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"MODERN TEACHING" NEEDS MODERN CONDITIONS – ROOM ACOUSTICS AS AN ERGONOMIC FACTOR

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ABSTRACT
The main topics of this interdisciplinary examination about "acoustic ergonomics of schools" are less the physical properties of classrooms than their effect on the teaching reality in everyday school life. The examination cast a light on the topical educational trends and the connected kind of work and communication behaviour in the classes by mean of two elementary schools. Referring to a database of 175 examined lessons it is analysed how different kinds of work (frontal lessons vs. differentiated lessons) have an effect on the "basic sound pressure level" (LA95) and the "working sound pressure level" (LAeq) in the classroom. In the second place it is discussed, which parameters can describe classroom acoustics appropriately, and investigated how an altered room acoustic (increased absorption, shortened reverberation time and improved speech intelligibility) affects the sound levels in context with each kind of work. For the first time exists the methodical possibility with an enlarged dataset writing not only to assess mean lesson values but also to look directly into teaching phases which are dominated by certain pedagogical characteristics. The results provide the basis for the further question (3rd place) about stress and working demand at teaching (cf. Tiesler: Noise a stress factor...?).

INTRODUCTION
Plenty of investigations into the phenomenon of "noise in schools" in recent years have shown without doubt that schools have become noisy places [1]; [2]; [3]. However, unlike in conventional workplaces (such as in industry) the noise level in the "school workplace" is not determined by machinery or other external factors but by the people working there. It depends on the process of teaching itself and is generated by the working processes and the behaviour of each individual as well as the whole class community. Noise in schools occurs within the classroom. They do not cause it. Of course in the classroom as elsewhere the SPL is determined to a great extent by room acoustic properties. However without establishing a precise link to the actual events in the classroom, a purely structural approach to the classroom will necessarily remain only theoretical.

THE CHALLENGE TO REFLECT – AND TO MEASURE – "TEACHING REALITY"
One of the principal reasons, why acoustics in classrooms is on the agenda and to certain extend under revision since some years is the fact that the educational systems in many countries are changing as never before. This is shown not only in an external school re-organisation but particularly in changed working practices. It is therefore also about new teaching methods, often called "student-centred teaching". A term that contains different activities, e.g. project work, weekly-plan teaching, pupil-centred working or workstation learning. The essential characteristic of this new teaching and learning culture is that pupils are more frequently working and learning independently - "autonomously". This leads not only to greater individuality of what is learnt but also changes the interaction within the classroom. The image of the teacher as a distributor of material; a conduit for preconceived knowledge, is receding. Pupils now need to spend more time on experiment, appraisal and discussion. Discussion groups, project groups and role-play locate the learning psychology approaches firmly in the

everyday events of schools. An essential concern in the recent study of the ISF (Institut for Interdisziplinäre Schulforschung; Institute of interdisciplinary School Research) of the University of Bremen about “Acoustic Ergonomics of School” [4] is to evaluate the acoustic-physical properties of the classroom within an as realistic teaching context as possible. This requires a multi-dimensional observation however, which compares the key factors of pedagogy, room acoustics and in a further stage, occupational medicine in a real setting.

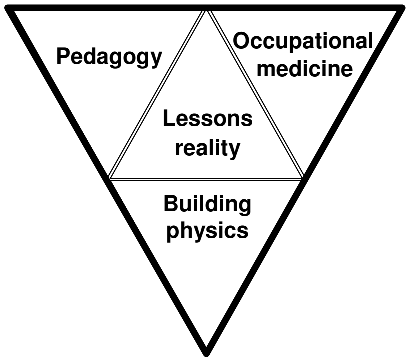

Figure 1. – Simplified Interaction Model of different factors influencing “lessons reality”

Extended dataset necessary

So achieve the required holistic description of “teaching reality”, 175 lessons in 2 primary schools were observed and analysed. Finally four different data pools were available:

- the basic room acoustic data from the classrooms (mainly RT and STI)
- the noise level that occurred during the lessons in the classroom
- the pedagogical procedure of the teacher and the teaching employed by him/her
- and the teachers own physiological reaction, detected by means of the heart rate.

As there was no comparable data available in the past, special attention was given to the lesson observation: Two students, trained beforehand with video recordings, observed in real time all parameters, that are necessary to describe the given communication scenario in detail. So the pedagogical processes were broken down into teaching methods and the associated communicative behaviour.

Table I. – Details of recorded parameters

Teaching Method	a) Direct Teaching b) Individual Work c) Working in Pairs d) Working in Groups e) Others
Share of Speech	a) Teacher to the whole class b) Teacher to individual pupils c) Pupil to the Teacher d) Pupil to the whole class e) Pupil to individual pupil
Organisation	Organisational Activity

All characteristics were recorded in real time at the start and the end of their occurrence at 1 sec. intervals and transferred to a computer. The second observer was employed in noting other events accompanied by noise on a monitoring sheet.

Different qualities for different functions

The two data sets each have a specific function within the analyses also based on their specific qualities. The data set from only one class in school 1 provided practically laboratory-style monitorable parameters. The same teacher taught the same class in the same classroom with almost the same timetable. The investigation period was free from unusual events. The only significant difference was change in the room acoustics which took place half way through the period. Based on recommendations from former studies [1; 5] the classroom was equipped with highly absorbent material at the ceiling and parts of the rear wall (Class A according to EN ISO 11654; $\alpha_w > 0.9$). With that reverberation time was reduced from approx. 0.7 s to 0.4 s.

School 2 delivered a considerably larger data set covering different classes, age groups, teachers, subjects and room acoustic conditions, underlining the nature of field research. Without making acoustic intervention this school provided the research team by chance with two storeys with quite small differences in RT and STI (0.7 "good" to 0.8 "very good").

The procedure
Referring to this database in a first step the effects of different teaching methods and communication scenarios on "basic sound pressure level" (LA95) and "working sound pressure level" (LAeq) in the classroom were analysed. In a second step was investigated how the room acoustics affect this level in the context of the respective teaching methods. A detailed time series analysis in conjunction with the large dataset made it possible to evaluate not only hourly average values but also to look directly into teaching phases dominated by specific pedagogical features. The results form the basis for further ergonomic questions about stress, fatigue and workload in teaching (see also Tiesler, G.: Noise a stress factor?).

FINDINGS

As expected, both the working noise level and the basic noise level in both schools depend greatly on the room acoustic conditions. The more attenuated the classrooms and the better the speech intelligibility, the quieter the teaching occurs in the classroom. The relationship is unexpected in the order of magnitude (Fig. 2) and strikingly linear (Fig. 3).

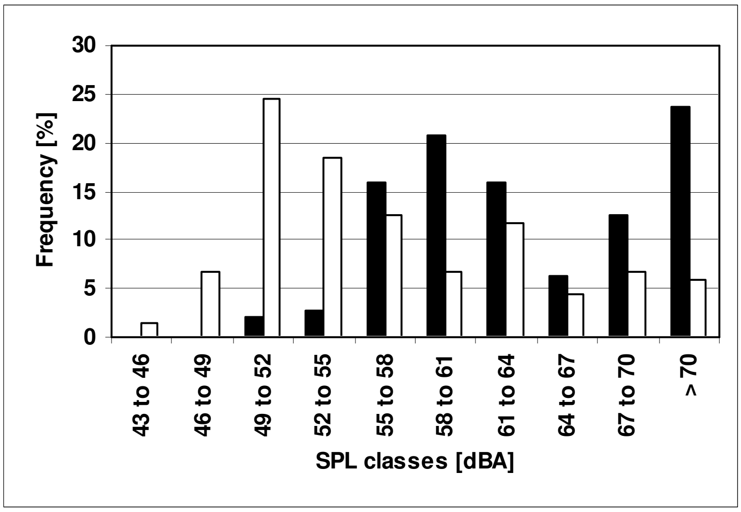

Figure 2. – Overall frequency distribution of the working SPL before (●) and after (○) refurbishment (school 1; incl. all observed lessons)

The field data set from school 2 not only confirmed the "laboratory" findings in school 1 but showed that even small differences in room acoustics can have significant effect on the occurring sound pressure level during the classes. Similar results are revealed by preliminary investigations of other data sets that showed a linear reduction of the basic SPL by around 1.6 to 2 dB. per 0.1 s reduced reverberation time [6].

As could be proved by a detailed analysis of the pedagogical data, this reduction evidently arose not from a changed pedagogical behaviour or by the possibly assumed fact that pupils or teachers spoke quantitatively less with one another. The cause must therefore lie in a reduced speech volume amongst those involved. There was also another striking phenomenon that could be shown in school 1: While in particular the basic SPL rose by an average 10 dB over the morning lessons before the refurbishment, this rise largely vanished after installing the absorbents [4].

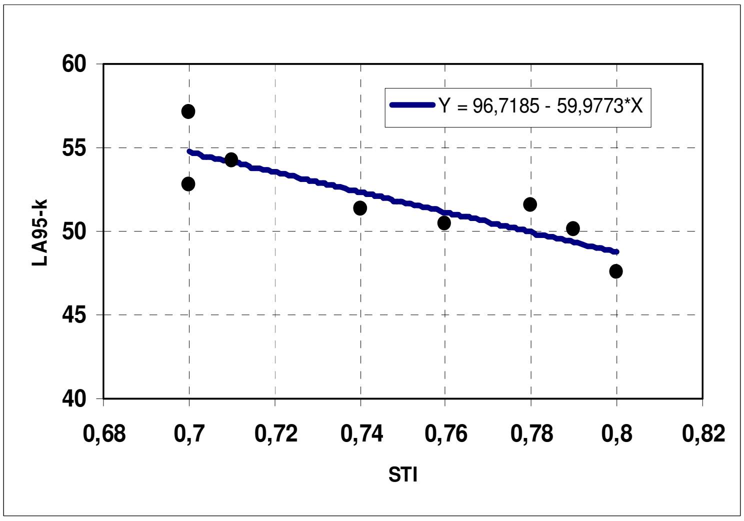

Figure 3. – Basic SPL in relation to the STI found for the 8 classrooms of school 2 with different acoustic properties; ground floor (●) and top floor (○)

Regression: Y=A+B*X

N	A	B	R	R^2
8	96.72	-59.98	0.85	0.73

The assumption that student-centred teaching methods in themselves produce a higher working SPL than direct teaching methods was only partly confirmed by the present data set. Surprisingly in both schools the different teaching methods barely differ with regard to the shares of teacher- and/or pupil-generated speech. Direct teaching accordingly does not mean that the pupils are not involved in the teaching events while student-centred teaching for its part does not mean that the teacher stops talking.

RELATIONS – ROOM ACOUSTIC AFFECTS MAINLY STUDENT CENTERED TEACHING

Nevertheless, the respective teaching methods differed greatly with respect to their sensitivity to the influences of the room's acoustic working environment!

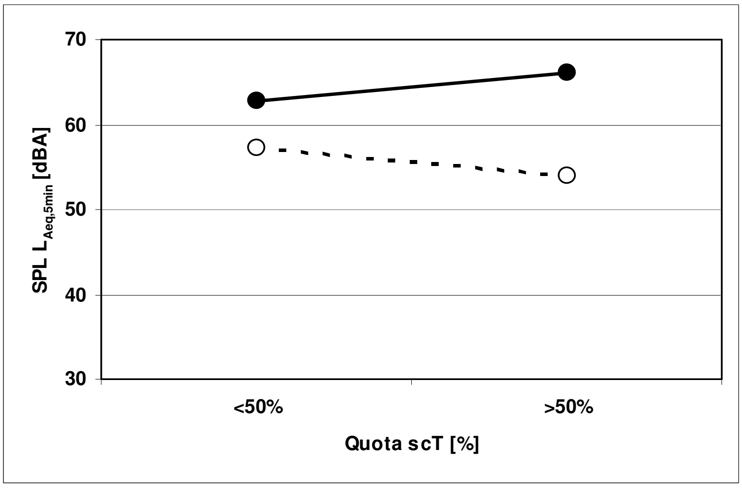

Figure 4. – Working SPL $L_{Aeq,5min.}$ in relation to share of student-centred teaching (scT) before (●) and after (○) the refurbishment, school 1.

The aforementioned dependence of the teaching noise level on the reverberation time and/or the speech intelligibility in the classroom was not the same for all teaching methods. In fact in school 1 the level reductions of an average 12 dB were more than double as high during student-centred working phases in comparison to before the refurbishment while the reduction observed during direct teaching phases was around 5 dB. If one assumes a physical level reduction of around 4 dB it becomes clear that during direct teaching phases a majority of the reduction is achieved by the physical absorption, while student-centred phases are particularly affected by a changed – quieter – behaviour of those in the room. The acoustic quality of the room is above-averagely significant during student-centred working phases. Student-centred phases after the refurbishment were on average even quieter than during conventional direct teaching (Fig. 4).

PROSPECT: HOW TO DESCRIBE AND TO CALCULATE CLASSROOM ACOUSTICS?

All classrooms that were measured during the evaluation done between 2001 and 2005 showed an extremely good correlation between the classical descriptors for communication rooms: RT and STI. However all of them were quite densely and scattered furnished and provided a comparatively diffuse sound field. Digging deeper into the analysis of the acoustic data some questions raised. So was the measured reverberation time largely independent of the number of people present in the room. In general the room occupancy did not affect the room acoustics as much as expected: the reduction of reverberation time by the additional absorption of the pupils – related to the situation at the outset – did not reach a significant order of magnitude of over 0.1 s. And even that effect was not as linear as assumed: The most Changes of reverberation time could be traced to the first approx. 10 pupils. Any further effect of filling up the classrooms up to 30 persons was negligible.

These first findings therefore give some indication that using Sabine’s formula, assuming more or less diffuse conditions, for predicting classrooms not necessarily needs to work properly. At least they put a question mark to the popular practise to measure empty rooms and “insert” the pupils later on arithmetical.

In the meantime investigations in far less diffuse classrooms supported these doubts. Nearly without any scattering objects close to the wall the measured reverberation times in a newly refurbished secondary school deviated from the calculated values in the high frequency bands more than 100%. Simply scattering the hard and smooth back wall with some wooden slats (Fig. 6) reduced RT at 2 kHz and 4 kHz more than 0.1 s without adding any absorption or making other changes to the room (Fig. 7).

Figure 6. – A “modern styled” secondary school classroom with wooden scattering slats

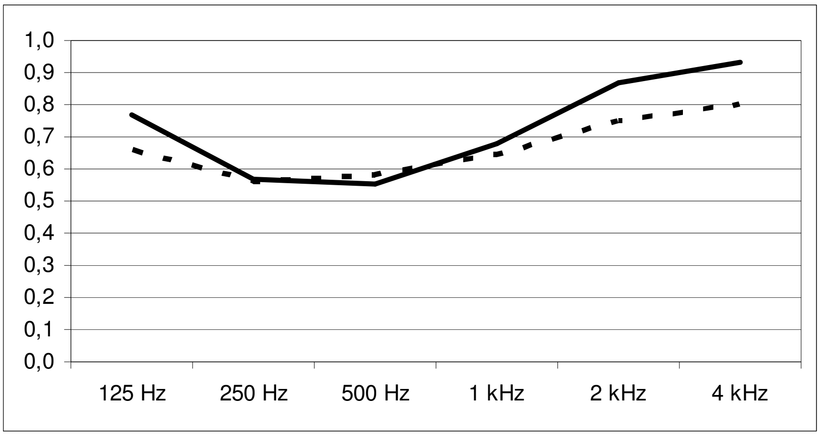

Figure 7. – Measured RT of above shown classroom without (——) and with (– –) slats

CONCLUSIONS

In the context of today's teaching methods, connected to new communication scenarios, the acoustic environment has a significance impact on the occurring situation in the classroom. Even classrooms that worked well for decades under traditional communication models (one speaker, quiet listening) require possibly a new assessment when in comes to student centred teaching forms. Then even small differences can play a big role: heavily attenuated classrooms with reverberation times of less than 0.5 s "produced" in this investigation under similar conditions clear lower working and basic sound pressure levels than rooms with reverberation times about 0.6 s (and with that according to most international standards).
Finally is has to be further investigated how far reverberation time (as well measured as calculated) at all is a reliable descriptor for the acoustic-ergonomic quality of classrooms.

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