International Journal on Advanced Science Engineering Information Technology

Vol.14 (2024) No. 3
ISSN: 2088-5334

A Design and Implementation of an Online Video Lecture System based on Facial Expression Recognition

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***Abstract*—Real-time online education facilitates education without requiring instructors and students to be physically present in the exact location, allowing for interactions similar to face-to-face teaching. However, when many students participate simultaneously, instructors face challenges, such as spending a lot of time understanding each student's learning status. Mainly, systems utilized for real-time online education, initially developed for business meetings, have limitations when repurposed for educational uses. Therefore, this paper presents the design and implementation of a video lecture system for real-time online education based on facial expression recognition. The system is a video lecture system based on Facial Expression Recognition, implemented with a web browser method, a classroom tool platform supporting teacher-student interaction, and facial expression recognition features based on an artificial intelligence engine. Engagement metrics utilize fundamental values like facial recognition, total learning time, and video playback to measure student engagement through facial expressions. Additionally, structured numerical data such as eye-tracking, motion tracking, drowsiness tracking, speaking, effective chatting, hand-raising, polling, and screen sharing are weighted and aggregated for calculation. Weights can be adjusted according to the nature of the lecture, such as discussion-based learning or cooperative learning. The system calculates student engagement levels, categorizing them as 'Active (90 points)', 'Moderate (80 points)', and 'Insufficient (70 points)', and is designed to provide this data to instructors asynchronously. Furthermore, a focus group interview was conducted with Edtech experts to validate the implemented system, and positive responses were obtained.**

***Keywords*—Online lecture; eye-tracking; motion-tracking; facial expression recognition.**

Manuscript received 5 Nov. 2023; revised 24 Dec. 2023; accepted 20 Feb. 2024. Date of publication 30 Jun. 2024.
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I. INTRODUCTION

To adapt to the Fourth Industrial Revolution era changes, creating and effectively utilizing a new ICT-based educational environment facilitated by EdTech necessitates exploring various strategies. In the traditional education environment, which had been relatively slow to evolve despite rapid societal changes, the COVID-19 pandemic catalyzed revolutionary educational changes, underscoring the necessity of an emergency education system to prepare for unforeseen events. The activation and quantitative expansion of education utilizing information and communication technology contribute to the democratization and expansion of educational opportunities and the improvement of educational efficiency and effectiveness.

Living in a society that has shifted from industrial to informational, we are inundated with a plethora of information via the internet, which is integrated into our daily lives. In the industrial society, education during the school-age years was sufficient to acquire the knowledge needed as a resource for a lifetime of work and living. However, in the information society, education during the school-age years alone is insufficient to adapt to the rapidly changing social environment, and there is a need for continuous acquisition of new knowledge.

Online education has become a prominent method of instruction, as it offers learners the opportunity to study without being hindered by location and time constraints. Especially after COVID-19, many educational institutions have tried to introduce online education, establishing ICT infrastructure capable of supporting online learning. Academic institutions have also advanced in organizational operations and capacity building of stakeholders for online education, which has enhanced the competencies and experiences of instructors and students. These experiences suggest that real-time online education using video lecture software will continue [1].

To ensure the sustainability of online education in universities, measures must be established to implement it through government policies and systems successfully. This includes creating a stable funding source for developing online education infrastructure and enhancing stakeholder capacity. It is also important to continuously verify the effectiveness of online education and find ways to share its effectiveness within the educational period [2].

From the learners' perspective, the expansion of online education has brought conveniences unavailable in traditional face-to-face lectures. For example, by uploading digital content to a learning platform, students can repeatedly listen to lectures until they fully understand the content. This also saves the time and effort of traveling to school, among other advantages. Additionally, the expansion of real-time online education using video lecture software has increased the demand for video lecture systems designed for educational purposes.

Instructors are utilizing various features of learning platforms to increase the effectiveness of online education, but this has led to an increased workload in monitoring attendance, class participation, and academic performance. In online education, instructors use various learning platform features to enhance learning effectiveness, but this has increased their workload for tracking attendance, class attitudes, and academic achievement. Furthermore, most remote video systems used in real-time online education have been primarily developed for remote meetings rather than lectures.

Therefore, this paper proposes a method where instructors, using a video lecture system for real-time online education, can recognize students' facial expressions through their cameras and collect and analyze unstructured and structured data in real-time. Additionally, the paper aims to design and implement a system that provides real-time feedback to instructors on each student's learning status based on the analysis results.

The system collects various data on students' facial expression recognition, learning behavior motion recognition, chat, evaluations/quizzes, surveys, and questions/answers. It analyzes this data to categorize students' engagement levels as 'Active Participants,' 'Moderate Participants,' or 'Participants with Insufficient Involvement' and relays this information in real-time to instructors. With this transmitted information, instructors can understand students' learning behaviors, enabling interaction in real-time online education similar to face-to-face lectures.

II. Materials and Method

A. Video Lecture System

Real-time online education allows instruction without instructors and learners being in the same physical space. A video lecture (or meeting) system is crucial for real-time online education. Post-COVID-19, various platforms and software have been utilized for this purpose. Education in every sector, from primary and secondary to higher and adult education, has expanded into real-time online formats. Therefore, developing and disseminating video lecture systems for educational purposes became important, repurposing platforms and software initially used for video conferencing [3]. Academic institutions have expedited digital transformation at an institutional level and have strived to adapt their operational structures to adopt real-time online education.

Integrating online education in educational institutions necessitates a learning management system and establishing infrastructure such as video lecture systems or software. For the sustained implementation of online education, it is imperative to have support from educational institution management, institutional policy changes, and a transformation in faculty attitudes [4].

A study on user perception comparing real-time online education with asynchronous online education based on learning management systems revealed that students find studying online content from the learning management system and then interacting with instructors in real-time online sessions more productive [5]. Real-time online education allows many students to participate simultaneously, which is advantageous for educating many learners. Still, it can be negative in terms of maintaining student attention and providing opportunities for participation. Research on the optimal number of learners for real-time online education found that classes using real-time video lectures in groups of 4-5 students showed the most positive effects [6]. Therefore, in real-time online education, it is necessary to use small group functions to encourage active student participation in classes. Just as in a traditional classroom, a unidirectional lecture approach by instructors can decrease the efficiency of learning in real-time online education.

Negative side effects associated with videoconferencing or lectures have also been reported. One of the most cited issues is videoconferencing fatigue (VCF), which refers to tiredness from participating in video conferences for work, education, etc. [7]. Therefore, when integrating videoconferencing systems into teaching, it is necessary to consider the convenience of use for instructors and learners and fatigue due to excessive use.

Research is ongoing to improve the performance of video lecture systems for more effective delivery. Issues such as network bandwidth, path redundancy, congestion, and the requested resource rate are being considered. Algorithms have been proposed to address packet loss, latency, and bandwidth issues to efficiently handle online video conference connection requests [8], [9]. Additionally, research has been conducted to provide accessible video conferencing systems for individuals with visual impairments [10].

In this paper, we aim to measure the participation level of learners in remote learning activities and support intelligent education based on AI by developing a video lecture system that applies facial expression recognition technology. Facial recognition technology, designed for identifying individuals in images or videos, involves localizing facial features such as eyes, nose, eyebrows, and mouth and then recognizing faces by matching them with pre-existing data. Biometric technologies are actively adopted in various industries due to their speed, convenience, and security advantages. As the accuracy of AI-based facial recognition systems has improved, it is being applied in various areas requiring authentication, such as shopping, finance, administration, security, and access control.

Facial expressions reflect a person's emotions, psychological state, social interactions, and physiological signals. To analyze the dynamic changes in facial expressions in real-time, it is necessary to extract optimal expression information that effectively reflects the temporal variations of facial movements and perform real-time tracking. A method of interpreting facial expressions based on an expression change model is also required that can actively describe the transitions between specific expressions. Facial expression analysis, through research into how emotions like sadness, anguish, anger, surprise, fear, and disgust are represented in facial expressions, has led to the creation of the FACS (Facial Action Coding System).

FACS defines 46 Action Units (AUs) to represent the movements of each facial muscle. Combinations of these AUs represent expressions, and TABLE 1 shows some examples of AUs defined in FACS and their descriptions [11]. For instance, a smiling expression can be predicted by the narrowing of eyelids, raising of the mouth corners, and opening of the mouth or lowering of the jaw, which can be represented as 'AU7 + AU12 + AU25'. FACS defines various combinations even for a single expression. However, FACS cannot serve as an absolute standard or method for facial expression recognition, as the criteria for the activation of each AU are unclear, and judgments can become ambiguous with incomplete combinations.

TABLE I
EXPRESSIONS OF ACTION UNITS DEFINED IN FACS

Action Units	Facial Movement Descriptions
AU 1	Inner eyebrows are raised
AU 2	Outer eyebrows are raised
AU 4	Eyebrows are lowered
AU 5	Upper eyelids are raised
AU 7	Eyelids become narrow
AU 10	The upper lip is raised
AU 12	The corners of the mouth are raised
AU 16	The lower lip is lowered
AU 23	Lips are tightly closed
AU 25	Mouth is open

A video lecture system is where participants in distant places use communication tools to interact in real-time, listen to each other's voices or see faces, and participate in non-face-to-face lectures [12]. Real-time remote learning utilizing a video lecture system is a method where an instructor's live lecture is attended by multiple learners remotely in the same time frame. When using a video lecture system for non-face-to-face classes, simultaneous use of various interactive tools such as whiteboards, web sharing, surveys, and Q&A sessions is necessary to deliver educational content effectively.

Thus, this paper facilitates real-time instructor feedback by analyzing individual learners' engagement through structured data such as quizzes, Q&A, surveys, and chats collected throughout the class and unstructured data based on students' behavioral patterns, such as AI-based facial and voice recognition.

B. *Learning Platform*

In online education, various attempts are being made to apply Edtech to teaching and learning methods to increase the efficiency and effectiveness of learning [13], [14]. Learning platforms upload content to servers, enabling learners to study at their convenience and storing information about their learning activities, which is later provided to instructors due to the learners' activities. In real-time online education, instructors provide content that is not uploaded to servers but live. Alternatively, learners may study the content beforehand using the learning platform and then participate in real-time online education through video lecture software like Zoom S/W.

However, storing learners' learning history data is challenging because most learning platforms and video lecture software are separate systems. Recently, Edtech, utilizing learning platforms, has been incorporated into convergent education using AI and virtual/Augmented Reality to combine creative, scientific, career, and SW/AI education into experiential and practical programs [15]. Edtech is also being proposed for use in subjects like art and physical education that prioritize experiential learning [16], [17], [18]. Moreover, various approaches are being proposed to enhance the learning efficiency of students with developmental disabilities using Edtech in regular schools and special education schools [19], [20].

Edtech is expected to gain influence in primary and secondary education and adult education, such as university and corporate training [21]. The adoption of non-face-to-face education in universities and the attempts to incorporate Edtech into various subjects are leading to improvements in students' learning abilities and the presentation of efficient lecture management styles [22], [23]. In corporate education, discussions on using Edtech are also underway for adult education, including training for working professionals and vocational skills development [24], [25].

Furthermore, new information and communication technology is being integrated into learning platforms. The development of e-learning content and online class operations, which utilize open-source software-based Deep Fake technology in learning platforms, has been undertaken with a focus on improving learning efficiency [26], [27], [28]. Various studies have been conducted on implementing IT technologies such as blockchain, Doc2Vec, and learning analytics into question-answering search systems on learning platforms [29], [30], [31]. Online education requires the integration of video lecture systems and learning platforms, as well as considerations for the sharing and managing of learning data between the two systems.

III. RESULTS AND DISCUSSION

A. *System Design*

Facial expression analysis begins with a pre-processing step where the face is detected (Face detection), and the result is passed to a Feature Extractor. This process involves extracting features using Feature Extractors such as SIFT (Scale Invariant Feature Transform) or HOG (Histogram of Oriented Gradients). The extracted features are then analyzed for emotions using classification algorithms like CNN (Convolutional Neural Network) or SVM (Support Vector Machine), and this analysis is then used to assess interest levels in the class. A pipeline using deep learning models for facial expression analysis was designed, and TensorFlow was used as the AI engine for analyzing learners' attitudes.

To implement the facial expression recognition feature in the video lecture system, the open-source Face-Api.js was selected. Face-Api.js is a JavaScript API for facial recognition in web browsers using Tensorflow.js, utilizing MTCNN (Multi-Task Cascaded Convolutional Neural Networks) for real-time JavaScript face tracking and facial expression recognition. Face-Api.js offers various facial recognition models such as SSD Mobilenet V1, Tiny Face Detector, MTCNN, 68 Point Face Landmark Detection Model, Face Recognition Model, and Face Expression Recognition Model. Among these, SSD Mobilenet V1, 68 Point Face Landmark Detection Model, and Face Expression Recognition Model were used to design the video lecture system.

For emotion tracking, the CNN model recognizes seven expressions: angry, disgusted, fearful, happy, sad, surprised, and neutral. However, the facial expression recognition feature was designed to identify only angry, disgusted, happy, and fearful expressions.

The target system of the video lecture system is a "video lecture system" specialized for interactive classes between instructors and learners in a remote setting, consisting of a video lecture system, a classroom tool platform, and an artificial intelligence engine.

- Video Lecture System: A real-time, interactive remote lecture system using PC or mobile.
- Classroom Tool Platform: Interactive tools used in real-time video lectures.
- AI Engine: An engine for monitoring learners and measuring their participation.

The video lecture system is implemented on a SaaS basis using WebRTC, and the classroom tool platform supports real-time interaction with various document formats like PPT, DOC, and PDF, as well as screen sharing and recording, whiteboard, chat, and surveys. The artificial intelligence engine uses an already-developed facial recognition engine to store unstructured data from facial and expression recognition. It performs learning participation analysis using structured data from learners' activities. Visualized information analyzed through the artificial intelligence engine is provided to instructors for use in giving feedback to students.

The video lecture system is designed to maintain readability for users even when the screen is divided to display multiple pieces of information simultaneously. It also supports the smooth operation of classes by providing essential features like whiteboard functionality for interaction, media sharing, file sharing, text conversations, and note-passing. Additionally, it is designed to easily create surveys and other interactive tools and ensure ease of integration with external systems.

Classroom tools used in the video lecture system were designed considering learners' extensive use of smartphones, making mobile support a mandatory feature. Other essential features include a shareable whiteboard, real-time chat, real-time recording, high-quality video/audio/data sharing, survey functionality, facial expression recognition, and small group video meetings.

In the video lecture system, participation design was considered with school classes in mind. In video classes, multiple students connect to a meeting room per instructor. The more students connected to each instructor, the more challenging and burdensome it becomes for the instructor to monitor student's learning status in real-time. To support this issue, the video lecture system was designed to provide a dashboard showing the usage status of the class tools. The system calculates and informs the instructor of the learners' participation in real-time, allowing the instructor to focus more on the lecture and send real-time notifications to less engaged students to encourage more active participation.

Learning engagement rates were calculated using fundamental values like facial recognition, total learning time, and learning content execution. Additional metrics such as eye tracking, motion tracking, drowsiness tracking, speaking, effective chatting, hand-raising, polling, and screen sharing were weighted and aggregated for the calculation. The weights can be adjusted according to the nature of the lecture, such as discussion-based or cooperative learning. Participation levels were calculated and set as 'Active (90 points)', 'Moderate (80 points)', and 'Insufficient (70 points)', and designed to provide this information to instructors asynchronously. The formula for calculating the learning engagement rate is shown below.

$$\begin{aligned}\text{Learning Engagement Rate} \\ &= (I * W) + (M * W) + (i * W) \\ &+ (S * W) + (C * W) + (H * W) \\ &+ (V * W) + (s * W)\end{aligned} \tag{1}$$

*Notes: Eye Tracking (I), Motion Tracking (M), Drowsiness Tracking (i), Speaking (S), Chat Count (C), Hand Raising (H), Polling (V), Screen Sharing (s), Number of occurrences (N), Time (T), Maximum Value (m), Weight (W), Laughter (h), Anger (a), Displeasure (d), Frustration (f)

For example, let's assume three students, A, B, and C, attend a 30-minute video lecture. Table 2 shows the calculation results of the learning engagement rate for students A, B, and C. Data such as identity verification, total learning time, and video execution are collected by default. The results of the learning engagement rate analysis are used to classify the types of learners, and these classification results are provided to instructors through a dashboard showing the usage status of the class tools. The learner type refers to each learner's unique learning style, defining their cognitive approach to learning or attitude towards it. The system classifies learner types into three categories: 'Active', 'Moderate', and 'Insufficient'. For quick visual recognition during class monitoring, the dashboard is designed to display the learners' status in blue (Active), orange (Moderate), and red (Insufficient).

The unstructured data from facial expression recognition can be inaccurate due to various environmental factors, making it inappropriate to fully reflect in the measurement of learning participation. Therefore, this paper proposes a design to provide separate information about learning satisfaction to instructors after the lecture. Instructors can use this information to assess learning satisfaction and adjust their teaching methods accordingly.

Learning satisfaction is designed alongside emotional changes and a timeline. For example, if all learners laugh together for 60 seconds, it could indicate that the instructor made a joke for attention diversion. If most learners are laughing, but one shows no emotion change, it could imply disinterest in the class. A high frequency of irrelevant emotion changes may indicate dissatisfaction and lack of focus on the lecture, suggesting lower learning satisfaction.

TABLE II

CALCULATION OF LEARNING ENGAGEMENT RATE FOR STUDENTS A, B, C

Category	Description	Unit	Weight	Maximum Value	Minimum Value	Formula	Learning Activity		
							A	B	C
Eye Tracking	Tracking Looking Away from the Monitor	Count	10%	10	1	(m-N)/m*100	1	2	5
Motion Tracking	Count of Face Disappearance from the Monitor	Count	10%	10	1	(m-N)/m*100	1	2	4
Drowsiness Tracking	Tracking Yawning or Sleepiness	Count	10%	10	1	(m-N)/m*100	1	2	3
Speaking	Microphone Reaction Time	Time (seconds)	10%	60	1	(m-T)/m*100	1	5	10
Effective Chat Count	Chat Writing	Count	20%	20	1	N/m*100	20	15	5
Hand Raising	Requesting Speaking Turn	Count	10%	10	1	N/m*100	10	7	1
Polling	Participation in Surveys	Count	20%	2	1	N/m*100	2	2	1
Screen Sharing	Sharing the Screen	Count	10%	2	1	N/m*100	2	2	1

*Set the maximum value for eye tracking, motion tracking, drowsiness tracking, speaking, effective chatting, hand raising, polling, screen sharing, and emotion tracking to m, with the minimum value set to at least 1.

*Results: Student A: 96.8333 (Active), Student B: 85.16667 (Moderate), Student C: 47.3333 (Insufficient)

Emotion tracking is designed to recognize only 'angry,' 'disgusted,' 'happy,' and 'fearful' out of the seven expressions identifiable by the CNN model. The facial expression recognition engine detects a learner's irrelevant emotion changes. It sends an alert to the instructor, who can identify distracted students in real-time and provide feedback to focus them on the lecture. Thus, learning satisfaction designed in the Facial Expression Recognition-Based video lecture system can be a tool for instructors to enhance their lectures and increase academic satisfaction.

B. System Implementation

For the video lecture system, the stability and scalability of the service are crucial, so an MS Azure SaaS cloud environment was established. The system includes separate configurations for the video lecture server, database server, and storage, with redundancy to reduce system load. The WebRTC (Web Real-Time Communication) based video lecture service can allocate and return cloud resources as needed, improving service quality. The quality of the WebRTC video lecture service is influenced by server resources (CPU, memory, network bandwidth, etc.), so it must be able to expand and contract quickly and elastically, and monitoring is necessary.

The Facial Expression Recognition-Based video lecture system was implemented with a web browser method (Web-RTC) for video lectures, a classroom tool platform supporting interaction between teachers and students, and an artificial intelligence engine-based facial expression recognition feature. Specifically, the video lecture system was implemented based on Web-RTC and responsive web design, integrating a facial recognition engine for face detection, emotion analysis, and eye tracking. The classroom tool platform was implemented with features such as various document sharing (PPT, DOC, PDF), screen sharing (own screen, application screen), whiteboard, discussion, chat, surveys, and lecture recording. The artificial intelligence engine uses a pre-developed facial recognition engine to store unstructured data of facial recognition and expression. It uses structured data of learners' activities to analyze participation and provide real-time information to instructors. The details of the system implementation are shown in Table 3.

To validate the developed system, a Focus Group Interview (FGI) was conducted with 12 EdTech experts, including instructors, after the system implementation. The questions asked in the expert FGI are as follows:

- Question 1: What is the most convenient video conferencing system you have used, and why?
- Question 2: What problems might arise when using a video conference system for video education?
- Question 3: What features do you think are necessary for a video lecture system for education?
- Question 4: The implemented video education system specializes in video education services. In particular, it analyzes learners' attitudes through facial (emotion) recognition and provides instructors with real-time learning status. Please share your opinion on learning analysis through facial (emotion) recognition.

Experts participating in the Focus Group Interview (FGI) responded that the most commonly used software for education, due to features like voting, shared editing, accessibility, convenience, familiarity, and stability, is ZOOM. Regarding the difference between video conferencing and video lectures, they responded that video conferencing tools are composed of only simple functions, making them unsuitable for education and inconvenient for utilizing various educational tools.

When asked what features they would like to see in a video lecture system, the experts suggested sharing of learning materials, facial recognition for login, communication between learners and instructors, whiteboard, review of previous educational content (lecture recording feature), student concentration monitoring, AI-based STT (Speech to Text) function, monitoring students' facial conditions, eye tracking, facial recognition, testing and Q&A features, and real-time monitoring of learning participation during education.

TABLE III
EXPRESSIONS OF ACTION UNITS DEFINED IN FACS

Category	Development screen	Development Content
Video Lecture System using Web Browser (WebRTC) Method		- User-Centric Design - Web-RTC Based - Responsive Web Design
Classroom Tool Platform		- Screen Sharing Feature - Electronic Whiteboard Sharing Feature - Document Sharing Feature
Application of Artificial Intelligence-Based Facial Recognition Engine		- Facial Recognition + Face Detection + Emotion Recognition + Eye Tracking

Regarding facial expression recognition, there was an opinion that it could enhance learning participation, especially in students with distracted attitudes like younger elementary school students, and that it could become increasingly sophisticated over time, eventually serving as valuable data for learning processes. There was also a response that the service needs to be advanced through improvements in the accuracy of facial recognition. In response to further inquiries about solutions, it was opined that while the service could significantly enhance communication efficiency between instructors and learners, more data accumulation and algorithm improvements are needed to produce accurate recognition results. Considering the expert opinions, the facial expression analysis-based video lecture system presented in this paper appears to have functionalities suitable for educational purposes. It aligns with the features the experts requested.

IV. CONCLUSION

Following COVID-19, educational institutions have recognized the convenience and efficiency of real-time online education and are gradually increasing its prevalence. In South Korea, recent legislative revisions now permit general universities to establish online undergraduate and graduate programs, suggesting that the expansion of online education will continue. Similarly, the expansion of online education is a trend observed globally, not just in South Korea. One significant challenge in real-time online education is the absence of specialized systems for video lectures. This complicates instructors' ability to manage large groups of learners and accurately gauge their learning progress.

This paper proposes a facial expression recognition-based online video lecture system utilizing an AI-enhanced facial recognition engine. This system is designed to deliver learners' real-time participation data to instructors and help instructors concentrate on their teaching activities during video lectures. This system aims to assist instructors in effectively managing learner information and to enhance the efficiency and effectiveness of classes. For instance, the system's facial recognition software is programmed to detect scenarios such as a learner disappearing from the screen or diverting their gaze from the monitor during a video lecture. This information is then relayed in real-time to the instructor, who can utilize it to provide immediate feedback to the student.

Ongoing refinement and enhancement of emotion recognition accuracy in the Facial Expression Recognition-Based video lecture system necessitates continual data collection on facial expressions. Given that most facial recognition databases for research are developed outside South Korea, there are inherent challenges in developing AI-based facial application technologies tailored for Koreans. The availability of a convenient Korean-style facial recognition database would enable the development of more sophisticated Korean-style educational services.

Subsequent research endeavors will focus on a more nuanced classification of learner types, encompassing leader, participative, independent, cooperative, and avoidance categories. The goal is to compute and communicate these participation levels to the learners. Furthermore, there is a need to build an advanced emotion recognition database and refine the system for more precise and accurate judgments.

This service is anticipated to foster an online learning environment conducive to seamless communication between instructors and learners, akin to face-to-face classes. It aims to reduce instructors' workloads in areas such as attendance, classroom demeanor, and academic achievement. From an educational standpoint, it is expected to elevate the satisfaction levels of instructors and learners, enhancing participation and learning outcomes. This contributes to addressing the paradigm shift in non-face-to-face education and reducing the learning disparities precipitated by COVID-19.

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