Using a smartphone to investigate classroom acoustics

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Abstract. We present a proposal for active learning about environmental acoustics and room acoustics for high school and undergraduate students. Students work on the concepts of sound pressure level and reverberation time through a set of activities centred on speech communication in the school. For experimental work, they use smartphone applications for sound measurement. At the end of the work, students would be able to suggest some actions to improve the acoustic comfort in school. The students' interest increases as they focus on their own experience. Moreover, they can apply and test the solutions that they propose.

1. Introduction

Environmental comfort includes the following areas: thermal, luminous (visual), acoustic and ergonomic comfort. There are two problems affecting acoustic comfort in rooms: too much noise entering the space from outside and from adjacent spaces, and bad sound control indoor. So, rooms require acoustic insulation in order to reduce the external noise, and acoustic conditioning in order to control the sound indoor (obtain an adequate reverberation, eliminate echoes, obtain a uniform sound field and an adequate sound intensity).

In classrooms, environmental factors can affect the process of learning and teaching. A poor acoustic performance of the classroom will have an effect on both the understanding by the students and the physical stress of the teacher [1]. Speech communication is an essential factor in school. Good acoustics for learning support easy verbal communication. With background noise, people may have trouble following conversations. Sources of noise can be situated outside of the school (vehicular traffic, aircraft flyover), in the hallways (foot traffic, conversation, compressors, boilers, ventilation systems), in other classrooms (amplified sound systems, music, conversation), and inside the classroom itself (ventilation systems, electrical equipment, conversation, furniture noise). Moreover, the comprehension of speech ( intelligibility) gets worse with reverberation.

The American National Standard for “acoustical performance criteria, design requirements, and guidelines for schools” [2] emphasizes, “Most speech communication in classrooms occurs in the presence of background noise. When background noise is present, intelligibility depends on the sound pressure level of the speech and also on the level of the speech relative to the level of the noise, that is, the signal-to-noise ratio (SNR). (...) Intelligibility increases as the SNR increases, either by raising the speech level or by decreasing the noise level. Speech perception research has shown that individuals with hearing impairments, speech and language disorders, or limited English proficiency require more favourable signal-to-noise ratios than individuals without these impairments or disorders to achieve high levels of speech intelligibility”.

The same standard says, “Classrooms are enclosed spaces in which sound produces reverberation. Reverberation times in excess of 0.4 s to 0.6 s reduce speech intelligibility both in quiet and in noise. When both background noise and excessive reverberation are present, their effects on speech intelligibility are additive for individuals with normal speech, language, and hearing abilities” [2].
Shield and Dockrell [3] found that the dominant source of noise in a primary school classroom is the noise generated by the pupils taking part in classroom activities. Therefore, acoustic education appears as a key factor in the prevention of noisy behaviour to improve the acoustic comfort in the classrooms.

2. Background

In noise pollution, the noise level is the background sound pressure level (SPL) at a given location. The sound pressure level (SPL) of a sound is:

$$SPL = 10 \log_{10} \frac{p^2}{p_{ref}^2} = 20 \log_{10} \frac{p}{p_{ref}} \text{ (dB)}$$

(1)

where $p$ is the acoustic pressure and $p_{ref}$ the reference value for airborne sound ($p_{ref} = 2 \times 10^{-5}$ N/m²). The threshold of human hearing corresponds to 0 dB, and the threshold of pain to 120 dB. Sound level meters (SLMs) are tools designed for measuring SPL. A-weighting is applied (dBA) in order to approximate the human ear's response to instrument-measured sound levels.

Reverberation is the build-up of sound resulting from wave reflections on room surfaces. It depends on the size, the shape, and the materials used in the room. Reverberation increases sound levels within the room and can distort speech intelligibility. Reverberation time (RT60 or RT) is the time required to the pressure level to decrease by a factor of 60 dB after the sound source has been silenced. In real environments, it is more common to use RT30 or RT20 that correspond to RT values extrapolated from the time required for sound to decay by 30 dB or 20 dB.

For furnished but unoccupied learning spaces, the American standard requirements [2] indicate that the “one-hour-average-A-weighted steady background noise level” cannot exceed 35 dBA, and the reverberation time cannot exceed 0.6 seconds for rooms with enclosed volume smaller than 283 m³, or 0.7 seconds for rooms with enclosed volume between 283 and 566 m³. For large spaces (gymnasia, cafeterias, etc.) with enclosed volume greater than 566 m³, sound-absorbing material should be installed to reduce noise and to control reverberation.

A wide range of acoustical software applications (‘apps’) for sound measurement and analysis are available for smartphones: basic sound level meters, sound recording, frequency analysis applications, signal generators, room acoustic measurement applications, etc.

Some relevant studies have investigated smartphone applications for the measurement of environmental noise and/or reverberation [4-7]. Results showed that SLM apps are best for entertainment purposes, as they are not accurate as SLMs because the internal microphone of one common smartphone has limited frequency and dynamic ranges. The age of the phone is important; on average, younger phones measure noise more accurately than older phones. Faber [8] highlights that simply purchasing, downloading, and installing the app does not ensure adequate preparation to conduct the measurements. Ostergren and Smaldino [9] recommended calibrating smartphone and software using a reference SLM.

Applications for estimation of reverberation time use simple impulsive sources like hand claps, balloon burst or wooden claps. Rizzi et al [10] found that hand claps have the least amount of energy among the considered sources and have no energy at all bellow 500 Hz so obtained results can be considered reliable only above 500 Hz and in small, quiet rooms. Bursting balloons present well-energized spectra from 250 Hz. The obtained SPL-peak increases with the balloon diameter. Wooden clap presents significant energy also for low frequencies and the amount of energy is intermediate between previous impulsive sources.

There are two forms to study intelligibility: measure objective parameters (speech transmission index STI, definition D50) or use speech tests to study the subjective responses of listeners (speech intelligibility) [11]. The speech tests include sequences of nonsense syllables or sequences of words. The results allow knowing how well a person hears and understands the ordinary conversation. Online tests can be used as models to design a simple speech test [12].

3. The active learning proposal

Students work on the concepts of sound pressure level and reverberation time through a set of activities. At the end of the study, they have to answer two questions.
3.1. Why sometimes we do not understand what other people are saying in the classroom?

The students receive a guide to the activities they have to perform. The guide includes some technical indications for experimental measurements:

- Search for information on what factors affect speech intelligibility.
- Study outdoor and indoor noise using SLM apps (see Figure 1). For each measurement point, place the smartphone in support at a height of 1.5 m from the floor and begin the measurement. Repeat measurement at least five more times and calculate the average. Note that dB is a logarithmic magnitude, so the simple linear average should not be used, but logarithmic average:

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\text{logarithmic average} = 20 \log_{10} \frac{\sum_{i=1}^{N} 10^{\text{SPL}_i/20}}{N}
\]

For the study of the noise arising from external sources (vehicle traffic, aircraft, and facilities near the school; places surrounding the classroom, such as sports court and patio; hallways and other classrooms), make the sound map of the outside area of the classroom.

For the study of the noise generated inside the room (conversation, the sound of furniture or electrical equipment), study the noise in different situations (students performing individual work, students performing group work, students entering or leaving the classroom, etc.).

- Study the effect of the background noise on intelligibility. Perform some speech tests, varying the background noise, in the classroom.
- Study the reverberation time using room acoustic measurement apps (see Figure 2). Background noise must be low, so, if students are in the classroom, they must be silent. Place the smartphone in support and begin the measurement. Step back and produce an impulsive sound. Wait for device feedback. Repeat measurement at least two more times. Obtain the average value of the reverberation time. Repeat the same process in the gymnasium of the school. Compare the obtained results and relate to the sound sensation in the two rooms.
- Study the effect of the reverberation on intelligibility. Perform some speech tests, in the classroom and in the gymnasium with low background noise.
- Study the joint effect of background noise and reverberation on intelligibility. Perform some speech tests, varying the background noise, in the classroom (low/moderate reverberation). Repeat the process in the gymnasium (high reverberation).
3.2. What can we do to get a comfortable acoustic environment in the classroom?

Based on the results obtained in the previous activities, students should point to the following actions:

- From the study of the outdoor noise: it is important to eliminate noise coming from external sources (sound insulation).
- From the study of the indoor noise and the effect of the background noise on intelligibility: it is important to avoid noisy behaviours.
- From the effect of the background noise on intelligibility: it is important to achieve good sound quality within the classroom (acoustic conditioning). They can find solutions such as absorbing wall and ceiling treatments, diffusers and resonators, decorative coatings, etc. These solutions help to control the reverberation time and the reflections (echoes) and to achieve sound field uniformity and adequate sound intensity.

4. Conclusion

Learn in a noisy classroom is hard. Frequently people do not hear or understand what others say. Too much reverberation can also cause poor classroom acoustics. Therefore, learning about environmental acoustics (noise) and room acoustics (reverberation) can help improve acoustic comfort at school.

In this work, we describe a set of activities centred on speech communication. The students discover how to get a comfortable acoustic environment by using smartphone applications to measure noise level and reverberation time, and by performing speech tests.

Teachers and students cannot design and implement professional solutions for sound insulation and acoustic conditioning. However, there are simple strategies that they can apply:

- Eliminate noise coming from the surroundings by closing doors and windows.
- Prevent and avoid noisy behaviours: reduce the noise using chair/table leg glides for smooth gliding, keep the noise level acceptable using classroom noise monitor (some of them provide easy feedback in the form of a standard traffic light).
- Generate sound quality within the classroom by installing curtains or cork sheets on some walls. Moreover, the students’ interest increases as they focus on their own experience and they can apply and test their own solutions.
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