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Examining the impact of surface material design treatments on traditional and collaborative instructional approaches in hybrid classrooms

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Hybrid teaching has gained substantial interest in higher education and is anticipated to influence future pedagogical reforms worldwide in the aftermath of the pandemic. Despite the adaptability of hybrid teaching as a flexible instructional design, various limits have emerged. Poor sound quality was a major challenge for distant students, impairing their ability to effectively comprehend lectures and engage in interactions with on-site peers and instructors. Therefore, this study aims to investigate the impact of surface material design treatment on two distinct educational approaches in hybrid classroom environments, namely lecture-based and collaborative learning. This study incorporates field measurements and acoustic modelling methods to develop effective surface design treatments that enhance the listening experience for remote students. Three significant acoustic parameters were assessed: reverberation time (RT), speech transmission index (STI), and speech clarity (C50). The results indicate that surface treatment on wall and ceiling areas have a substantial impact on the important acoustic parameters that emphasizes on speech intelligibility. The findings from an in-depth investigation are beneficial for designers and educational institutions in ensuring appropriate acoustic quality for hybrid learning settings. This setting concurrently enhances students' learning experiences and performance.

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1. INTRODUCTION

The pedagogical landscape is undergoing significant transformation as a result of subsequent surges of COVID-19. Higher education institutions are rapidly transforming their instructional approaches to fulfil their obligation to teach. The use of hybrid learning has garnered significant attention due to the ongoing changes in the educational landscape. The hybrid virtual classroom concept involves one group of students attending the course on campus while concurrently allowing other individual learners to engage remotely from a location of their choosing via the same platform [1]. In light to this substantial effect, hybrid learning and teaching have been extensively embraced as an alternative to the traditional face-to-face method. The abrupt transition in educational delivery has facilitated the swift advancement of this growing method of learning and teaching [2]. Despite the existence of digital education for decades, its extensive use during the crisis was unprecedented, attributable to advantages such as locational flexibility, convenient lecture recording, effective communication, and rapid feedback mechanisms [3]. A comprehensive review indicated that hybrid learning enhanced student autonomy and elevated student satisfaction and grades, while outcomes varied among research based on participant characteristics and delivery-related factors [4].

The effective implementation of hybrid classrooms has emerged as a significant concern for educators throughout the world [5]. From the educators' standpoint, the efficacy of teaching is partially contingent upon the instructor's proficiency in utilising technology [6], thus the teacher must engage in active learning regarding technological applications and be afforded opportunities to experiment and assess results based on scientific proof [7]. According to Olt, 2018 [8] the phenomenon of hybrid virtual learning from the viewpoint of the remote participant concluded that the remote participant's experience is most effectively described by the concept of 'ambiguity' concerning group membership, technological functionality, and location. The remote students felt marginalised from the primary class because of their physical separation from the face-to-face class, particularly when they faced technical challenges without prompt assistance. Concurrently, the F2F pupils saw neglect as the instructor devoted much time to addressing technological issues [9].

A critical inquiry on pedagogical issues is identifying the most effective technology for enhancing the social presence of remote students [10]. A drawback of the learning environment is frequently the absence of visual and auditory signals that are typically perceivable from the students [7]. Due to this loss, it is essential for the teacher to regularly raise questions during the lecture and remain attentive to students' contributions to mitigate the distancing effects [11]. Additionally, students participating in the class online should experience equivalent sound quality to those attending in person, as the audio element has been identified as critical for success [12].

A clear issue exists in assuring the communication of instructors' and classroom students' voices to distant students with adequate quality [13]. These constraints emphasise the necessity of developing educational settings and infrastructure for hybrid classrooms to improve learning experiences and outcomes. Therefore, rethinking traditional classrooms design approach is needed to make them fit for hybrid learning [14]. The classroom and instructional conditions can substantially influence the perceived audio quality for remote learners where the quality of perceived sound was strongly influenced by changes in both infrastructure and technology used [15]. Based on past research [16], The foremost factor to consider for establishing an effective learning environment is the acoustic performance of the classroom. The acoustic quality of the classroom significantly influences students' cognitive development [17], [18] and concentration capability [18].

This study seeks to evaluate the effect of surface treatment with highly absorptive materials on the ceiling and wall areas of lecture rooms concerning the acoustic quality perceived by microphones for remote students. This study examines two distinct learning methodologies: conventional lecture-based instruction and collaborative learning, among two diverse lecture room sizes.

2. METHOD

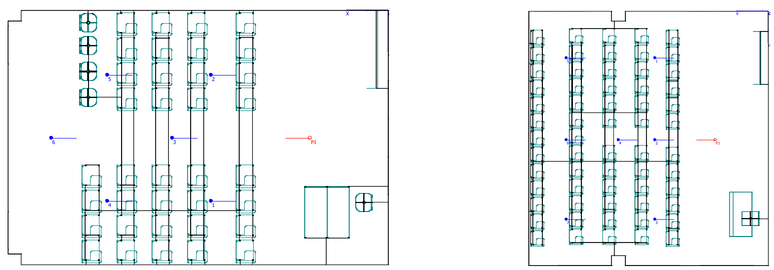
Two lecture rooms from a public university in Malaysia were determined for the assessment of acoustic performance. The acoustic assessment carried out in unoccupied room settings comprises the evaluation of background noise (BN), reverberation time (RT), and speech transmission index (STI). Table 1 provides an overview of the selected lecture rooms.

Table 1. Overview of classroom details.

Lecture room	Width (m)	Length (m)	Height (m)	Floor Area (m^2)
LR1	8.6	6	2.5	51.6
LR2	8.2	8.7	2.8	71.3

A. FIELD MEASUREMENT

The background noise level (BNL) was measured by recording the continuous equivalent sound levels (LAeq) in unoccupied classrooms throughout the operation of the heating, ventilation, and air conditioning (HVAC) systems. Before the measurement started, all windows and doors were securely closed, thereby accurately representing the learning environment. The receiver's placement, seen in Figure 1, aligns with the student's position. At each receiving location, the BNL was assessed for a duration of two minutes, with data recorded at one-second intervals. A Cirrus CR:171B sound level meter (SLM) was used to assess the sound pressure level. The SLM was positioned 1.2 meters above the floor, precisely at the height of the student's ears. The investigation entailed computing the mean A-weighted sound pressure level for both lecture rooms, encompassing a frequency range of 63 Hz to 8000 Hz.



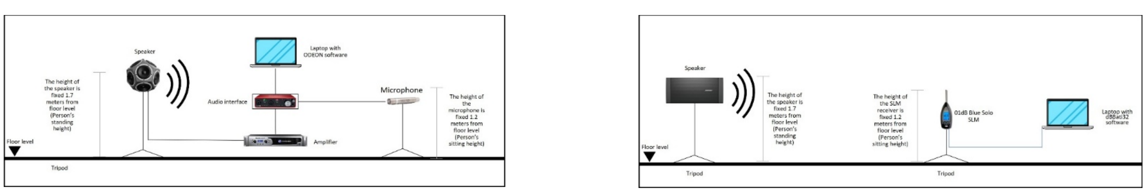
(a) (b)

Sound source Receiver

Figure 1. Sound source and receivers' locations of (a) LR1 and (b) LR2 lecture rooms.

A dodecahedron loudspeaker with omnidirectional properties was used for reverberation time measurement. The audio signal was produced by connecting the loudspeaker to a Crown XLS1000 amplifier. The auditory signal output was recorded using the GRAS 46AE ³" microphone, positioned 1.2 meters above ground level, and connected to the Scarlett 2i4 audio interface. The RT values were computed with the ODEON room acoustic software version 17. The RT was assessed at a receiver site identical to that of the background noise level measurement. Figure 2a depicts the schematic diagram of the equipment arrangement utilised for RT measurement.

For STI assessment, a BOSE M101 speaker was engineered to be positioned at a height of 1.7 meters above the floor in the lecturer's specified teaching zone to function as the sound source. A sweep signal simulating an amplified human voice level was produced via the Minirator MR2 signal generator. The auditory signal was recorded and examined via the Blue Solo 01dB sound level meter, which was connected to the dBBati acoustic measurement software. Figure 2b illustrates the configuration of the equipment employed for STI measurement.



(a) (b)

Figure 2. Schematic drawing of equipment configuration of (a) RT and (b) STI measurement.

B. ACOUSTIC SIMULATION

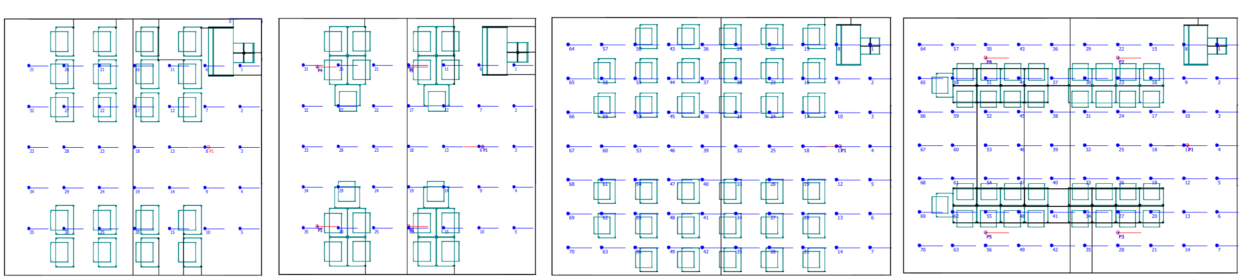
The 3D model of the lecture rooms was constructed using Sketchup Pro® software as depicted in Figures 3a and 3b. Precisely determining the surface area is crucial to minimise errors in the model during the validation process. The verification process for room models allows a maximum reduction of 80% in surface material [19]. The degree of reduction may vary and is influenced by factors like modelling techniques, model configurations within simulation software, and the accuracy of the scattering and absorption coefficients of materials.

Prior to initiating simulation work, it is essential to verify the acoustic parameters of the 3D model to confirm that they correspond with the actual room conditions. The procedure was conducted using ODEON Room Acoustic Software version 12. It is crucial to verify the appropriateness and effectiveness of the material applied to the surface of each model to achieve the desired outcomes. Modifying the type and position of the sound source, collectively with the receiver's location, is essential based on the site configurations. To ascertain the ideal duration of the impulse response for RT computation, a preliminary estimation of the reverberation time is required before validating the model. Conversely, the program was employed to compute the STI utilising the background noise data gathered from on-site observations. The relative difference of just noticeable difference (JND) for RT and STI must meet the minimum recommendation before commencing the simulation program. The speech clarity (C50) parameter was omitted from the verification process owing to equipment constraints during field measurement.

The simulation centered on examining the impact of surface treatment on wall and ceiling areas with respect to RT, C50, and STI at certain microphone receiver locations. The microphones were installed at a height of 2 meters above the floor, which is common for hybrid learning environments. Their configuration was in a grid pattern with a spacing of 1 metre. The total quantity of microphones utilised was 35 for the small lecture room and 70 for the medium lecture room, as illustrated in Figure 4. The simulation featured two standard spatial configurations for each lecture room: one for lecture-based learning (rows and columns) and another for collaborative learning (modular). In the context of collaborative learning, four sound sources (natural-raised human voice) were strategically placed at each group cluster to represent on-site students. In lecture-based learning, a single sound source was placed in the lecturer's teaching space. Both classroom models are assigned identical materials for each surface, with detailed information available in Table 2. The acquisition and subsequent analysis of RT and C50 data were performed for 1/1 octave band settings ranging from 125 Hz to 8000 Hz. Furthermore, STI results were calculated at each microphone location.

(a) (b)

Figure 3. 3D model perspectives of (a) medium-sized, and (b) small-sized lecture rooms.



(a) (b) (c) (d)

Sound source *Microphone receiver*

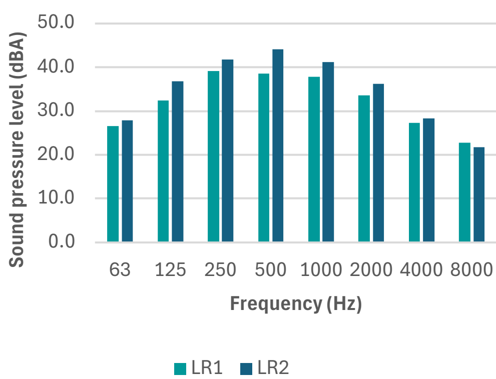
Figure 4. Microphone receivers' locations of (a & b) small-sized and (c & d) medium-sized lecture rooms.

Table 2: Surface material assignment for each surface in ODEON.

Surface	ODEON material
Floor	Smooth painted concrete
Wall	Smooth painted plaster
Ceiling	Suspended Fiberboard/gypsum tiles
Students table	Furniture table
Students chair	Chair metal wood unoccupied
Lecturer chair	Empty chair upholstered cloth cover
Window	Ordinary glass window
Door	Hollow door
Whiteboard	Whiteboard

3. RESULTS AND DISCUSSIONS

A. FIELD MEASUREMENT



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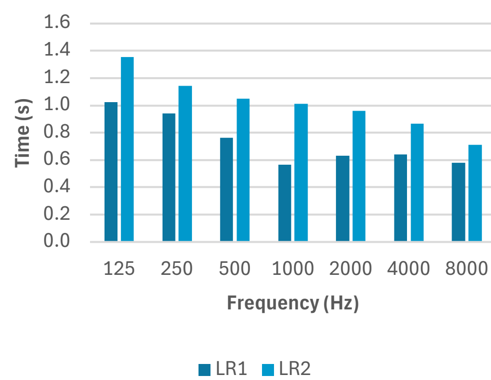

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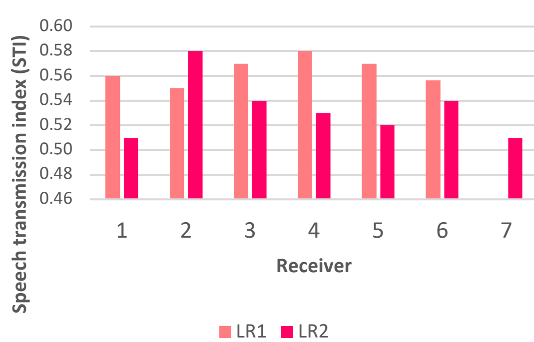


(c)

Figure 5. Field measurement results of (a) background noise, (b) reverberation time and (c) speech transmission index for LR1 and LR2 lecture rooms.

Figure 5a illustrates the LAeq data recorded in both lecture rooms. The collected data indicates that the mean LAeq values for LR1 and LR2, while the HVAC system is running, are 44.3 dBA and 47.7 dBA, respectively. According to Building Bulletin 93 [20] and ANSI/ASA S12.60 [21], it is recommended to maintain a maximum background noise level of 35 dB (A) in an unoccupied classroom; nevertheless, neither class achieved the stipulated maximum permissible background noise level.

The ANSI/ASA S12.60 [18] standard recommends a reverberation time (RT) of 0.6 seconds for classroom volumes less than 283 m³. For classroom volumes above 283 m³, a RT of 0.7 seconds would be ideal. The recorded RT data in LR1 and LR2 are illustrated in Figure 5b. The mean RT for LR1 and LR2 is 0.74 seconds and 1.01 seconds, associated with quantities of 129 m³ and 198 m³, respectively. The numbers do not meet the specified criteria established in the ANSI/ASA S12.60 guideline. Nonetheless, the results conformed to the stipulated maximum outlined in Building Bulletin 93 due to the predominantly reflecting characteristics of the surface materials employed in both lecture rooms environments. Razali et al. [22] states that the most effective intervention for attaining optimal reverberation time in classrooms is to decrease ceiling height and employ materials with enhanced sound absorption properties to mitigate reflection effects.

The evaluation of the STI rating was performed in both lecture rooms, with receivers positioned strategically at multiple locations. Figure 5c displays the difference in STI ratings among receivers located in distinct places within LR1 and LR2. The findings indicate that the STI rating is categorised as "fair," evidenced by the average ratings of 0.56 and 0.53 for LR1 and LR2, respectively.

B. MODEL VERIFICATION

The process of verification entailed the evaluation of RT and STI data acquired from both simulations and on-site measurements. The relative difference between the Just Noticeable Differences (JNDs) of the RTs was computed for comparison. The recommended subjective limen for RT and STI should be below 5% and 0.03 of the relative difference [23]. Bistafa and Bradley [24] suggest that a maximum relative difference of 10% for RT is acknowledged as the ideal practicable precision level for engineering applications. A calculation was conducted to determine and compare the mean RT values at frequencies of 125 Hz and 8000 Hz, together with the STI values at different locations, for both the on-site and simulated data. The results indicate that the models of both lecture rooms fulfil the standards established of a relative difference of less than 10% for RT and 0.03 for STI, as presented in Table 3.

Table 3 Just noticeable difference (JND) of reverberation time and speech transmission index.

Parameter	Lecture room						Recommended JND
	LR1 (Average)			LR2 (Average)			
	On-site	Simulation	JND	On-site	Simulation	JND	
Reverberation time	0.74	0.71	3.4%	1.01	0.94	7.7%	< 10%
STI	0.56	0.56	0	0.53	0.52	0.01	0.03

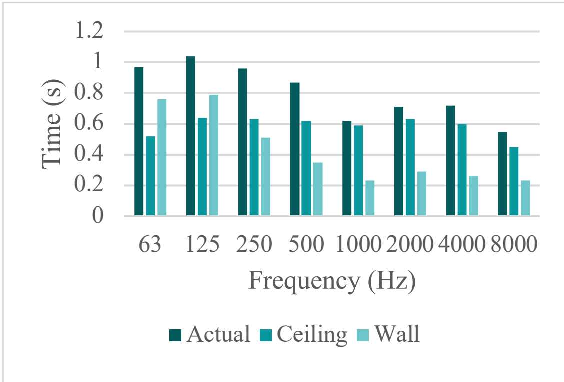
C. ACOUSTIC SIMULATION

I. REVERBERATION TIME (RT)

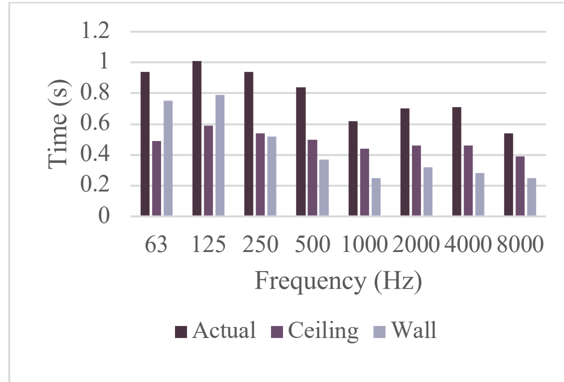
In accordance with the regulation established by Building Bulletin 93 [20], a maximum RT of 0.8 s is required for unoccupied and furnished classrooms. While ANSI/ASA S12.60 [21] requires an RT of 0.6 s for classroom volumes less than 283 m^3 and 0.7 s for volumes greater than 283 m^3. Figures 6a and 6b display the RT findings obtained in a small lecture room for collaborative and lecture-based learning, respectively. The average RT for actual collaborative and lecture-based learning environments are 0.80 seconds and 0.79 seconds, respectively, which fall short of the standards defined by ANSI/ASA S12.60 but comply with the recommendations of Building Bulletin 93. Following the treatment of the ceiling surface, the RT improved to 0.59 seconds and 0.48 seconds. The results indicate further enhancement, as all wall surfaces treated with absorptive material had average RTs of 0.43 s and 0.44 s, respectively.

In the medium-sized lecture room, identical patterns of findings were identified, as seen in Figures 7a and 7b. The RT results for actual, ceiling treatment, and wall treatment are 0.86 s, 0.53 s, and 0.51 s, respectively, in collaborative learning environments. In a lecture-based condition, the average RT recorded are 0.86 seconds, 0.64 seconds, and 0.5 seconds for the actual, ceiling treatment, and wall treatment conditions, respectively. The primary factor contributing to the notable enhancement in RT is the absorptive properties of the materials employed for ceiling and wall treatment. Consequently, an increased amount of sound energy is absorbed within the rooms.

Small-sized lecture room



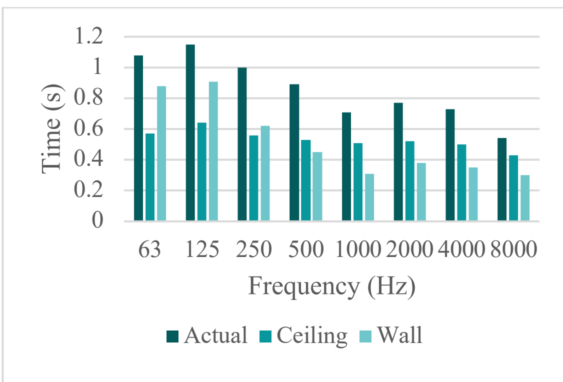
(a)



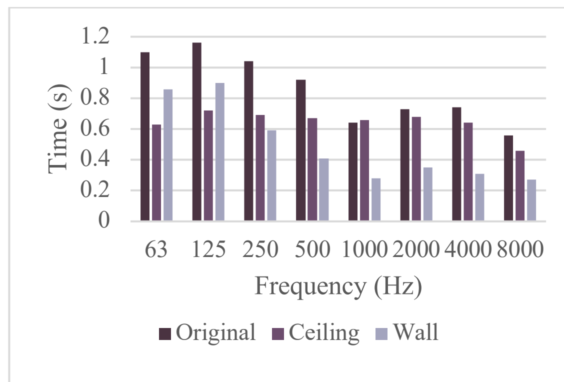
(b)

Figure 6. RT results of (a) collaborative learning and (b) lecture-based learning.

Medium-sized lecture room



(a)



(b)

Figure 7: RT results of (a) collaborative learning and (b) lecture-based learning.

II. SPEECH TRANSMISSION INDEX (STI)

Collaborative learning

An STI assessment of several surface treatments at numerous sound source locations was performed for small and medium-sized lecture rooms. The aim of the simulation is to analyse the effect of surface treatment in collaborative and lecture-based environments on the STI rating. Figures 8 and 9 depict the STI values of diverse surface treatments at various sound source locations in small to medium-sized lecture rooms, specifically tailored for collaborative learning environments. Research indicates that a minimum STI value of 0.6 is essential for optimal speech intelligibility in educational settings. Figure 8 demonstrates that the majority of microphone receivers satisfy the minimal required STI value of 0.6 in real room conditions. The STI rating improved when the ceiling surface was treated with absorptive material. The STI results indicate enhanced performance following the application of acoustic panels to the wall surfaces. A notable enhancement was observed in the microphone receivers situated near a 1.5-meter radius of the sound source. Comparable results were observed in the medium-sized lecture room.

Nonetheless, certain microphone receivers demonstrated a decline in STI value, particularly for sound sources student 1 and 2. This is attributable to the placement of the sound source, which was situated at the front of the lecture room and orientated towards the front wall. The directivity of the sound source towards the front of the lecture room results in a reduction of STI for the microphones positioned at the rear.

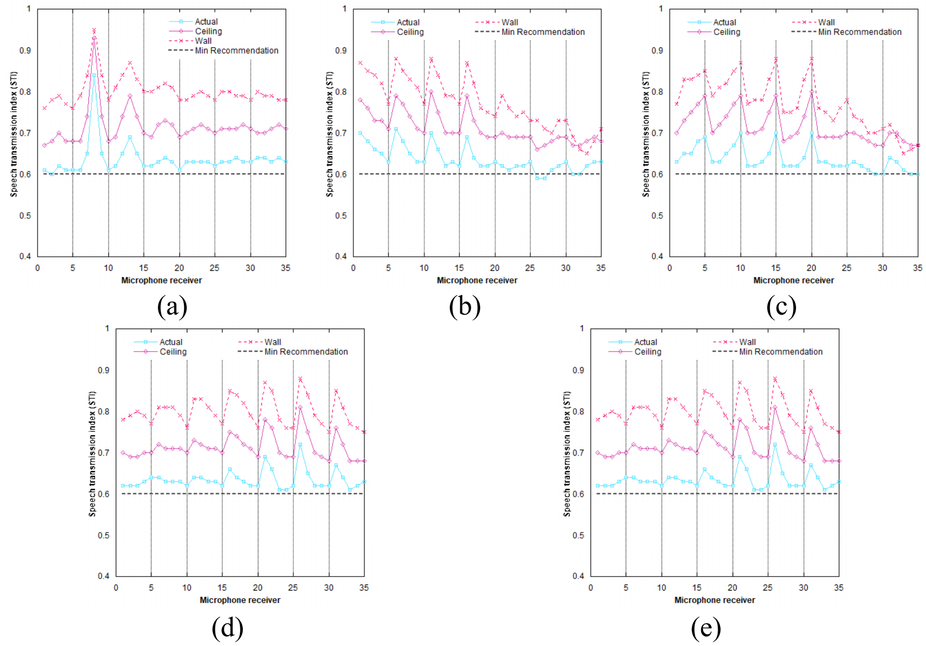


Figure 8. STI results of small-sized lecture room for sound source location at (a) lecturer, (b) student 1, (c) student 2, (d) student 3 and (e) student 4.

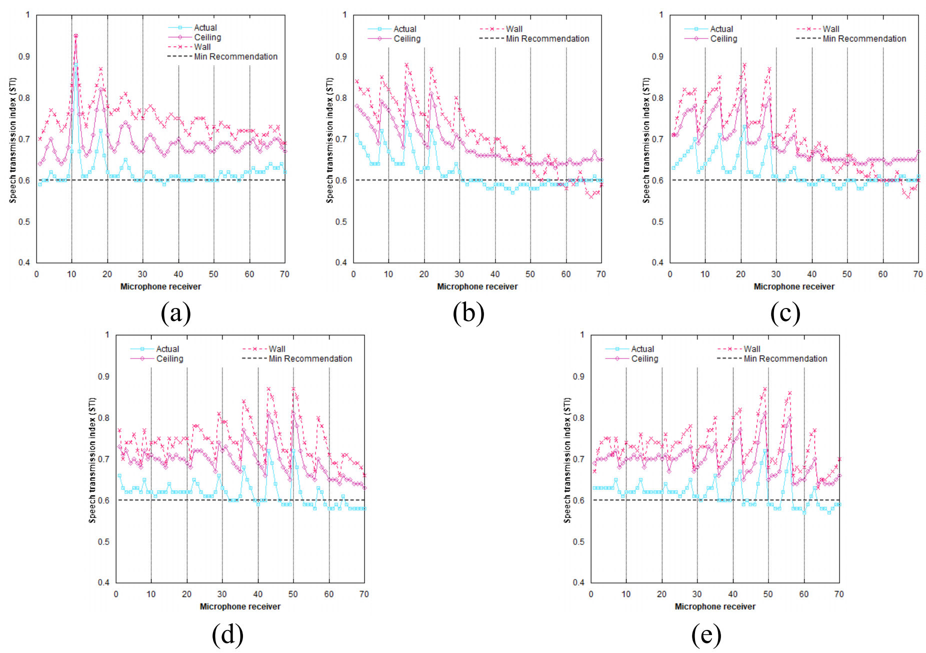
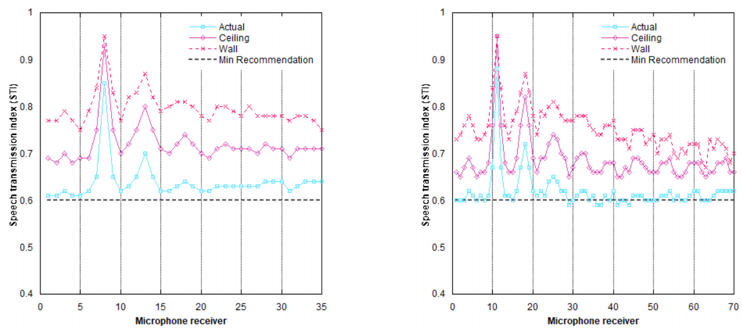


Figure 9. STI results of medium-sized lecture room for sound source location at (a) lecturer, (b) student 1, (c) student 2, (d) student 3 and (e) student 4.

Lecture-based learning

The assessment of STI ratings for various surface treatments in lecture-based environments was conducted in small and medium-sized lecture rooms. Figure 10 illustrates the STI values of several surface treatments for small and medium-sized lecture rooms, specifically designed for lecture-based learning situations. The results indicate that most microphone receivers meet the minimum STI threshold of 0.6 under actual room settings. The STI rating enhanced when the ceiling surface was coated with absorptive material. The STI results demonstrate improved performance after the installation of acoustic panels on the wall surfaces. The STI ratings enhanced from good to exceptional at specific microphone positions upon the application of the wall and ceiling surface treatment. This signifies that RT possesses a robust correlation with the STI value. As the RT value is reduced, the STI ratings improve.



(a) (b)

Figure 10. STI results of lecture-based learning for (a) small-sized and (b) medium-sized lecture rooms.

III. SPEECH CLARITY (C50)

Collaborative learning

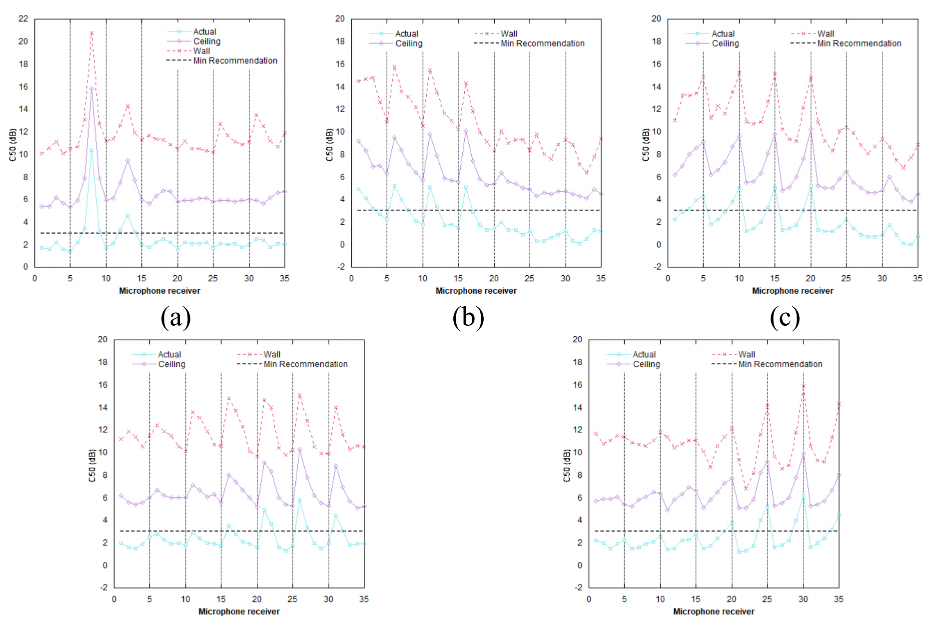
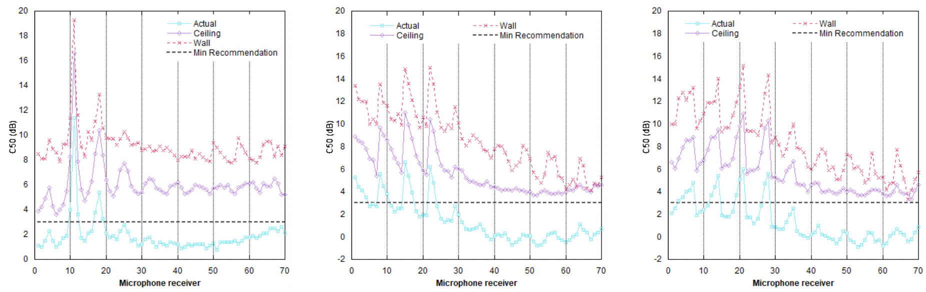


Figure 11. C50 results of small-sized lecture room for sound source location at (a) lecturer, (b) student 1, (c) student 2, (d) student 3 and (e) student 4.



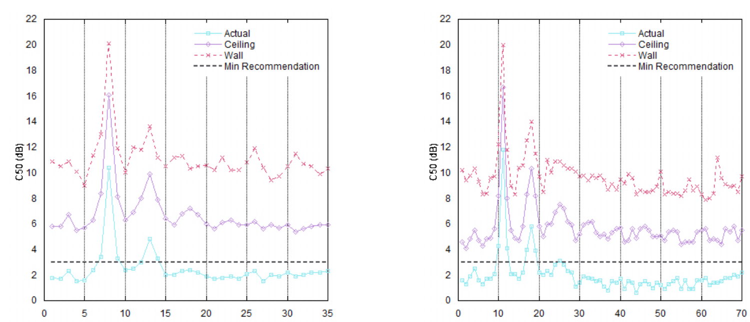
(a) (b) (c)

(d) (e)

Figure 12. C50 results of medium-sized lecture room for sound source location at (a) lecturer, (b) student 1, (c) student 2, (d) student 3 and (e) student 4.

In order to determine the C50 value for both lecture rooms, the same configurations of microphone receivers were utilised. C50 is one of the acoustic indicators that can be used to evaluate the quality of speech intelligibility in classrooms. For the purpose of ensuring that students are able to understand what is being said in the classroom, it is essential that the C50 value be at least 3 dB. The C50 results for small and medium-sized lecture rooms are depicted in Figures 11 and 12, respectively, and they are shown at various sound source locations and surface treatments. The C50 data that were recorded followed a pattern that was remarkably comparable to the STI results. It has been discovered that the minimum suggested C50 value of 3 decibels in actual room conditions is only satisfied by a select few microphone receivers that are situated in close proximity to the sound source. On the other hand, when the wall and ceiling surface were treated independently, all the microphone receivers showed significant improvements that went beyond the C50 minimum requirement. The fact that this is the case suggests that RT has a significant association not only with STI but also with C50. The decrease in the RT value corresponds to an increase in the improvement of C50.

Lecture-based learning



(a) (b)

Figure 13: C50 results of lecture-based learning for (a) small-sized and (b) medium-sized lecture rooms.

In lecture-based learning environments, similar patterns were discovered. Figure 13 illustrates the C50 results for small and medium-sized lecture rooms, displaying various sound source locations and surface treatments for lecture-based learning settings. The minimum recommended C50 value of 3 decibels in real room settings is met only by a limited number of microphone receivers positioned near the sound source. Conversely, when the wall and ceiling surfaces were treated separately, all microphone receivers exhibited substantial enhancements that exceeded the minimal C50 threshold. This indicates that RT has a substantial correlation with both STI and C50. The reduction in the RT value correlates with an improvement in C50.

4. CONCLUSION

The study executed an acoustic simulation in two lecture rooms featuring distinct surface treatments and varying pedagogical methods for hybrid learning. The findings indicate that the surface treatment of walls and ceilings significantly influenced the RT, STI, and C50 values in both small and medium-sized lecture rooms across various instructional methods, including lecture-based and collaborative learning settings. A comparable pattern of results for STI and C50 was noticed in both lecture environments and pedagogical methods. All acoustic measurements demonstrate substantial improvements following the treatment of ceiling and wall surfaces with absorptive materials. Additional research is necessary to investigate other various design elements on enhancing the acoustic performance of hybrid learning lecture rooms.

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