriculum should formally acknowledge multimodal and technology-assisted assessment as a valid form of measuring student learning outcomes in inclusive classrooms. Furthermore, these findings can inform teacher education programs to include modules on digital inclusion and accessibility in EFL instruction.

Teachers' reflections throughout the project also provide valuable guidance for shaping future professional development and inclusive education policies. Many teachers expressed that participating in this multimodal assessment project expanded their understanding of how assistive technologies can be integrated not only for accessibility but also for pedagogical enrichment [16–18]. These reflections suggest that teacher training modules should emphasize the intersection of technological, pedagogical, and accessibility competencies, aligning with the TPACK and Universal Design for Learning (UDL) frameworks. Structured workshops and mentoring sessions could help teachers develop practical strategies for using STT and TTS tools to design flexible assessments, accommodate diverse learner needs,

and foster equitable participation. At the policy level, these findings indicate the need for inclusive education guidelines that explicitly incorporate digital accessibility standards and support systems for continuous teacher capacity building. Embedding such reflective practices into national or regional teacher development programs would ensure that inclusive technological innovations like STT and TTS become sustainable, scalable, and contextually responsive across special and mainstream educational settings [40,41].

In summary, the study contributes to both theory and practice in inclusive EFL education by demonstrating how STT and TTS technologies can enhance multimodal assessment, foster inclusive participation, and improve student performance. The findings confirm theoretical perspectives from inclusive pedagogy and UDL while also extending the literature by providing empirical data from SMALB settings in Indonesia. By using a mixed-methods approach, the study captured both the statistical impact and the lived experiences of learners and educators, providing a holistic picture of inclusive technology integration. Future research should investigate long-term impacts of these tools on literacy development, explore additional modes such as image-to-text and gesture-to-text, and examine the perspectives of parents and other stakeholders in inclusive education. Ultimately, equitable EFL instruction must not only adapt to student needs but also evolve through the integration of meaningful, context-sensitive technologies [38,39].

5. Conclusions

This study examined the implementation of Speech-to-Text (STT) and Text-to-Speech (TTS) technologies in multimodal English language assessment for students with disabilities in special senior high schools (SMALB) in Semarang, Indonesia. Drawing on a mixed-methods approach, the research found that the integration of these tools supported inclusive pedagogy by enabling students with diverse needs to participate meaningfully in EFL learning and assessment. STT allowed students with motor difficulties to express their ideas orally, while TTS facilitated reading comprehension and listening activities, especially for learners with visual or cognitive impairments. The use of these tools aligned with the principles of Universal Design for Learning (UDL) and inclusive pedagogy, promoting multiple modes of representation and response. Quantitative findings revealed increased student engagement and improved performance, while qualitative data captured students' growing confidence and autonomy. At the same time, the study uncovered challenges, such as technology unreliability, limited voice recognition accuracy, and the need for teacher readiness, pointing to the complexity of implementing assistive technologies in under-resourced inclusive settings. Overall, the study contributes to the growing body of research on inclusive digital education and highlights the potential of STT and TTS tools to enhance equitable access, personalized instruction, and meaningful assessment in EFL classrooms for students with disabilities.

The implications of this study extend to classroom practices, teacher training, and educational policy. EFL teachers in inclusive settings should be encouraged to adopt STT and TTS tools not merely as accommodations but as integral elements of multimodal and differentiated instruction. Professional development programs must equip teachers with the skills to design inclusive lesson plans and assessments using assistive technologies. Furthermore, school leaders and policymakers must ensure that infrastructure, such as devices, internet access, and technical support, is readily available in SMALB and other special education institutions. The Merdeka Curriculum's emphasis on student-centered and differentiated learning could be further strengthened by explicitly integrating guidelines for inclusive digital assessment. In addition, cross-sector collaboration between educators, software developers, parents, and government bodies. This is essential to create sustainable, context-sensitive technological solutions that accommodate local language and disability needs. Future research should explore the long-term impacts of these tools, develop more inclusive applications tailored to local contexts, and assess the role of families and communities in supporting inclusive technology use. Ultimately, the findings affirm that inclusive digital assessment is not just a technological innovation, but it is a moral and pedagogical imperative for ensuring every learner's right to equitable, meaningful education.

Author Contributions

Conceptualization, W.W. and L.M.S.; methodology, W.W.; software, L.M.S.; validation, W.W., Y.Y. and E.F.P.;

formal analysis, W.W.; investigation, H.P.; resources, E.F.P.; data curation, H.P.; writing—original draft preparation, W.W.; writing—review and editing, W.W. and L.M.S.; visualization, H.P.; supervision, W.W.; project administration, E.F.P.; funding acquisition, H.P. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Universitas Persatuan Guru Republik Indonesia Semarang and Approved on May, 2025.

Informed Consent Statement

Informed consent was obtained from all subjects involved information about the research objectives, procedures, and their rights, including the option to withdraw at any stage without penalty in the study.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. However, they are not publicly accessible in order to protect participant confidentiality and comply with privacy regulations.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix A

Table A1. Research Intervention Procedure.

Phase	Week(s)	Activities Conducted
Orientation & Familiarization	1–2	- Teachers trained in STT/TTS integration - Students introduced to apps in simple tasks. - Trial use during warm-up activities.
Pre-assessment Phase	3–4	- Baseline tasks in speaking, writing, listening, reading. - TTS provided input for reading passages and task instructions - STT tested for short spoken responses.
During Assessment Phase (Cycle 1)	5–7	- STT used for speaking tasks (narration, dialogue). - TTS used for listening comprehension tasks - Combined use for integrated speaking–listening activities.
During Assessment Phase (Cycle 2)	8–10	- Writing tasks via STT (paragraphs, short essays) - Reading texts delivered by TTS. - Peer collaboration encouraged (pair/group work).
Post-assessment Phase	11–12	- STT used for student reflections (oral-to-text journals). - TTS used to deliver feedback and model correct sentences - Students revised work based on audio feedback.

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