

Collaborative Synchronous Hybrid Learning Environments: Opportunities and Audio/Acoustic Quality Challenges

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Abstract: This exploratory study focuses on both pedagogical and technological challenges to anticipate teachers' needs for information technologies that support a collaborative synchronous hybrid learning environment. This is based on the OECD's PISA assessment mentioning a decline in students' academic performances, especially in problem-solving skills and collaboration, and the growing interest for digital tools dedicated to the learning environment. Our survey confirmed both the teachers' interest in specific innovative pedagogical scenarios, made possible by collaborative synchronous hybrid learning environments, and their concern about audio quality problems, already encountered in classic distance learning situations. This survey is supported by an "in lab" protocol which explores the technical challenges of audio and acoustic quality associated with two multi-group scenarios in comparison with the classic scenario. We identified that interfering speech issued from several speakers who are relatively close to each other and sometimes mobile in the classroom are creating drastic intelligibility issues that are always more acute for the distant person. The survey revealed that this form of hybrid learning could lead to specific learning difficulties and fatigue for both students and teachers, which could be objectively assessed.

1 INTRODUCTION

The recent Covid-19 epidemic and the restrictions implemented to minimize the spread of the disease highlighted new challenges, especially in education. The OECD's PISA assessment of learning performances in 2022 revealed an "unprecedented drop" in scores of assessed countries, showing the impact of the epidemic on the educational system (OECD, 2023). More specifically, teachers faced challenges in the implementation of collaborative learning, even though those techniques have been increasingly favoured for its social, academic and psychological benefits (Laal & Ghodsi, 2012; Marreh & Velankar, 2024). In 2015, reports from the OECD already emphasized the importance of developing students' "collaborative problem-solving skills and attitude towards collaboration" (OECD, 2017). The 2022 PISA assessment also highlighted that the decline in performances began "well before" the

beginning of the pandemic and could indicate a more systemic issue (OECD, 2023).

To tackle the drop in performances and future challenges that may occur due to circumstantial events, companies providing educational resources, labs and schools need to work together to provide sustainable tools that support a fundamental rethinking of teaching and learning.

The European iTEC Innovative Technologies for Engaging Classrooms project, involving 26 partners (14 ministries of education, technology providers and research organisations), was promoting the use of technology and innovative educational tools to improve educational performances (Ellis et al., 2015). This extensive study showed that integrating digital tools and platforms to the learning environment improved collaboration and pedagogy for both students and teachers (Lewin & McNicol, 2015). Therefore, efforts were made to develop synchronous hybrid classrooms: students both on-site and remote could participate and learn simultaneously. Even

though synchronous hybrid learning has proved effective in improving problem-solving skills (Ariani et al., 2022) as well as students engagement, retention and communication, a lot of “*pedagogical and technological*” challenges persists (Raes et al., 2020).

The growing interest towards collaborative work mentioned before incentivised teachers to develop its practice hybrid synchronous settings. However, studies showed that available video conference tools that are not intentionally designed for this purpose were challenging to use for collaborative hybrid synchronous work (Glazunova et al., 2023; Ortega-Arranz et al., 2024; Raes et al., 2020).

The orchestration load, the lack of experience with digital tools and synchronous hybrid learning environments, the availability of live interactions between on-site and remote participants are major areas of improvements for teachers and students when faced with these new tools (Carruana Martín et al., 2023; Racheva & Peytcheva-Forsyth, 2024; Raes et al., 2020). In addition to these pedagogical challenges, several studies highlighted the key role of the audio setting to ensure a successful learning experience (Detyna et al., 2023; Raes et al., 2020).

These observations lead us to investigate the pedagogical and technological challenges of collaborative synchronous hybrid learning. After describing our approach towards this subject, we designed an exploratory study structured in 2 parts.

The first part consists of a preliminary survey of middle and high school teachers in France that aimed at assessing:

- their insights on synchronous hybrid learning tools, based on their experience of already available tools,
- their experience of face-to-face collaborative group work,
- their perspectives and concerns regarding pedagogical scenarios made possible by collaborative synchronous hybrid learning.

The second part was designed based on responses from the survey mentioning technical challenges of audio and acoustic quality associated with this learning environment. The design of dedicated algorithms to enhance the audio experience required a standardised -adapted ITU-T- subjective assessment of speech quality (intelligibility, comfort, etc.) according to different pedagogic scenarios mentioned in the survey.

The main objective of this exploratory study is to anticipate technical and pedagogical concerns as soon as they are identified in order to co-develop solutions

and tools fitted to teachers’ and students’ needs regarding collaborative hybrid synchronous learning.

2 BACKGROUND AND APPROACH

It's interesting to note that as early as 2001, a French study by GRESEC (Groupe de Recherche sur les Enjeux de la Communication) pointed out that the failure of collaborations between suppliers of distance learning solutions and teachers - customers of these solutions - was due in particular to (translation) “*the conflict between two logics: the logic of manufacturers, focused on efficiency (optimal use of technology) and the logic of users, based on usefulness for users, particularly in relation to the needs of learners*” (Ologeanu, 2001). Our exploratory study attempts to approach the problems of collaborative synchronous hybrid learning from these 2 points of view, while being aware of the difficulty of jointly conceptualising such an environment.

In order to conceptualise the underlying constraints and challenges of complex pedagogical scenarios, it is beneficial to be able to have a “physical” representation of the situation. For this purpose, the French company Quietam Studio (Bordeaux, France) inaugurated in 2023 the ClassLab, as well as the MAIA online platform dedicated to synchronous hybrid collaborative activities. Figure 1 shows a hybrid collaborative tested configuration of ClassLab.



Figure 1: Conceptualisation of ClassLab.

The ClassLab is composed of 3 unconnected table islands (foreground), an asynchronous broadcast for a seated group (right) and 3 connected table islands for synchronous interaction both face-to-face and remotely in real time (background). It is the analysis of this synchronous collaborative configuration that we focus on here. These equipment allow the study of real-life pedagogical scenarios and the audio/acoustic challenges that will need to be resolved on the

associated digital platforms. The conceptualisation needs to be both pedagogical and technical.

Pedagogically, involved parties should bear in mind that the collaborative problem-solving competency was defined by PISA as “*the capacity of an individual to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution*”. Its three collaborative problem-solving associated skills are establishing and maintaining shared understanding, taking appropriate action to solve the problem and establishing and maintaining team organisation. Those skills have to be considered and developed in a digital context (OECD, 2017), therefore, the structure of the exploratory survey carried out is designed to anticipate the pedagogical opportunities and technical concerns associated with this new mode of collaboration, based on teachers' past experience of face-to-face collaborative practice and synchronous hybrid learning.

Technically, involved parties must be able to conceptualise the encountered scenario schematically, then algorithmically and finally optimise the integration of algorithms dedicated to enhancing this new hybrid multi-group collaborative experience on a digital platform. To do this, we need to draw inspiration from problems encountered in traditional video conferencing situations, in order to design and assemble the associated technological building blocks. State of the Art 2023 on *Audio Signal Processing in the 21st Century: The important outcomes of the past 25 years* provides an accurate summary of advances and bottlenecks in multichannel audio (Richard et al., 2023). However, the challenges resulting from a collaborative synchronous hybrid learning environment are seemingly unprecedented. As in the classic hands-free video conferencing situation, the main difficulty lies in this time it's multi-loudspeaker/ multi-microphone coupling from neighbouring groups.

3 SURVEY

Our survey was designed to explore the practices, challenges, and perceptions of teachers regarding collaborative learning and distance education, as well as their potential combination in hybrid modes.

3.1 Method

After gathering basic demographic and professional information about the participants, we focused on assessing how teachers integrate digital technologies into their distance teaching practices in order to better understand the level of skill and comfort of teachers with online teaching. We also asked their feedback on their use of digital tools, especially the quality of their teaching experience. Teachers were then questioned about their use and feedback on collaborative activities. Finally, we introduced the concept of collaborative hybrid (a combination of face-to-face and distance) learning environment and gathered their perspectives and concerns regarding the implementation of these methods in their classrooms.

The general objective of the survey is to collect data to analyse how different practices affect teaching and learning, identify barriers to their effectiveness, and evaluate the interest in innovative hybrid approaches. This study aims at identifying pedagogical scenarios directly from the source - the teachers - to design technical solutions directly from those real-life scenarios. This study could give insights to further improve educational policies and teaching practice by promoting a more thoughtful integration of technologies and collaborative methods in education.

The exploratory survey was distributed to around 100 teachers between June, 2023 and December 2023 and 26 teachers completed the survey. The survey was distributed to middle schools and highschools in the Nouvelle Aquitaine region (France), as well as professional training organisations and members of the INSPE (Institut National Supérieur du Professorat et de l'Éducation). The survey was relayed by emailing and posts via LinkedIn. No benefits or rewards were offered.

13 men and 13 women responded to the survey. The vast majority of the respondents teach in French schools, only 2 teach in Canadian schools. More than 42% of the respondents have been teaching for more than 20 years, around 23% have 10 to 20 years of experience teaching, 19% have 3 to 10 years of experience and around 16% have less than 3 years of experience. The respondents specialise in very diverse subjects, from languages to sciences, technology, management and economy. The respondents were distributed in 3 groups : approximately 40% teach in middle school, 26% teach in highschool and 34% teach in other types of schools such as professional training schools or in multiple schools.

3.2 Results

The first part of the survey inquires about teachers' usage of collaborative work in the learning environment. More than $\frac{3}{4}$ of the respondents use collaborative work at least once a month, 40% of which very regularly (at least once every week). Learners are presented with diverse activities when doing collaborative work, such as "thematic studies", "bibliographical research" or "problem solving". Furthermore, several teachers mention that collaborative work often results in a specific type of restitution ("oral/exposé", "creation of a poster", "production of videos"). More than half of the teachers mainly organise groups of 3 to 5 students. The majority of teachers surveyed believes that collaborative work is beneficial for students' learning and personal development: almost 75% of respondents believe it improves self-confidence, 87% believe it improves critical thinking and teamwork, over 80% believe it improves communication between students and group cohesion, and more than half think it is a way to motivate students and avoid school failure. In general, our survey indicates that teachers favour the use of collaborative work methods -including hybrid- for student development, particularly their attitude towards collaboration.

In order to better understand their needs regarding digital resources, we focused the second part of the survey on their experience with those devices. Nearly 65% of the surveyed teachers use digital learning resources regularly in their classroom. Although the majority of respondents generally report having had correct audio and video experiences with the tele-teaching tools, several recurring problems are raised by users: more than 40% reported having regular connection and interruption issues, and half of them experienced regular latencies. In addition, the majority have noticed echoes or disturbing and unwanted noises during video conferences, of which a quarter regularly. Most mention "ambient noise" such as an "urban atmosphere" or "keyboard noises", interfering words and two responses mention Larsen effects between several microphones and speakers. These problems related to the use of current video conferencing tools generate an extra effort to understand important messages for almost 42% of respondents and more than 65% report that their students regularly raise these concerns during use. These results reveal that the integration of digital resources in education raises technical problems, especially audio quality issues, which are not yet solved by existing solutions.

Lastly, we wanted to gather the opinion of teachers regarding collaborative hybrid learning, for which no software has been specifically developed, to the extent of our knowledge. Nearly 72% of the surveyed teachers would like to be able to have hybrid groups in their classroom if they could, namely groups composed of remote and on-site students. Together with the ability to better accommodate students unable to come to class, they also mention the ability to create mixed classrooms between regions or countries or to enable teachers of exotic subjects to teach several classes, improving the availability of teachers. However, the teachers that responded that they would not like this setup mainly explain that they would struggle managing the remote students. Only 36% of the surveyed teachers had the opportunity to test this setup, mainly during the Covid-19 pandemic. However, 50% of the surveyed teachers think that these setups could improve student's problem-solving skills and nearly 75% think that it can improve collaboration between students, while allowing teachers to be more available and enabling a better integration of remote students in the class.

3.3 Discussion

Our survey showed that teachers are interested in developing and acknowledge the benefits of collaborative learning activities in their class, as shown in similar studies (Laal & Ghodsi, 2012; Marreh & Velankar, 2024). It also showed the growing usage of digital resources in the learning environment, even though teachers and students still face technical difficulties when using those resources (Rafiq et al., 2024).

Interestingly, even though very few teachers already tried using collaborative hybrid or "blended" learning environments, their responses show a positive perspective on these scenarios. These improvements to group work organisation and performances were already noted as early as 2006 (Graham, 2006). It could be interesting to confront these perceptions with students' perspectives and measure their performances in an hybrid collaborative setting.

Another interesting result came from confronting teachers' experiences of collaborative work with their concerns regarding hybrid collaborative settings: only 15% of the surveyed teaches experience disciplinary issues when setting up collaborative work, but this number raises to 50% when they are asked if, in their opinion, setting up an hybrid collaborative environment could induce disciplinary

issues. Moreover, nearly 75% of them think that setting up this kind of environment could drastically increase their workload. These results showed us that hybrid collaborative environments raise both technical and pedagogical concerns. Those concerns should be addressed together with involved parties such as teachers, students, educational facilities but also companies in order to co-create future tools adapted to hybrid collaborative learning.

In the survey, teachers identified 3 main coupled issues when they used video conferencing tools that could also be raised in a hybrid collaborative setup: echo, howling (Larsen effect) and both ambient noise and noise from competing speech sources from neighbour groups. Thus, solutions to these issues must be developed in order to adapt digital tools to their use in blended learning environments:

- Multi-input/multi-output echo cancellation in neighbouring ilot situations, including teacher mobility, which induces non-stationarity of the echo channel. The diversity of echo situations in hands-free sound systems and their resolution in challenging contexts is of great economic importance and the subject of international R&D challenges (Shetu et al., 2024). The current trend is towards hybrid signal/IA solutions (see for example (Chen et al., 2021)).
- Early detection and reduction of howling in adjacent ilot situations. This feedback problem is still under investigation (Zhang et al., 2023).
- Noise reduction in multi-group situations, where the ambient noise is made up of ambient noise and interfering -or concurrent- speech from several speakers who are relatively close to each other and sometimes mobile in the classroom. Personalised speech enhancement methods as speaker diarization ("who speaks and when") are algorithmic solution paths (Eskimez et al., 2021; Wang et al., 2019).

Following this survey, we decided to focus on investigating the technical challenges raised by a hybrid collaborative setting on the audio quality of digital tools.

A subjective audio and acoustic quality evaluation protocol was set up in a simplified situation with 2 face-to-face groups, each with its own remote counterpart. The measurement protocol followed ISO and ITU-T recommendations (P.800, P.808, P.831) as far as possible in this unusual situation. In the present study, we will only show the subjective results regarding the competing speech issue.

Overall, we noticed that between 20% to 54% of teachers chose the third level out of five when responding to questions targeting the potential

advantages of a collaborative hybrid learning environment (versus 8% to 25% when asked about collaborative activities only - without the hybrid setup). We interpreted those results as a struggle to consider the perspectives and concerns relative to this kind of learning environment ; emphasising the need to test real-life scenarios.

4 IMPACT OF HYBRID AND COLLABORATIVE SCENARIO ON AUDIO QUALITY

The survey highlighted the impact of the hybrid situation on audio quality, such as the appearance of echoes, feedback and environmental noise, which disrupts intelligibility. To quantify these effects, in collaborative situation we designed a test protocol that compares 3 scenarios:

- *Scenario 1 classic "L1-D1"*: a **"one to one"** hands free audio communication between a local room and a distant room.
- *Scenario 2 multichannel "L2-D2"*: with **two** simultaneous **"one to one"** hands free audio communication in separate sessions but in the same local room.
- *Scenario 3 multichannel "L2-D1"*: where there is a **"one to two"** hands free audio communication between 2 two persons in the local room with different devices and 1 person in a distant room.

4.1 Method

The protocol was partially based on the ITU-T standards¹ such as P831 (1998) standard on *Subjective performance evaluation of network echo canceller*, P.832 (2000) on *Subjective evaluation of hands-free terminal performance*, and adapted to account for our specific hybrid application.

The aim of this study is to focus on the variation induced by the two multi-group scenarios in comparison with the classic scenario. We aimed at understanding the impact of 5 varying parameters that could influence the audio quality. The parameters are presented in Table 1.

¹ <https://www.itu.int/>

Table 1: Tested parameters for hybrid communication protocol.

Parameters	Definition	2 levels of variation
Echo path	Variation of echo path: simulation of a teacher moving between groups or steady in a position	V1: steady position V2: path with continuous variation (from point A to B)
Communication system distance	Distance between communication systems specific to L2-D2 and L2-D1 scenarios	V1: distance 1 V2 : distance 2
Speaker voice level	Speaker voice level translated into: low voice, normal voice, forced voice	V1: normal voice V2 : forced voice
Type of communication	Monologue or conversational situation	V1: single remote speech V2 : double remote speech
Multi-group communication in local	Interfering speech in the classroom	V1: single local speech V2: local speech and interfering speech from neighbouring group

The number of tests for each scenario was:

- L1-D1 classic scenario : 8 test conditions
- L2-D2 and L2-D1 multi-channel scenarios: initially 32 (2^5) test conditions each, but we reduce it to 16, ($2^{((5-1))}$) each, using a fractional factorial design approach to estimate the main effects.

For each test condition, 1 to 4 sentences (phonetically balanced) were used by test participants. These lists of sentences were taken from the Combescure and Fournier sentence lists, as well as the phonetically-balanced HINT test sentences used in subjective testing, particularly in vocal audiometry by audiologists (see for example (Chevret et al., 2012)). In total 310 sentences were used and mixed so that test subjects only hear the sentences once in the same scenario.

Finally, test subjects were asked to answer 8 questions **Q.i** (in French) related to communication quality for each condition test using ITU-T P.835 standard for “*subjective test methodology for evaluating speech communication systems that include noise suppression algorithms*”:

Q.1: What is your opinion of the connection you have just used? [5] Excellent [4] Good [3] Fair [2] Poor [1] Bad

Q.2: Did you experience any difficulties speaking or listening in this connection? [5] Very strong [4] Important [3] Medium [2] Small [1] None

Q.3: How would you rate the quality of communication? [0] Inacceptable [1] Acceptable

Q.4: How would you rate the degradation caused by the echo of your own voice? [5] Imperceptible [4] Perceptible, but not annoying [3] Slightly annoying [2] Annoying [1] Very annoying

Q.5: How would you rate the other degradations (truncation, various noises, etc.)? [5] Imperceptible [4] Perceptible, but not annoying [3] Slightly annoying [2] Annoying [1] Very annoying

Q.6: How do you find the voice of the person you are speaking to? [0] Not natural [1] Natural

Q.7: How would you rate the overall sound quality of the communication? [5] Excellent [4] Good [3] Fair [2] Poor [1] Bad

Q.8: How would you rate the listening effort required to understand the message? [5] Absolute relaxation: no effort [4] Attention required; no appreciable effort [3] Moderate effort [2] Considerable effort [1] Meaning incomprehensible despite every possible effort

The scenario L1-D1 was repeated 3 times with different persons (6 test subjects in total) and L2-D2 and L2-D1 scenarios were performed once. In total 10 naive test subjects participated in the protocol and all have signed a consent agreement for using test results for research purposes.

4.2 Results and Discussion

Firstly, we compared the quality perceived by people in the different rooms: local and distant. Table 2 shows the average subjective scores **on all the test conditions** for each question, Q1 to Q8 for each scenario (more details are available in (Brudieux et al., 2024)).

Table 2 shows that the overall quality deteriorates in L2-D2 and L1-D1 scenarios compared to the classic L1-D1 scenario, with unacceptable communication reported in the L2-D1 situation. For example, the overall sound quality of the communication decreased from excellent for L1-D1 to fair and poor for respectively L2-D2 and L2-D1 in the local room.

Table 2: Subjective evaluation of audio communication quality by test subjects in local and distant room for the scenarios L1-D1, L2-D2 and L2-D1.

Q. Num	Subjective Evaluation in distant room			Subjective Evaluation in local room		
	L1-D1	L2-D2	L2-D1	L1-D1	L2-D2	L2-D1
Q.1	4.25	4.06	2.92	5	4.43	3.17
Q.2	1.62	2.28	2.85	1.16	1.59	3.71
Q.3	0.91	0.71	0.71	1	0.81	0.32
Q.4	4.87	4.90	4.57	5	5	2.85
Q.5	4.37	3.21	3.07	4.83	3.63	2
Q.6	0.87	0.87	1	1	1	0.5
Q.7	3.91	3.09	3.14	5	3.78	2
Q.8	4.12	3.03	3.28	4.75	4.09	2.03

We further analysed the effect of **interfering speech** by specifically extracting subjective quality measures from the protocol to compare the situation with and without interfering speech for the 3 questions Q2, Q7 and Q8 in both the local and distant rooms as shown in figure 2.

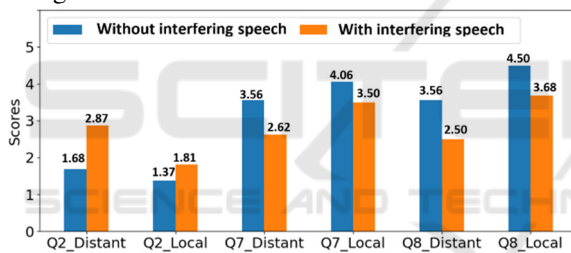


Figure 2: Subjective evaluation of audio communication quality in local and distant rooms for the scenario L2-D2 with/without interfering speech.

The overall results were consistent with a degradation of the audio quality by interfering speech as measured in:

- (Q2) Speaking and listening difficulties are greater,
- (Q7) The overall sound quality of communication is poorer,
- (Q8) The listening effort required to understand the message is greater.

Interestingly, the degradation of the audio quality and intelligibility seemed to always be more acute for the distant person. This can be explained by the fact that the communication arriving at the remote user is in mono compared to the local speakers: the signal is composed of a mixture of all interfering and useful speech signals, and the user will therefore not be able to use spatial cues to differentiate the two speech streams. This result is especially significant, as it

indicates the need for the development of a specific noise reduction system inside digital tools to reduce the impact of interfering speech.

Furthermore, in the in-lab situation tested, there was only one interfering speech stream (from the only neighbouring group). According to the survey, in face-to-face group work, teachers usually work with either groups of 2 students (32%), or groups of between 3 and 5 students (42%). These issues are thus likely to be worse in those setups, or setups with more than two groups, compared to the simplified version tested in this study. Studies and challenges have already identified the difficulties of untangling speech signals and are focused on solving this specific issue (Cutler et al., 2021).

5 CONCLUSION

This study on anticipating teachers' needs for Information Technologies to support a collaborative synchronous hybrid learning environment confirmed:

- teachers' interest in specific innovative pedagogical scenarios made possible,
- their concern about the extra preparation and handling workload.

Specifically, the technical concerns regarding the audio quality were confirmed by subjective in-lab protocols in simplified situations. Those were identified to be due to the specific loudspeaker/microphone acoustic couplings between groups inherent to the collaborative environment. There is a pressing need to focus algorithmically on the drastic audio quality degradation caused by interfering speech from neighbouring groups, which disturbs distant speakers in a given group (for more details, see (Brudieux et al., 2024)).

Verdel (translation) stated that “*there is a growing awareness of the importance of learning spaces, combining a desire for modularity and diversified use of digital tools*” (Verdel, 2023) thus encouraging the early identification of technical obstacles that may hinder the development of innovative digital tools dedicated to the learning environment.

Our study could benefit from gathering more teachers' and students' feedback, investigating further the pedagogical scenario “in vivo” and test the robustness of a hybrid passive/algorithmic solutions in different class configurations: table arrangement in islands, use passive insulation panels, number of groups and number of students per group, ...

Innovative technologies exist to solve some of the problems encountered in audio quality, such as the creation of speech zones with self-distributed

acoustic swarms (Itani et al., 2023). However, the scenario of these studies does not correspond to low-cost algorithmic solutions for democratisation of collaborative synchronous hybrid learning in schools. These hybrid collaborative educational scenarios generate algorithmic solutions that must automatically adapt to the classroom configuration. We can reduce the complexity of algorithms, while improving their robustness, through common sense solutions: recommendations for modular passive isolation of groups and classroom behaviour charter, as specified in the standards for acoustic quality and comfort in open office spaces².

We are aware that the next step is to provide more theoretical contributions relating to the impact of these new educational scenarios implemented.

Our survey also highlighted the concern for an increased fatigue caused by noisy learning environments and extensive digital tools usage: nearly 75% of teachers agreed that poor audio quality combined with the ambient sound inherent to the collaborative activities could contribute to students fatigue and lack of involvement. For both pedagogical and technical reasons, it is of significant importance that companies and researchers continue to quantify the effects of collaborative synchronous hybrid learning on the potential fatigue of students. This increased mental load has been raised by the French Senate³ and has been objectified on adults by EEG measurements carried out by Microsoft on the Microsoft Teams software⁴. The ZEF scale (Zoom Exhaustion & Fatigue Scale), validated on a large scale with adults, seems promising to evaluate the fatigue of students (Fauville et al., 2021). The scale was designed to measure the exhaustion and fatigue felt by users of videoconferencing, caused by intense visual and close-up contact, reduced mobility, a higher cognitive and emotional load than in face-to-face situations, and vocal fatigue. The auditory fatigue could be integrated into the ZEF scale and tested on a population of learners.

Altogether, this study emphasises the need for the development of tools dedicated to hybrid collaborative learning environments, co-developed by teachers, educational facilities, software companies and equipment providers.

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CONFLICTS OF INTEREST

HT, MS and YB report personal fees from Quietam Studio as employees, during the conduct of the study.

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² ISO 22955:2021 Acoustic quality of open office spaces.

³ www.senat.fr/rap/r21-259/r21-2591.pdf

⁴ www.microsoft.com/en-us/worklab/work-trend-index/

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