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RESEARCH ARTICLE

A Holistic Approach to Enhance Learning Experiences for People With Hearing Disabilities in Online and Traditional Classroom Settings

MARIO PEREZ-ENRIQUEZ, JOSE LUIS LÓPEZ-CUADRADO, AND ISRAEL GONZÁLEZ-CARRASCO

Universidad Carlos III de Madrid, ROR: https://ror.org/03ths8210, Computer Science and Engineering Department, Avenida de la Universidad, 30 (edificio Sabatini), 28911 Leganés (Madrid), España

Corresponding author: Israel González-Carrasco (igcarras@inf.uc3m.es)

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ABSTRACT Digital technologies are key to how knowledge is communicated and accessed in the constantly changing educational landscape. Accessibility, which guarantees that everyone, regardless of ability, has equal opportunity to interact with educational content, is fundamental to this growth. This paper presents an integral framework for hybrid and online learning environments that provides different functionalities to address the diverse needs of students with disabilities in educational environments. The approach focuses on accessibility and user-centric design. It includes features like live transcription, synchronized recordings, and compatibility with assistive technologies to ensure equitable access to educational content and promote user engagement. The framework emphasises the live session features, AI-generated content, and the system's ability to improve accessibility and user engagement. Moreover, integrating a Learning Management System (LMS) streamlines the teaching and learning process, offering educators and students a centralised platform for accessing essential resources. The paper also includes a detailed account of the user testing conducted to evaluate the framework's effectiveness and usability. A comprehensive analysis of user feedback, auto-generated resource examples, and a thorough examination of various user scenarios have been undertaken to evaluate the system's performance comprehensively. The overall perception of the proposed system achieves remarkable results, obtaining an average valuation of 4,46 out of 5.

INDEX TERMS Accessibility, education, natural language processing, machine learning.

I. INTRODUCTION

IN the evolving landscape of education, digital technologies play a pivotal role in shaping how knowledge is accessed and shared. Central to this evolution is the principle of accessibility, ensuring that all individuals, regardless of their abilities, have equal opportunities to engage with educational content. This paper introduces an integral framework for online and hybrid classrooms, focusing on its live session functionality, AI-generated resources, and potential to enhance accessibility and user interaction.

Students, especially students with disabilities, need support for their learning process. For students with hearing disabilities, several studies have analyzed their specific needs [1], [2]. Students with hearing disabilities may benefit from automatic transcriptions and sign language

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interpretation.Acknowledging students' diverse learning needs, the system offers extensive customization options to facilitate individual preferences. Users can tailor their learning environment by adjusting layout, content visibility, and navigation settings. Additionally, adjustable font sizes and colour schemes cater to individuals with visual impairments, promoting inclusivity and ensuring full engagement with educational content.

The live session feature facilitates seamless video, audio, and screen content sharing, fostering effective communication and participant collaboration. Integrated live transcription and subtitle functionality ensure clarity for all users, particularly benefiting those with hearing impairments.

Moreover, the platform leverages AI to generate resources that enhance the learning experience. AI-driven algorithms automatically produce transcription documents, synchronized recordings with auto-generated subtitles, and unique notes documents, providing valuable tools for reviewing and reinforcing course materials.

Furthermore, the web platform is a comprehensive Learning Management System (LMS), offering a centralized hub for accessing course materials, participating in live sessions, and engaging in collaborative activities. The system streamlines the teaching and learning process by consolidating essential features into a single platform, promoting efficiency and effectiveness.

The paper also presents the outcomes of user tests conducted to evaluate the efficacy and usability of the framework. Through a detailed examination of various user scenarios, examples of auto-generated resources, and analysis of user feedback, we offer a comprehensive assessment of the system's performance. This includes insights into the types of questions raised during testing, the corresponding results, and practical scenarios demonstrating the application of the platform's features. By integrating user testing data into our analysis, we aim to provide a balanced evaluation of the web portal's functionality and its impact on improving accessibility and user experience in educational environments.

This research paper aims to delve into the functionality and architecture of the web portal, focusing on key features such as live transcription, subtitles, and extensive customization options. Through a detailed examination of these features, the paper seeks to provide insights into how the platform offers a holistic solution for classroom environments. By emphasizing integrating innovative technologies and user-centric design principles, the platform aims to create an inclusive and engaging learning environment for all users. In summary, this work's main contributions are a learning framework with features to enhance learning accessibility and the results of the efficacy and usability evaluation of these features performed with users with hearing and without disabilities.

The paper consists of six sections and is structured as follows. Section II reviews the relevant literature and the domain background associated with accessibility issues in education. Sections III and IV expose the main features of the proposal, including the architecture of the framework, components and pipelines. Section V presents the evaluation and results obtained, and Section VI discusses the conclusions and future lines of research.

II. BACKGROUND

Creating an inclusive educational environment is not just a matter of providing access to resources; it's about ensuring that every student, regardless of their abilities, has the same educational experience. In the dynamic landscape of modern education, this involves addressing a myriad of challenges that students with disabilities encounter in both physical and online classrooms [3], [4].

According to Article 26 of the Universal Declaration of Human Rights [5], the right to education is a fundamental human right. The Universal Declaration states that all boys and girls should be entitled to free basic education. Everyone should have equal access to education, without exception, and special consideration for vulnerable groups. This would allow adults and children to develop their abilities and skills and actively participate in society. Accessibility is becoming increasingly important for individuals with disabilities. Children with disabilities make up one of the many groups of children in developing countries who are still not enrolled in elementary school. However, legislators are becoming more aware of educational exclusion and their entitlement to an education [6].

Moreover, the Salamanca World Conference on Special Needs Education endorsed the idea of inclusive education involving the Education for All (EFA) strategies. This is one of the most significant international documents that has ever appeared in the field of special education. The Salamanca Statement argued that regular schools with an inclusive orientation are ''the most effective means of combating discriminatory attitudes, building an inclusive society and achieving education for all'' [7], [8].

Hearing impairments, for instance, pose significant communication barriers. Traditional and online classrooms often rely heavily on auditory instruction, leaving students with hearing impairments struggling to access information and fully engage in discussions [9]. The lack of consistent availability and integration of assistive technologies, such as real-time captioning, further exacerbates these challenges, leading to feelings of isolation and exclusion from classroom interactions critical for learning and social development.

Visual impairments present another set of obstacles. Essential course materials, including printed textbooks and visual aids, may be inaccessible to students with visual impairments [10]. Moreover, physical classroom barriers, such as inaccessible seating arrangements or navigation challenges, can impede their mobility and independence. The lack of optimization for screen readers and alternative navigation methods in online environments further complicates access to educational content and resources.

Students with intellectual disabilities require personalized teaching approaches and accessible learning materials to meet their diverse needs [11]. However, traditional classroom

settings often struggle to provide flexibility and support, reducing engagement and comprehension. Additionally, these students may require additional social and emotional support, which may not be readily available or adequately addressed in mainstream educational settings.

Considering the requirements of students with disabilities discussed so far, the proposed system includes accessibility support during the class. It provides additional materials at the end of the class. In section V, we include specific questions about the usefulness of the features provided by the system.

In this context, E-learning can be an effective educational approach for people with disabilities to acquire self-determination and empowerment. This can happen thanks to flexibility, interactivity, and the customization of a learning pathway. E-learning is also incisive because it can eliminate time-space constraints [12].

The development of new web technologies, the ease of access to the Internet, and the growing desire for flexible learning have all contributed to the global adoption of online learning [13], [14]. Particularly with COVID-19, online learning has become increasingly popular and widely used. The significance of instructional videos in online learning cannot be overstated since they directly impact students' pleasure and online learning results [15].

Moreover, since the impact of the COVID-19 pandemic along with the development of information and communication technology (ICT), the paradigm of the learning process has shifted from traditional classroom to distance learning systems [16], [17]

To stem the coronavirus's spread, governments began acting in March 2020, closing schools and almost instantly implementing remote learning. In the end, around 150 countries closed their schools [18]. In response to the COVID-19 educational crisis and to avoid the risk of depriving their students of education, the majority of institutions, particularly those in upper secondary and higher education, shifted from traditional in-class education to online teaching and learning by the end of March 2020 [19].

However, the COVID-19 pandemic showed that inclusive videoconferencing technologies are as important as accessible educational platforms. Even though real-time transcription and video conferencing capabilities are readily available, current solutions frequently fail to address the unique accessibility needs of students with visual and hearing impairments in the educational context. Therefore, studies on platforms like Teams, Zoom, and Google indicate that accessibility still needs to be improved to satisfy the requirements of those with disabilities [20], [21].

For instance, Zoom was favoured over Google Meet and MS Teams, according to the study reported in [22]; nevertheless, none of the tools was completely accessible using a keyboard and screen reader. Limited personalization and minimal engagement with the content are two further restrictions that have been noted. Reference [23] performed a heuristic expert evaluation of the main videoconference tools using a checklist based on accessibility requirements drawn from standards, concluding that while all platforms address some accessibility aspects, none fully cover all criteria. In this regard, it is crucial to combine an accessible videoconferencing system with an accessible portal so that the student can access all of the information. Adding multimedia resources, instructional platforms, videoconferencing capabilities, and supplemental materials is crucial to hybrid learning and offers opportunities to improve accessibility, claim [24].

The creators of [25] describe a web-based platform that allows for the synchronized and configurable presentation of subtitles in single- and multi-screen scenarios. Although it is not incorporated into a learning environment, this environment might be utilized for online learning. During the pandemic, [26] integrated a video conferencing system with an online education gaming environment for children with special education requirements, emphasizing students with an autism diagnosis. Numerous articles explain and review the use of videoconferencing tools and online learning platforms. Nevertheless, there is a deficiency in integrating video conference systems, learning management systems, and student-required accessibility features.

Additionally, since simultaneous content transmission (audio, audio description, captions, sign language interpretation, and presentations) is a significant concern for educators and students, it must be addressed [9]. In this study, we provide an online teaching platform that integrates various accessibility features (audio description, sign language interpretation, and captions) with the components of a video conference system and learning management system.

Proactive measures and innovative solutions are essential to address these multifaceted challenges. The proposed platform, focusing on accessibility, user customization, and adaptive resources, aims to break down communication barriers, provide tailored learning experiences, and ensure equitable access to education for all students. By prioritizing inclusivity and accessibility, the web portal seeks to create an educational environment where every student feels valued, empowered, and capable of achieving academic success.

III. PROPOSED SYSTEM

In response to the complex challenges confronting students with disabilities in educational contexts, the proposed system offers a holistic approach to enhance their learning experiences. By acknowledging and addressing the diverse needs and obstacles encountered by individuals with various disabilities, the system aims to foster accessibility and active engagement in both online and traditional classroom settings. The subsequent analysis examines the system requirements objectively, assessing their potential to impact learning outcomes for students with disabilities positively:

- **User-centric design**: The platform prioritizes a user-friendly interface, ensuring ease of navigation for students with diverse abilities. A clear and intuitive layout and consistent design elements enhance accessibility and usability. Additionally, the customizable interface caters to individual needs and preferences.

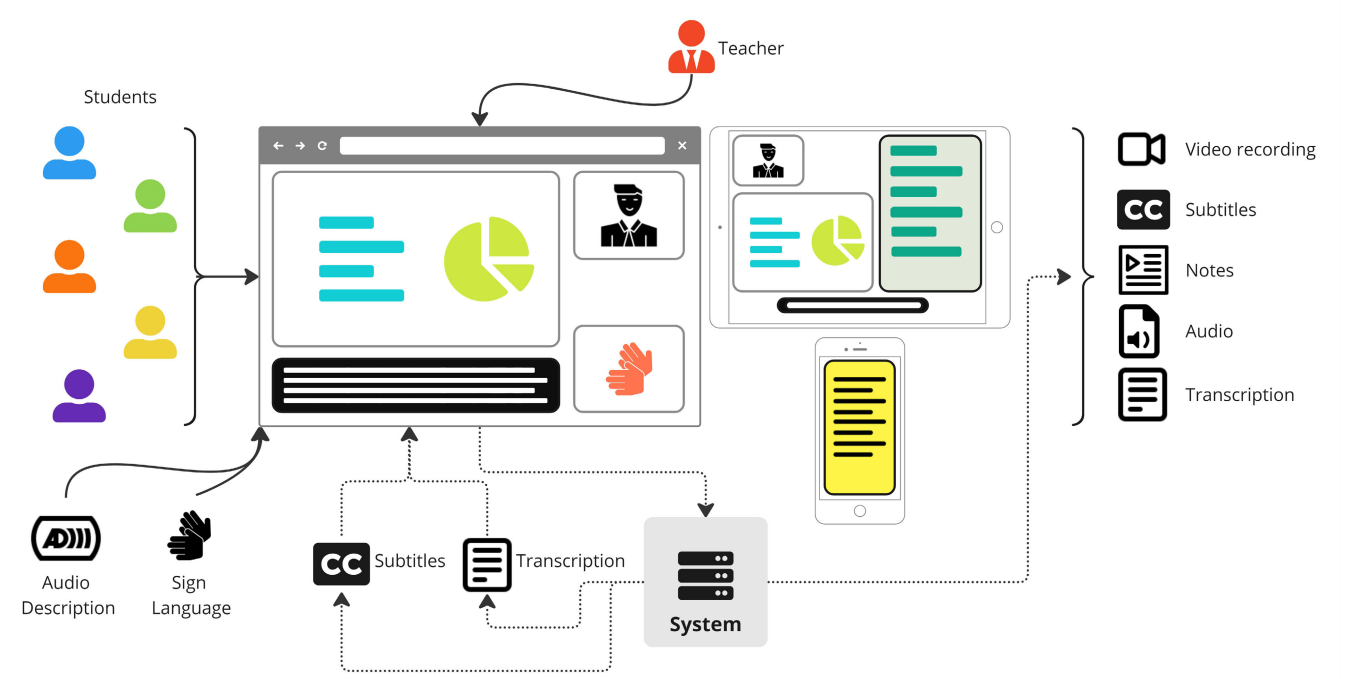

FIGURE 1. System overview.

- **Live Transcription and Subtitles**: This feature integrates live transcription and subtitle functionalities, catering to students with hearing impairments. It ensures access to spoken content during live sessions by providing synchronized text-based representations of verbal communication, allowing lookback, so the students can see what was previously explained in the session. This enhances comprehension and retention for students relying on visual or text-based information. Additionally, the platform can include channels for non-automatic sign language interpretation and audio description to accommodate students' specific needs.
- **Transcription Document**: The platform automatically creates a transcription document after each session. This resource is particularly beneficial for students with hearing impairments and those with visual or cognitive disabilities. It allows users to revisit class content, facilitating comprehension and review of key concepts. The transcription document serves as a detailed record of the session's dialogue, providing users with an accessible overview of the discussion.
- **Notes Document**: This unique feature combines transcripts of sessions with synchronized scene transitions, providing a dynamic resource suited to diverse learning styles. It is an extensive reference tool, allowing users to revisit course content at their convenience, thereby facilitating understanding and reinforcing important concepts.
- **Synchronized Recordings with Automatic Subtitles**: Through synchronized recordings, students can revisit lectures at will. They can control the playback speed, pause, rewind, and take notes as needed, all while accessing automatically generated subtitles that enhance comprehension. Additionally, accompanying auto-generated notes provide supplementary information, facilitating deeper understanding and retention of the lecture content.
- **Integrated Learning Hub**: The proposed system functions as an all-in-one Learning Management System (LMS), providing educators and students with a centralized platform. Seamlessly integrating live sessions, course content, and auto-generated resources simplifies teaching and learning processes. Instructors can manage materials and conduct sessions while students access resources.
- **Support for Assistive Technologies**: The system's compatibility with assistive technologies, such as screen readers and alternative input devices, is vital for ensuring equal access for students with disabilities. Rigorous compatibility testing and adherence to accessibility standards, such as the Web Content Accessibility Guidelines (WCAG), are necessary to guarantee an accessible user experience.

To the best of our knowledge, we have not found a similar framework that includes all the proposed features together. Despite in this paper the system is tested with people with hearing disabilities, the proposed system has been designed to address the diverse needs of students with disabilities, providing a range of functionalities that enhance accessibility in educational settings.

For students with hearing impairments, live transcriptions, and subtitles enable them to follow classes in real-time, allowing students to revisit any part of the transcription for clarification. These aspects are relevant because if the students get lost during the explanation, they can go back to the live transcription, review the previous speech, and continue with the class. Moreover, a sign language interpreter can join sessions to offer additional support when needed. Including a specific sign language channel allows students who prefer (or need) the sign language interpretation to follow the class. Additionally, synchronized video recordings with automatic subtitles are valuable for reviewing class content as if attending the session live. These students also benefit from the detailed transcription and notes documents, further aiding their comprehension. When the session has sign language interpretation, it is also included in the recording.

Students with visual impairments benefit significantly from the system, particularly through the automatically generated notes document, which provides the visual content of the session along with the transcription. In addition, an audio description provider can join the session to ensure visual content is accessible. Also, the customizable Live Sessions UI of positions, font sizes, colours and contrast allows these students to enhance their experience. In addition they can review the contents by listening to the recorded audio file and by using screen readers for the transcription document.

The system also addresses the needs of students with intellectual disabilities. These students benefit from the real-time transcriptions and subtitles, which help them to keep pace with the lecture. The ability to revisit missed information in the transcriptions is key. After the session, the auto-generated notes, transcription documents, and video recordings with subtitles allow them to review the material at their own pace, improving their understanding and retention.

In addition to these tailored features, all users benefit from the system's accessible and customizable user interface. Teachers can also edit and refine the auto-generated content using the system's UI, ensuring accuracy and adding more context such as captions for images. Moreover, integrating the system with a Learning Management System (LMS) streamlines the teaching and learning process, offering a centralized platform for both educators and students to access essential resources. Figure 1 provides an overview of the system architecture. Next section describes the system design in detail.

IV. SYSTEM DESIGN

This section explores the system's architecture, comprising essential components like the Frontend, Content Management System (CMS), LiveSessions API, NLP API, and Media Server. This structural overview sheds light on how these elements collaborate to facilitate user interaction and content management within the platform.

The application accommodates three user roles: teachers, students, and providers. Teachers can create courses and live sessions and manage user access and course materials. Students have access to course materials and can participate in live sessions. Providers offer sign language interpretation and audio description services, aiding users with hearing or visual impairments during the live sessions.

A. FRONTEND

The platform's user interface is carefully designed to prioritize accessibility and adhere to industry-standard design principles. Extensive mockups and iterative design processes were employed to refine the user experience, ensuring intuitive navigation and usability for all users. This approach focuses on usability, accessibility, and user preferences, resulting in an interface that offers optimal functionality and ease of use. By identifying and addressing potential design flaws early, the final interface provides a seamless experience for users with diverse needs.

The Frontend is the gateway for users to access the application, courses and live sessions. It is the interface through which users interact with the platform, facilitating easy navigation and engagement with educational resources. It has been developed using Angular alongside Material design for component styling, ensuring an accessible and intuitive user interface. Additionally, it's designed to seamlessly adapt to various device formats, including desktops, tablets, and mobile devices, accommodating multiple input methods for enhanced usability across different platforms.

Particular emphasis was placed on ensuring accessibility for users who rely on screen readers. The semantic meaning of HTML tags and the logical hierarchy of elements were carefully considered to facilitate intuitive tab navigation. This meticulous attention to detail ensures that all users, including those with disabilities, can effortlessly navigate the platform and engage with its features. In addition, it includes an audio alert system tailored for users with visual impairments, providing auditory cues for changes within the application.

The user interface contains many views, however, we will only focus on the main page where users can access their courses and sessions, an example of a course page and the live sessions page.

The primary page layout follows a standard format, featuring a top bar, sidebar, and main content sections. This consistent structure promotes ease of navigation and familiarity, enhancing the user experience. A search button triggers a modal search bar, enabling users to efficiently locate courses and sessions, improving accessibility regardless of navigation preferences or abilities. Additionally, the sidebar provides convenient access to sessions and courses, which users can toggle via a button on the top bar. This design choice enhances accessibility by allowing users to personalize their viewing experience based on individual preferences. Clear visual cues and animations further contribute to the user-friendly interface.

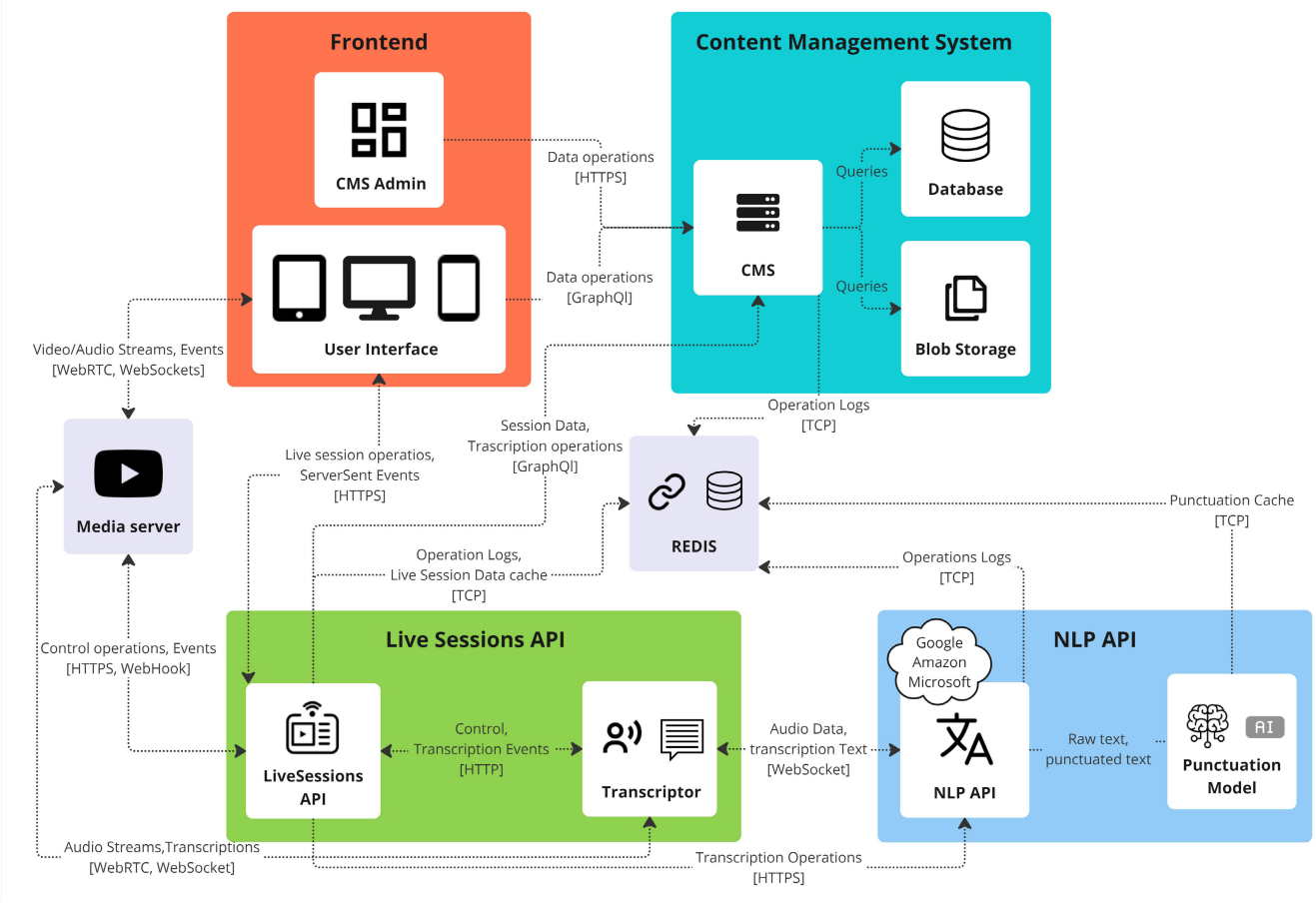

FIGURE 2. System architecture and connections.

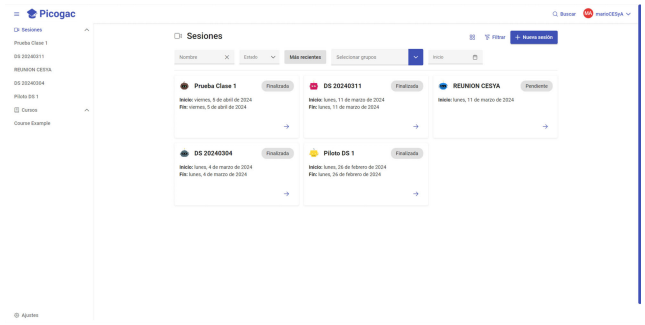

FIGURE 3. Sessions list view.

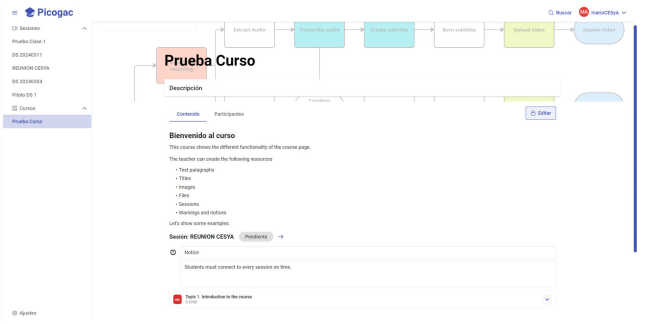

FIGURE 4. Course view.

Moreover, the main content section offers flexible display options, presenting either a list of courses or sessions, with the session list also available in a grid format. This adaptability caters to diverse user preferences, offering multiple viewing options to enhance usability. Notably, for the sessions list, minimal information is displayed for each item, such as session name, status, dates, and groups, with additional details available in a detailed view. This layout is shown in Figure 3.

In Figure 4 the course view interface enables teachers to share various content resources like images and files efficiently. They can customize the course page by adding titles and paragraphs and rearranging items. Teachers can also link sessions to courses and manage user access, facilitating smooth course administration. In addition, this view consolidates access to course content and live sessions within a single platform, offering users convenient access to their course materials and seamless integration with live sessions.

The live session view offers users a customizable layout, enabling them to arrange and resize items to suit their preferences. A sidebar on the right provides access to

FIGURE 5. Live session view 1.

FIGURE 6. Live session view 2.

additional features, while a bottom button dock offers quick access to essential functions. Additional items dynamically appear in the main section when users share their camera or screen, allowing them to interact with content as needed. Users have control over adjusting, resizing, showing, hiding, or making items full-screen, granting them flexibility in their viewing experience.

The transcription panel showcases live transcriptions and captions with customizable background colours and text sizes for improved readability. Users can personalize their viewing experience by associating each transcription with a customizable colour. The sign language interpretation panel and audio description channel can be toggled on or off based on user preferences.

Accessible via a toggle button at the top right corner, the sidebar gives users access to various features in a tabbed interface. Users can easily navigate between chat, participant list, and device settings, simplifying access to essential functions. Users can engage with others in the chat tab using different message types, each colour-coded for easy identification. The participant list tab empowers teachers to manage session permissions, while the transcription panel allows users to customize colours for improved accessibility. Adjustments made by users are automatically saved between sessions, ensuring consistency in their experience. Figures 5 and 6 show different configurations of the Live Sessions' interface.

Finally, the system relies on the CMS to populate views with data and authenticate users. Additionally, it depends on the LiveSessions API to facilitate live session functionality.

B. CONTENT MANAGEMENT SYSTEM

It provides the central data access point and user authentication within the system. It encompasses the data layer responsible for storing course materials, user profiles, and session information while also ensuring secure access to other system components through authentication services. Additionally, the CMS features an admin panel for administrators to configure system settings, manage user permissions, create groups and users and oversee platform activities.

In terms of data storage, it uses a relational database to store normalized data, including course materials, user profiles, and session information. Additionally, it employs a storage blob to store large files effectively. This separation allows for efficient management of different data types within the system, ensuring scalability and reliability.

It has been built using Strapi, a robust content management system allowing extensive customization. In addition, it facilitates efficient data modeling and diverse access mechanisms while providing administrators with an intuitive interface for content visualization and editing. Its role-based access control system offers precise data access and operations management, contributing to a secure and organized system environment.

Finally, it logs all operations on the REDIS instance to ensure system observability.

C. LIVESESSIONS API

It acts as the central hub for all live session functionalities within the platform, handling session scheduling, user authentication, and communication with the Media Server for audio and video streaming. The media server management is facilitated through a client that listens to a Webhook channel, enabling it to respond to session lifecycle events. These events are then broadcasted to users using Server-Sent Events (SSE). Additionally, it interfaces with the CMS for data retrieval and authentication. Furthermore, it connects to a Redis Instance to cache session data, enhancing performance and providing lifecycle updates for data changes in the CMS.

Developed using NodeJS, specifically NestJS, the system offers a robust and scalable foundation, which provides a REST API independent from the frontend implementation.

Moreover, the LiveSessions API is responsible for transcribing the sessions, using a unique approach involving the creation of a "ghost" participant in the session. This implementation uses a chromium instance, wherein each tab is a transcriber client connected to the session. The "ghost" participant captures and listens to the audio streams from each user, subsequently transmitting this audio data via Web Socket to the Natural Language Processing API for conversion to text. These text responses are then broadcasted to all session participants utilizing the media server signals mechanism, ensuring the seamless flow of transcriptions in real time.

Additionally, the LiveSessions API manages the creation of autogenerated resources such as notes, transcriptions, and

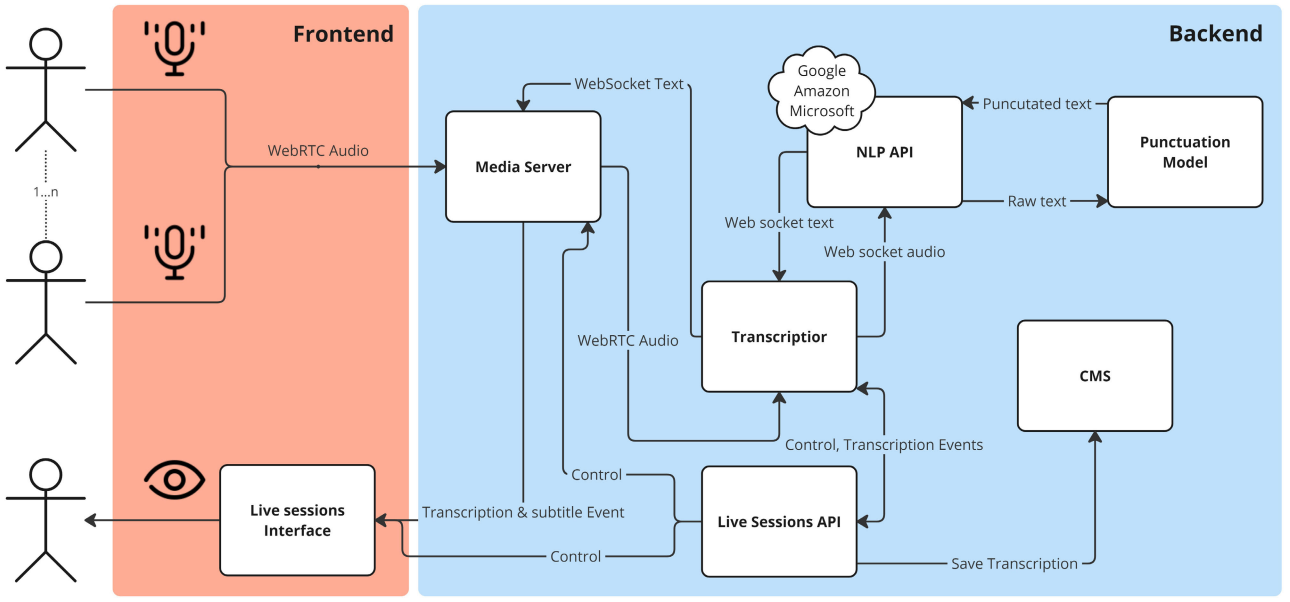

FIGURE 7. Live transcription proccess.

recordings with automatic subtitles. It listens to session completion events and executes the necessary tasks accordingly. The resource generation process is shown in Figure 8.

The generated documents are the following:

- **Transcription document**: Created from the final response outputs of the NLP API speech service during live sessions, this document presents transcriptions ordered by creation date and identified by the user. Available in PDF and plain HTML formats for accessibility to screen reader users.
- **Video & audio recording**: Generated by downloading recordings from the Media Server, processed using FFMPEG to extract audio, transcribe, and embed subtitles into the video file. The resulting video and audio are uploaded to the platform in MP4 and MP3 format, respectively.
- **Subtitle file**: Produced by utilizing the NLP API speech service to transcribe the full video, processing the response output with a set of rules to generate a WebVTT subtitle format.
- **Notes**: Generated by extracting images using a scene detection algorithm from the video recording. The time information of the images and the transcription extracted from the NLP API are then combined into a document available in PDF and HTML formats.

Finally, it logs all operations on the REDIS instance to ensure system observability.

D. NLP API

The NLP API is tasked with live transcription and subtitle generation during live sessions. It's designed to be versatile, integrating seamlessly with various speech-to-text services like Google, Azure, and AWS. This flexibility allows for straightforward integration with additional services if needed.

Developed using Node.js, particularly NestJS, the NLP API offers a robust API featuring REST and WebSocket endpoints. WebSocket is crucial in providing real-time transcriptions for session audio streams, leveraging speech services. Each audio stream has its streaming recognizer and corresponding WebSocket for efficient data transmission. Transcription services typically provide interim and final recognition results. While interim results are immediate, they may change until a final result is received. To balance accuracy and speed, interim results are sent immediately, and the Frontend can choose to aggregate them over time to improve stability.

For live subtitles, interim results are aggregated, and a subtitle result, which may include multiple segments, is produced every 4000ms. However, the front end only displays them after a 1-second delay to ensure subtitle quality while minimizing latency.

Before transmitting transcriptions and subtitles, the speech API output undergoes further processing using an in-house trained Transformers model. This step automates punctuation, which is crucial for languages like Spanish, where standard speech-to-text APIs offer limited punctuation functionality. Trained on diverse corpora, the Transformer Model delivers state-of-the-art results for Spanish language transcriptions. As latency is paramount, the models are converted to their quantized versions using Onnx, in addition to temporarily caching the punctuation results in the REDIS instance. The transcription process is shown in Figure 7.

Finally, it logs all operations on the REDIS instance to ensure system observability.

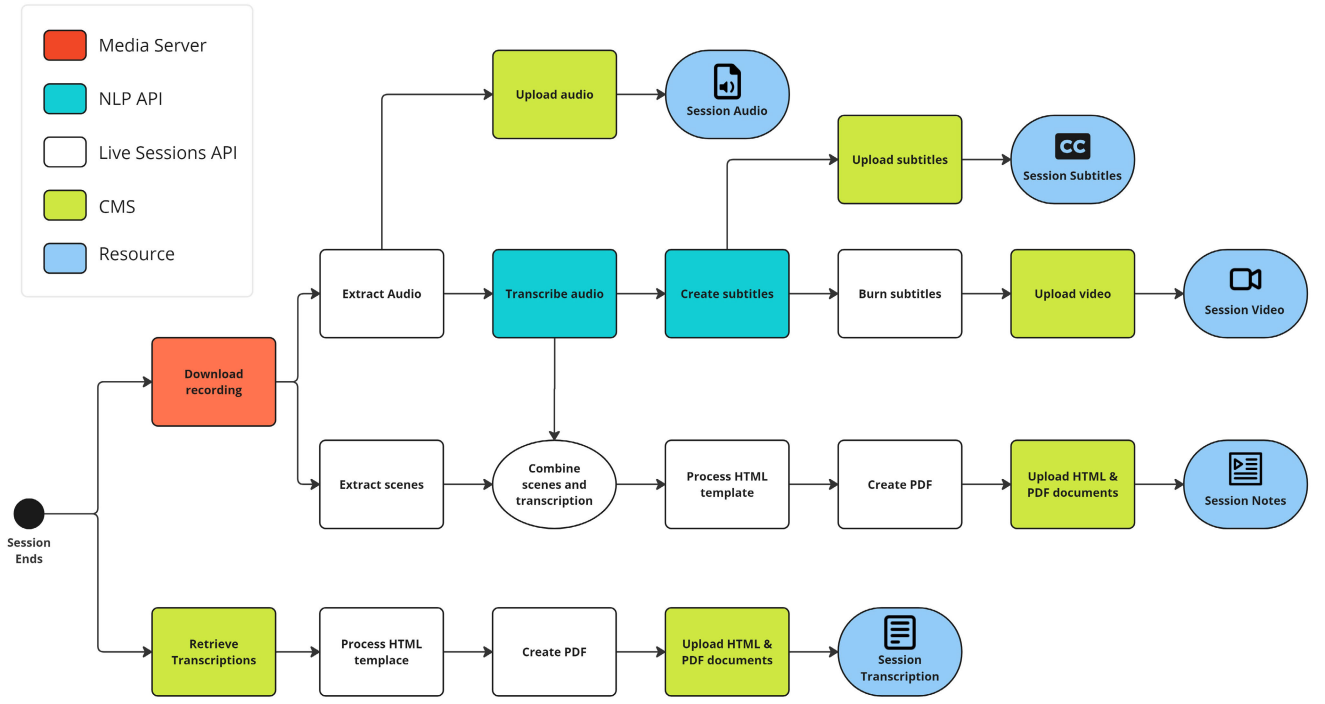

FIGURE 8. Live session auto-generated documents.

E. MEDIA SERVER

The system utilizes OpenVidu, a robust WebRTC solution, to handle data and signalling planes. WebRTC enables real-time communication over web browsers through APIs and protocols. OpenVidu simplifies integration into web and server applications by providing an abstraction layer over WebRTC.

In the system, WebRTC facilitates audio, video, and data transmission between users in live sessions, enabling direct peer-to-peer communication without intermediary servers. OpenVidu manages the complexities of establishing and maintaining these peer connections, ensuring seamless communication.

OpenVidu adopts an event-driven architecture on the signalling plane, efficiently handling session negotiation and management. This architecture enables smooth message exchange between the Frontend and LiveSessions API for tasks like session initiation, participant management, and session lifecycle.

The media server implementation offers recording capabilities through a web template. This template operates similarly to the ''ghost'' participant in live sessions, seamlessly joining the session without other users' awareness. Once it joins a session, it functions like a standard client, displaying media streams within the UI provided by the live template. However, the layout of the template can be managed by the presenter. This feature allows presenters to dynamically control the recording layout in real time, determining which elements are included or excluded from the recording and whether specific user streams are captured.

Finally, Figure 2 shows the complete system architecture with the different functionality blocks, components and the connections between them.

V. USER TESTS

The system has been tested by teachers and students at Universidad Carlos III de Madrid and associations of people with hearing disabilities. To that effect, all participants signed an informed consent to participate in the experiment.

For testing the tool, 48 students and 2 professors from Universidad Carlos III de Madrid and associations of people with hearing disabilities participated in the experiments. 18 participants had hearing disabilities, 16 students were part of a Master's Program, 15 were part of a second-year degree program, and 17 were part of an association of people with hearing disabilities from 18 to 32 years old.

All participants received a class that lasted around 20 minutes. The students took the class and connected to the system with their devices (laptops and tablets). Each student connected using anonymous users randomly assigned and configured the environment according to her preferences, including the transcriptions and the projection of the class contents.

Once the students connected, the teacher exposed the class contents, similar to those of regular classes. The teacher used

TABLE 1. Questionnaire for students.

Please answer the following questions and choose the option that best suits your opinion. Options from 1 to 5, where 5 is the best and 1 is the worst.
Common questions in all experiments
1. Has the speed of the subtitles allowed you to follow the class well? (Very fast, Fast, Speed was good, Slow, Very slow)
2. Have you noticed a lot of mistakes or spelling mistakes in the subtitles? (None, Too Few, Few, Many, Too Many)
3. Do punctuated captions help you understand the class better?
4. Does the transcript help to understand what was explained at the end of the class?
5. Overall, how would you rate the tool?
Questions related to recordings (experiments 2 and 3)
6. At the end of the class, does the recording help to understand what was explained?
7. Do the captions in the recording follow the audio?
8. How would you rate the quality of the subtitles in the recording?
Questions related to automatically generated notes and overall satisfaction with the tool (experiment 3)
9. At the end of the class, do the notes generated help to understand better what was explained?
10. Did you follow the class better, thanks to the tool?
11. I think using the tool will help make the class more interesting
12. I believe that the tool can improve teaching in the subjects
13. I have used other videoconferencing or online teaching tools (Blackboard Collaborate, Zoom, Google Meet...)
14. I think this tool unifies the content and teaching of the class well.
15. I would like to use this tool in the rest of the classes
16. I would like to use this tool in other subjects
17. Using the tool has distracted me

simple Bluetooth earbuds connected to his laptop for the microphone.

Finally, after attending the class and reviewing the automatically generated recording and class notes, the participants answered the questionnaire presented in table 1. The question related to the speed of the subtitles was answered with values from ''very slow'' to ''very fast'', and the question related to the number of errors perceived in the automatic transcription was answered with values from ''None'' to ''Too many''. The rest of the questions were answered with values from 1 to 5, where 5 corresponded with the best valuation and 1 with the worst.

The test took place in three different experiments. Table 2 summarises the organisation of the three sessions, the number of students and the questions they answered at the end of the experiment. The students were not currently using a similar system to compare with. All participants answered the question ''Overall, how would you rate the tool''.

In experiment #1, 16 Master's degree students received a class using the tool. In this first experiment, students only followed the class using the proposed tool, and at the end of the class, they could review the transcription generated.

In experiment #2, 17 students with hearing disabilities received the class using the tool like experiment #1. Apart from the transcriptions, at the end of the class, the students received a recording with slides, captions and audio automatically generated by the system.

In experiment #3, 15 students with a 2nd-year degree received a class using the tool like experiment #1. In this last experiment, at the end of the class, they viewed an automatic recording of the speech and slides with automatically generated captions (like experiment #2) and a document with the class notes generated by the system.

The class notes combined the transcription with screenshots taken from the slides, and the system generated them automatically. Figure 9 shows a capture of the recording. It contains the automatically generated captions. The system integrates the captions as closed captions in the recording so that the students can choose whether to show them according to their preferences and disabilities. Before sharing the class notes, the teacher edited the notes to solve a small number of transcription errors and some format adjustments. Figure 10 shows a sample of the result. The video with the automatically generated captions was shared as is, without any post-editing.

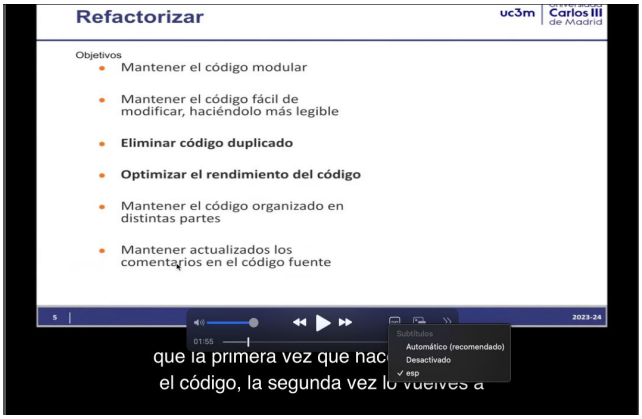

FIGURE 9. Capture of the automatically generated recording.

To evaluate the system, the results of the experiments may be classified into three different parts.

- Evaluation of the live transcriptions during the class and the overall perception of the tool (questions 1 to 5 of the questionnaire). All students from the three experiments answered these questions.
- Evaluation of the automatically generated videos with the slides and the audio of the class, as well as automatically generated captions (questions 6 to 8 of

TABLE 2. Summary of experiments.

Experiment	Students	Questions	Tested Features		
			Automatic transcription	Class Recording	Automatic Class Notes
Experiment 1	16	1-5	✓	✗	✗
Experiment 2	17	1-8	✓	✓	✗
Experiment 3	15	1-17	✓	✓	✓

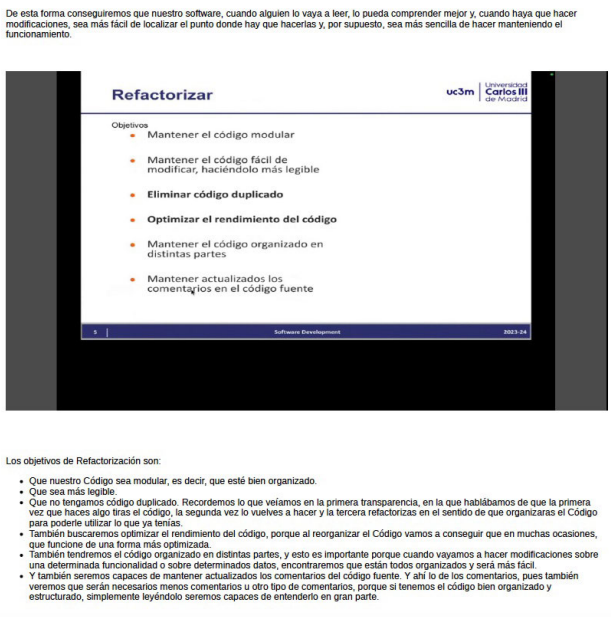

FIGURE 10. Sample of the generated class notes.

the questionnaire). These features were evaluated in experiments #2 and #3.

- Evaluation of the automatically generated notes (questions 9 to 17 of the questionnaire). These features were evaluated in experiment #3.

A. EVALUATION AUTOMATICALLY GENERATED CAPTIONS AND OVERALL PERCEPTION OF THE TOOL

Questions may be classified according to the different aspects involved in using the tool. Questions 1 to 4 were related to the automatically generated transcriptions. Table 3 summarises the answers to these questions. All students answered them, next the results are analysed in detail.

Figure 11 depicts the answers about the perception of the students on the transcriptions speed. It shows that all students perceived the transcription speed as good (67%) and fast (21%). Transcriptions appear a few seconds after the teacher speaks, so these two values fit with the course of the class. The percentage of students with hearing disabilities that perceived the speed as good was 61%, lower than the 70% of students without disabilities. 5% of students with hearing disabilities perceived the transcriptions as slow. 17% of students with hearing disabilities perceived the transcription speed as "Very fast" versus 7% of students without disabilities. This parameter is very dependent on the students. The speed of

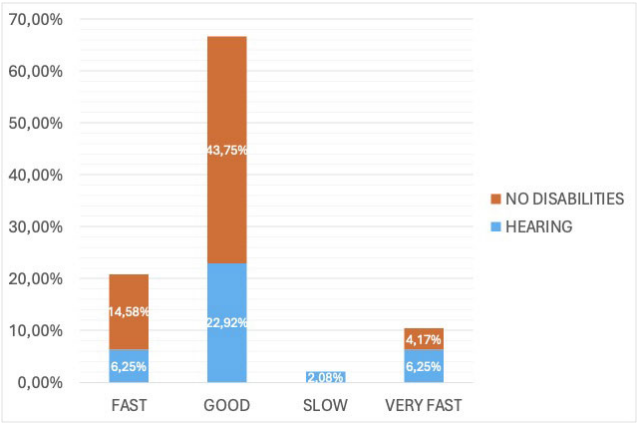

FIGURE 11. Perception about transcription speed.

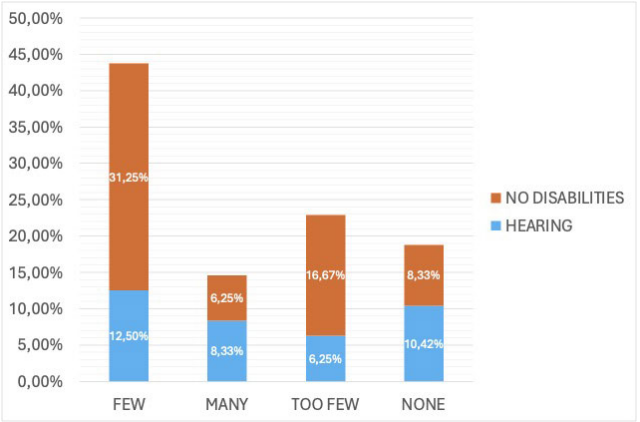

FIGURE 12. Perception about transcription errors.

the transcriptions also depends on the pace of the teacher's speech. In this sense, teachers must adapt their speech's pace to their audience, considering that some (especially those with hearing disabilities) may need to read the transcriptions.

Another important aspect is the perception of transcription errors. Transcription errors are unavoidable, and the number of errors may affect the student's attention and comprehension of the contents. Figure 12 compares the students' error perception. The figure shows that 22% of students with hearing disabilities (8.33% of all students) perceived the number of errors as many, while 28% (10.42% of all) did not perceive transcription errors. The rest of the students with disabilities perceived few or too few errors. Regarding students without disabilities, 10% of students (6.25% of all) perceived many transcription errors, 13% (8.33% of all) did not perceive errors while the rest perceived few or too few.

TABLE 3. Questions about transcriptions and overall evaluation.

	Answers	Very Fast	Fast	Good	Slow	Very Slow
Q1 (transcription speed)	48	5	10	32	1	0
	Answers	**None**	**Too few**	**Few**	**Many**	**Too many**
Q2 (transcription errors)	48	9	11	21	7	0
	Answers	**1**	**2**	**3**	**4**	**5**
Q3 (punctuation help)	48	0	0	3	14	31
Q4 (transcript help)	48	0	0	2	12	34
Q5 (overall evaluation)	48	0	0	2	22	24

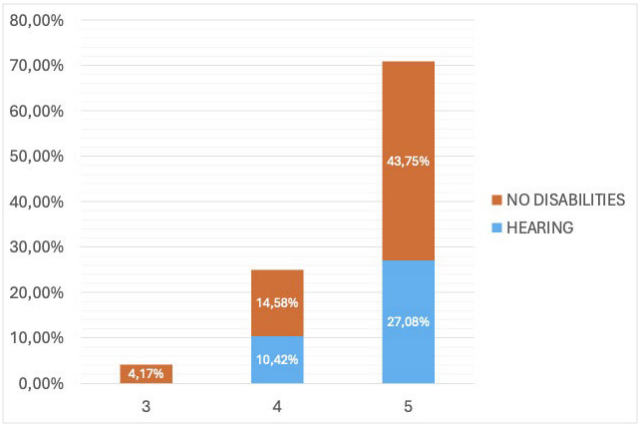

FIGURE 13. Perception of the transcriptions utility (Values from 1-5).

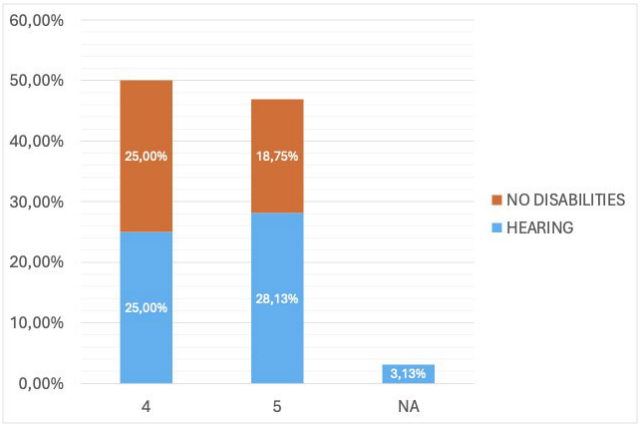

FIGURE 14. Perceived recording utility.

In this case, students with hearing disabilities are supposed to pay more attention to the live transcriptions. For this reason, a higher percentage of students with hearing disabilities perceived the number of errors as many.

Despite the difference in perceptions, the perception of errors is generally few or too few, and the perception of the utility of the transcriptions is 4,67 out of 5. Figure 13 shows how the distribution is uniform between students with and without disabilities, with most of the valuations between 4 and 5 and only two students without disabilities marked the value 3.

B. EVALUATION OF THE RECORDING GENERATED BY THE TOOL

Thirty-two students (14 without disabilities and 18 with hearing disabilities) reviewed a recording generated by the system that only included the slides and the teacher's voice. This recording also contains captions automatically generated and synchronised based on the transcriptions. Table 4 summarises the answers to these questions.

Thirty-one students answered the question related to the utility of the recording (Figure 14) and one did not answer the question. In this case, all students answered 4 or 5. Looking at the graph, students with hearing disabilities rated the recording slightly better than students without disabilities. However, it can be concluded that all students perceive the utility of the automatically generated captions, especially when reviewing the class contents. Nowadays, many people like watching videos instead of reading, which could be one of the reasons for this.

Regarding the quality of the captions (Figure 15), 89% of students with hearing disabilities valued the quality of the captions as 4 or 5 out of 5, versus 78% of students without disabilities. It can be seen that students with hearing disabilities rated the quality slightly better than students without disabilities. The other aspect considered about the captions was the level of synchronisation (Figure 16). 94% of students with hearing disabilities and 86% of students without disabilities valued the synchronisation in 4 or 5 out of 5.

We can conclude that the results obtained with the automatic caption feature are both useful and of high quality, as perceived by the students. Moreover, people with hearing disabilities especially benefit from this feature, being able to review the lecture with captions after class.

C. EVALUATION OF THE AUTOMATICALLY GENERATED NOTES

Finally, 15 students tested the latest feature included in the system. Figure 17 shows the perception of the students about the automatic notes generated by the tool; one of the students didn't answer, while the other 14 students rated the notes between 3 and 5, with 5 being the most chosen answer.

In addition, since the participants were not currently using any similar tool, they were asked about their experience with videoconferences and online teaching tools in this last experiment. Figure 18 illustrates the results, showing that 13 out of 15 students rated 4 or 5 their experience in this kind of tool. This observation underscores the widespread adoption of video conferencing and online learning tools

TABLE 4. Questions about the recordings generated by the tool (questions 6-8).

	Answers	N/A	1	2	3	4	5
Q6 (recording help)	32	1	0	0	0	16	15
Q7 (recording captions sync.)	32	1	0	0	2	13	16
Q8 (recording captions quality)	32	0	0	0	3	13	14

TABLE 5. Questions about the notes generated and the experience of using the tool.

	Answers	N/A	1	2	3	4	5
Q9 (notes help)	15	1	0	0	2	6	6
Q10 (follow the class better)	15	0	0	1	6	4	4
Q11 (class more interesting)	15	0	0	1	4	7	3
Q12 (improve teaching)	15	1	0	0	2	4	8
Q13 (used other tools before)	15	0	0	0	2	2	11
Q14 (unify content and teaching)	15	0	0	1	2	4	8
Q15 (like to use in more classes)	15	0	0	2	2	7	4
Q16 (like to use in other subjects)	15	0	0	2	3	5	5
Q17 (distracted with the tool)	15	0	1	10	4	0	0

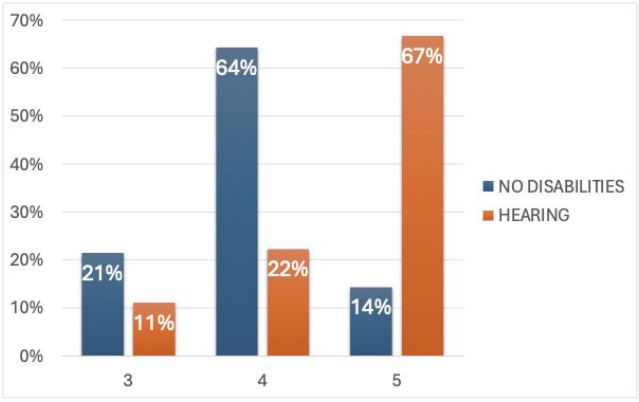

FIGURE 15. Perceived captions quality.

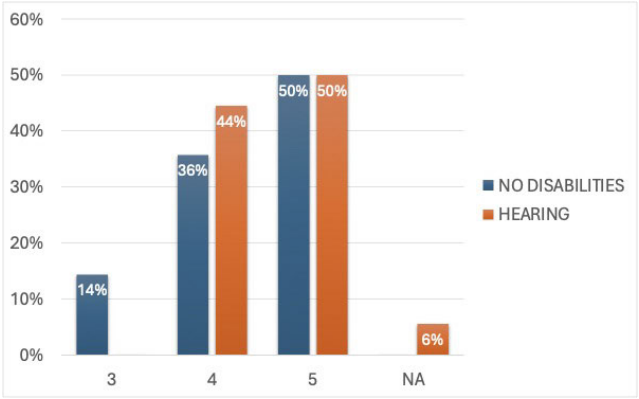

FIGURE 16. Perceived captions synchronisation.

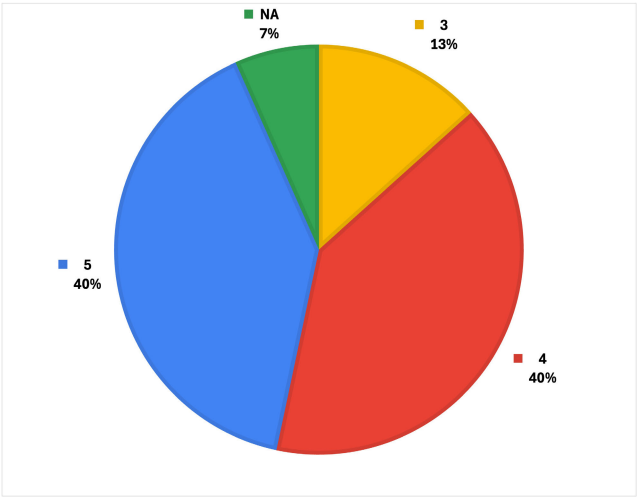

FIGURE 17. Perception about generated class notes in experiment #3 (Values from 1-5).

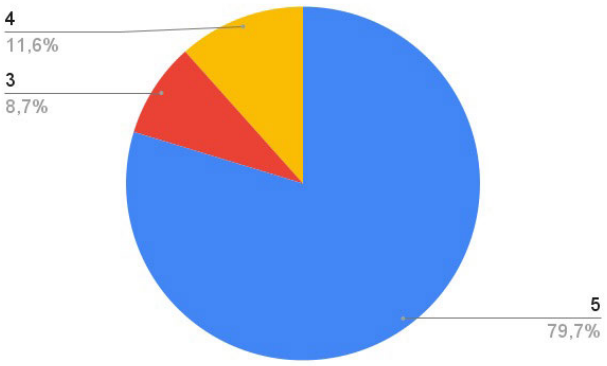

FIGURE 18. Experience on videoconference and online teaching tools in experiment #3 (Values from 1-5).

during the pandemic in Spain. This is a remarkable point because users have used other tools in the past, and their opinions are based on previous experiences.

The students received all the elements in this last experiment to support the learning experience. They answered additional questions about their satisfaction with the tool. Figure 19 shows the average values. About the improvement in following the class, the average value of the students was 3.73. There was a question related to the student's perception of distractions when using the tool. The average

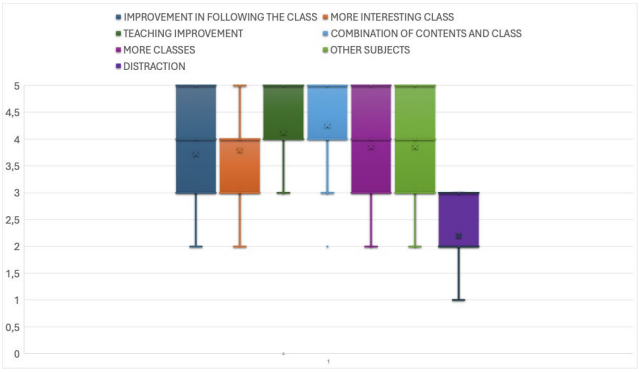

FIGURE 19. Average satisfaction with the tool after experiment #3(Values from 1-5).

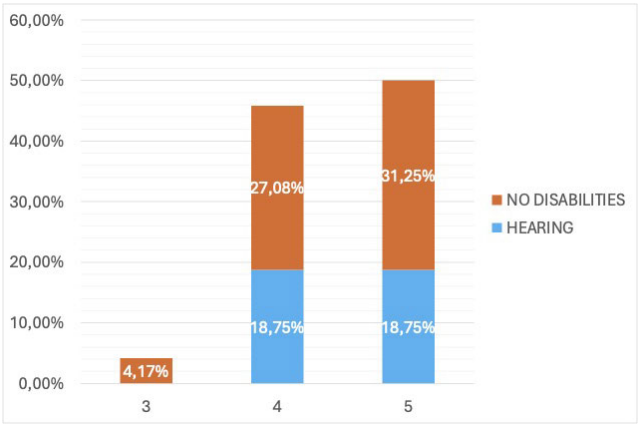

FIGURE 20. Overall Evaluation.

value for this question was 2.2. Since it is a novel tool for them during the class, it could affect the student's attention. Using the tool, students also answered whether the class was more interesting. In this case, the average value was 3.8, so it could be an incentive to make the classes more attractive to the students. It could also be seen that the students believed that the tool could improve teaching subjects (average of 4.42 out of 5). In general, the students also thought that the tool unified classes and contents well (average of 4.27 out of 5). Regarding using the tool in more classes and other subjects, students answered an average of 3.87 in both cases.

The overall valuation of the 48 students is 4.46 out of 5 (on average). As shown in Figure 20, more than 90% of the students valued the system with 4 and 5 points (out of 5).

D. DISCUSSION

In summary, the overall perception of the proposed system achieves remarkable results. The students followed the class, receiving the projection of the slides on their devices and the transcription of the teacher's speech. That benefited students with hearing disabilities since they could read the transcription while paying attention to the slides. At the end of the class, the students of experiment #2 also reviewed the video with the slides with the teacher's speech, and in experiment #3 the automatically generated notes, mixing the transcription with captures of the slides. Students valued these two aspects positively. The perception was slightly better for the recording, but the authors believe the notes are an invaluable asset when preparing for the exam. Furthermore, students with hearing disabilities may benefit from these notes. Also, in future work, the system can include further processing of these notes, like automatic summarising or simplification (for students with cognitive disabilities).

The authors have analysed the indicators from several points of view to evaluate the system's efficiency. There is no single measure of efficiency, but it can be assessed by considering the different features and the overall evaluation of the student's experience. As shown in previous subsections, the students tested three main features and evaluated the system overall.

Furthermore, students with disabilities are one of the primary groups who may benefit from the proposed system. For this reason, the system's overall evaluation should consider the opinions of students with hearing disabilities.

First, let us consider two key points regarding the efficiency of automatic transcription: speed and errors. Good transcription speed allows readers to follow the text without losing words or making significant effort. On the other hand, errors may cause distractions or misunderstandings. In this sense, 67% of students considered the transcription speed good, and 21% considered it fast. As discussed before, this speed also depends on the teacher's speech pace (if the teacher speaks fast, the transcription will also be fast). Regarding transcription errors, only 7 students out of 48 perceived the number of errors as many (none of them answered "too many"). Different aspects affect the number of errors, but the results showed that the errors did not hinder the students from following the class. The students' valuation of the help of transcriptions was 4.67 out of 5. Furthermore, the students scored the improvement of the transcription's punctuation with 4.58 out of 5. It can be concluded that the transcription worked well, and the students perceived it as beneficial. As a limitation, it is remarkable that the quality of the transcription is highly dependent on the quality of the sound: high-quality microphones, one speaker at a time, and no background noise help to obtain a good transcription. If the sound is not good (noise, several speakers at a time, fast or unclear speaking), the quality of the transcription will be lower. The transcription is now available in Spanish, in future work other languages will be included.

From the point of view of the efficiency of the recordings, students rated the utility of the recordings with an average value of 4,48 out of 5; that is, they find the recordings and think that those recordings can help them out of the class. This indicator shows that the automatic recordings are a feature the students value and want to use. Regarding the quality of the automatically generated captions for the recording and the synchronisation of the captions with the recording audio, students rated them as 4,45 out of 5 and 4,28 out of 5, respectively. Considering only the students

with hearing disabilities, the average rating was 4,53 and 4,55, respectively. It can be concluded that students found the recordings helpful and of good quality.

Finally, regarding the automatically generated notes, the students rated them with 4,29 out of 5. As a conclusion, the automatically generated notes

In summary, all indicators obtained results above 4.2, and 4 and 5 were the choices most selected by the students in all the questions. Looking at the overall rating, the system obtains an average of 4,46 out of 5. Considering this value as an overall efficiency measure, it can be concluded that the students have accepted the system and that its features are perceived as useful and of good quality.

It is not easy to compare the system with others because, to the best of our knowledge, we have not found a similar framework that includes all the proposed features together. With the proposed system, we aim to build upon the capabilities of previous systems to offer a comprehensive solution for both educators and students. In [25], authors present a system design that provides subtitles for pre-recorded videos, allowing users to sync them across multiple devices and customize elements such as colour, position, and font size. The study received highly positive feedback, with all users agreeing on the value of the customization options.

Inspired by these insights, our system incorporates similar functionality but extends it to live sessions rather than pre-recorded content. We offer real-time subtitles and live transcriptions with customizable features, providing students with the flexibility to adjust the subtitles according to their preferences. This live interaction, combined with the high level of personalization, enhances the accessibility and usability of the platform, making it suitable for a wide range of educational needs.

Another study [9] presents a case study focused on teachers' perspectives regarding online teaching for hard of hearing students. The researchers highlight the challenges of using Blackboard and other learning materials to accommodate students with hearing disabilities. In particular, they raise concerns about the accessibility of these platforms and the difficulty of creating materials that are fully accessible to hard of hearing students. Key takeaways from the study include the need for accessible online teaching platforms that support live sessions with integrated accessibility features, such as sign language interpretation, and the challenges posed by using Learning Management Systems (LMS) alongside live sessions.

Taking these findings into account, we aimed to address these issues in the design and functionality of our system by developing a more streamlined, accessibility-first platform tailored to online education. Our system offers live transcriptions and subtitles during sessions while providing options for integrating accessibility providers such as sign language interpreters and audio descriptors, ensuring a more inclusive learning experience.

Additionally, once a session concludes, the system automatically generates notes and transcription documents that are immediately available to students, giving them direct access to all class materials. Teachers can further refine these resources if needed, ensuring that content is both comprehensive and accessible. Unlike traditional approaches where LMS and live session platforms are separate, our system integrates both functionalities into a single, cohesive package. This eliminates the need for users to switch between multiple applications, simplifying the process.

In this work, the tests have focused on the student's use of the tool and their perceptions of how it can benefit their learning process. Once the results show that the students perceive the system as valid and the participants in the tests value the different features (automatic transcriptions, automatic recordings and automatic class notes) with high grades, further work will focus on the evaluation of the improvement of the academic results with the use of the system. To do so, students with and without disabilities will use the system following several classes. A control group will follow the same classes without the support of the proposed tool. At the end of the experiment, teachers will assess the students' progress to determine whether or not the use of the system improves the student's results. However, this evaluation is out of the scope of the current work.

VI. CONCLUSION

This paper presents a framework for hybrid and online learning environments that supports students with disabilities. The proposed system offers automatic transcription of the teacher's speech and, if the services are available, specific channels for audio description and sign language interpretation to aid students with disabilities to follow the class. At the end of the class, the system generates a set of resources to support the student's work after the class. First, the system creates automatic notes based on the transcriptions obtained during the class combined with captures of the slides shown by the teacher during the class. Finally, the system can create a recording of the teacher's speech and the slides used during the class to help students review the contents afterwards. This recording includes automatically generated captions synchronised with the teacher's speech so that students with hearing disabilities can activate them.

In conclusion, our research and development efforts have led to a robust platform tailored to the varied needs of educators and students. The successful implementation of live transcriptions and auto-generated resources, such as captioned recordings, and automatically generated class notes, has positively impacted the learning experience.

The design of our system, developed with a focus on accessibility and usability principles, has been instrumental in ensuring a seamless and intuitive user experience. Leveraging cutting-edge technologies like WebRTC and web technologies, we have enabled rapid prototyping and development cycles, facilitating prompt user feedback. Additionally, integrating our in-house machine learning transformer model, which provides automatic punctuation

marks for the transcriptions, has significantly improved the quality of transcriptions and subtitles.

User tests have provided valuable insights into the platform's effectiveness and usability in real-world educational scenarios. Forty-eight students tested the tool in three different experiments. Feedback from participants with different disabilities, ages and backgrounds has been pivotal in refining the platform's features. Features like live transcriptions and captioned recordings have proven particularly beneficial, improving comprehension and retention of course materials The participants answered questions related to the features' helpfulness and quality and the platform's overall evaluation. The answers were on a Likert scale of 1 to 5. Thus, students rated the helpfulness of automatic transcriptions as 4,67 out of 5 and the transcription quality as 4,45 out of 5. Students who tested the automatic recordings scored the helpfulness as 4,48 out of 5, and the quality of the automatic captions generated for helping students with hearing disabilities as 4,29 out of 5. Finally, the helpfulness of the automatically generated notes was rated as 4,29 out of 5. Most answers were 4 or 5, indicating that students evaluated the tool positively. The average overall rating of the tool was 4,46 out of 5, confirming that the students' experience was positive.

Future iterations of the system will expand upon our current successes and findings. We plan to introduce automatic summarization of live session transcriptions, providing students with concise summaries of class content for easy reference. Additionally, enabling users to playback session recordings alongside transcriptions without leaving the system, will further enrich the learning experience. Ongoing efforts will also focus on improving the auto-formatting of automatically generated class notes, ensuring greater accuracy and readability. Learning comfort is another aspect to be assessed. In the experiments we have assessed the perception of the participants about the helpfulness of the platform's features and the their overall evaluation on using the tool. In future experiments participants will answer questions about the improvement of their learning comfort using the tool. Finally, further experiments will also focus on measuring the improvement in the student's grade with the platform. From the point of view of scalability, further studies will test the scalability of the system in different educational environments.

In summary, our platform represents a significant stride towards providing equal opportunities and creating a more inclusive learning environment. This paper's main contributions are a learning framework with features to enhance learning accessibility and the results of the efficacy and usability evaluation of these features performed with users with hearing and without disabilities. By integrating innovative features and adhering to user-centric design principles, we have addressed the diverse needs of our users while laying the groundwork for future advancements in educational technology. As we continue to iterate and refine the platform, we remain committed to delivering an enhanced learning experience for students and educators.

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MARIO PEREZ-ENRIQUEZ received the master's degree in computer science from Universidad Carlos III de Madrid. Specializing in full-stack application architecture for web applications and mobile platforms, including the deployment of machine learning models, he has contributed to accessibility projects, particularly in enhancing educational experiences for diverse users. He also developed transformer models to improve accessibility for transcribed text. Currently, he is a Researcher on accessibility projects within the university, furthering his dedication to leveraging technology for diversity and accessibility in education.

JOSE LUIS LÓPEZ-CUADRADO received the Ph.D. degree in computer science from Universidad Carlos III de Madrid. He is currently an Associate Professor with the Computer Science Department, Universidad Carlos III de Madrid. He is also a Senior Researcher with the Spanish Center for Captioning and Audio Description. He has collaborated on several national and international projects. He is the co-author of several papers in international journals, books, and conferences. He also collaborates as a reviewer in several international journals. His research interests include accessibility, software engineering, and recommender systems.

ISRAEL GONZÁLEZ-CARRASCO received the Ph.D. degree in computer science from Universidad Carlos III de Madrid. He is currently an Associate Professor and the Assistant Manager of the Computer Science Department, Universidad Carlos III de Madrid. He is also the Manager of the Spanish Center for Captioning and Audio Description (CESyA). He has been involved in different national and international projects. He is the co-author of several papers in international journals (indexed in ISI-JCR) and international conferences. His research interests include soft computing, software engineering, and accessibility. Moreover, he is a member of the editorial reviewer board of international journals (indexed in ISI-JCR) and a member of the organizing committee at international conferences.