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ABSTRACT

This document consists of two papers. The first, titled "Good Classroom Acoustics Is a Good Investment," identifies and estimates some of the costs for good acoustics in new school construction. It also identifies and estimates some previously unrecognized economic benefits of good acoustics, as well as some of the hidden costs of marginal or poor acoustics. Costs and benefits are compared using recent economic data from the United States. Results suggest that the economic benefits of good acoustics far outweigh its costs. Therefore, a case can be made that good classroom acoustics is a good economic investment. The second paper, "The Impact of Classroom Acoustics on Scholastic Achievement," reviews speech communication criteria and studies that have linked scholastic performance with acoustical noise or reverberation. Some studies link aircraft noise with delayed language acquisition, reading deficiencies, reduced motivation, and long-term recall of learned material. Others link ground transportation noise with reduced academic achievement. Aside from reduced speech intelligibility, little data were found to gauge the impact on learning achievement from heating, ventilating, and air conditioning noise; from the noises of students interacting in cooperative learning environments; or from reverberation. Despite their incomplete nature, some useful inferences can be drawn from these studies. For example, evidence for cumulative impact of poor acoustics on scholastic achievement suggests that good acoustics be made a high priority for children in lower grades. (EV)

Two Papers on Classroom Acoustics

-Good Classroom Acoustics is a Good Investment

-The Impact of Classroom Acoustics on Scholastic Achievement

Lubman, David
Sutherland, Louis C.

Presented at the 17th Meeting of the International Commission for Acoustics
Rome, Italy
September 2-7, 2001

Full text available at:
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17th ICA, Rome, Italy, Sept. 2-7, 2001
Good Classroom Acoustics is a Good Investment[1]

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The incremental costs for achieving good classroom acoustics is a small fraction of total costs of new school construction. But since school construction funding is limited, good acoustics must compete with other programs intended to improve the education and lives of citizens. Good acoustics can survive this competition if decision makers are convinced that its costs are justified by their economic benefits. A proper economic study of this question has never been attempted. However, informal engineering estimates made by acousticians, audiologists, and material vendors suggest that the case for good classroom acoustics is strong. This paper identifies and estimates some of the costs for good acoustics in new construction. It also identifies and estimates some previously unrecognized economic benefits of good acoustics, as well as some of the hidden costs of marginal or poor acoustics. Costs and benefits are compared using recent economic data from the USA. Results suggest that the economic benefits of good acoustics far outweigh its costs. Therefore, a case can be made that good classroom acoustics is a good economic investment. The authors intend this paper to inspire others to more fully study the economic, social, and educational benefits of good acoustics.

DO BENEFITS OF GOOD CLASSROOM ACOUSTICS JUSTIFY THEIR COSTS?

The education of its citizens is essential to all modern societies. Most formal education takes place in classrooms. Classroom learning typically involves intensive speech communication between teachers and students, and among students. The effectiveness of this communication, and hence, the effectiveness of the learning environment is mediated by acoustical conditions in the classroom. Good classroom acoustics greatly facilitates learning. With good classroom acoustics, learning is easier, deeper, more sustained and less stressful. Excessive noise and reverberation in classrooms are barriers to learning to the extent that they degrade or inhibit speech communication.

Poor classroom acoustics degrades the educational process for all students and teachers. It is also true that noise and reverberation are selective barriers to learning. Young children, adult learners, and persons with hearing, language, speech, attention deficit or other learning disabilities are especially vulnerable to marginal or poor acoustics.

The educational benefits of good classroom acoustic environments have not been quantified. This creates a problem. Absent clear statements of their benefits to learning, the features necessary to ensure good classroom acoustics are often omitted from classroom design specifications. Even when acoustical features are initially included in design, they are often removed in value engineering design exercises because they are perceived as costs without quantifiable benefits. It is important therefore to quantify the cost benefits of good classroom acoustics. This paper previews some exercises intended to quantify the benefits.

Costs for New School Construction

Figure 1 shows recent costs for K-12 (Kindergarten through 12th grade) US classrooms for the year

2000.

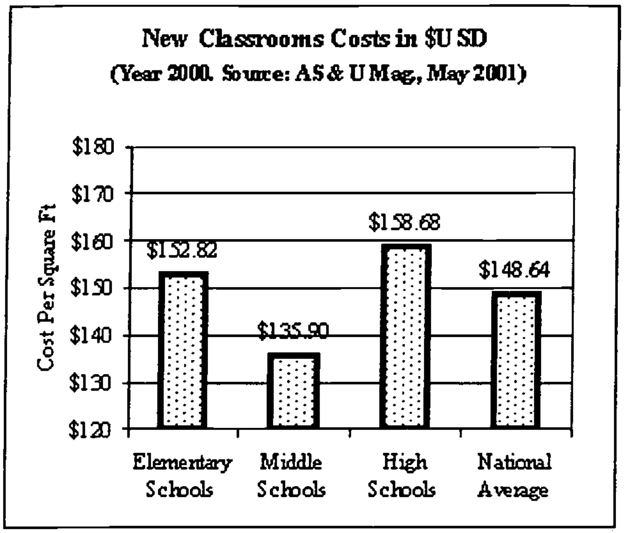

FIGURE 1. Costs per square foot for new schools in US

Costs for Acoustical Ceilings

Ceiling Costs	**NRC 0.55 (Fair)**	**NRC 0.75 (Good)**	**Difference**
Total cost per room	$1054-$1221	$1443-$1610	$384
Cost per year (20 year life)	$53 – $61	$72 – $80	$19.20
Cost per student per year	*$2.64 - $3.05*	*$3.60 - $4.03*	*$.97*
Reverb time for unocc. 10,000 cubic ft room with 9' ceiling	*0.75 sec.*	*0.56 sec.*	*0.19 sec*

Table 1. Cost and performance of two ceiling acoustical treatments for a small classroom (30 students ,1110 sq. ft.)

Some classrooms suffer from excessive reverberation due to insuffi-ient sound absorption. If the ceilings are not too high, a cost-effective way of introducing sound absorption is with an acoustical ceiling. Table 1 shows that the cost difference between a mediocre acoustical ceiling of NRC (Noise Reduction Coefficient) 0.55 and a good ceiling with NRC 0.75 is less than $1 USD per student, when amortized over a 20 year lifetime. It also shows that unoccupied classroom T_{60} for the mediocre ceiling is 0.75 sec., somewhat too high for a learning space. The better ceiling reduces T_{60} by almost 0.2 sec, which can make a noticeable improvement.

Educational Benefit of Upgraded Classroom Acoustical Ceiling

The maximum T_{60} recommended for unoccupied classrooms of about 10,000 ft 3 is o.6 sec. Table 1 shows a T_{60}. of 0.75 sec with the NRC 0.55 ceiling, which exceeds this recommendation.. If the classroom has a fairly high ceiling of about 11 or 12 ft (not recommended), T_{60} may even exceed 0.8 sec. Even if the SNR (speech-to-noise ratio) is an excellent 15 dB, the RASTI (Rapid Speech transmission Index) score will be only about 0.6, which is marginal for learning. Upgrading the acoustical ceiling reduces T_{60} by nearly 0.2 sec., which increases RASTI scores by about 0.05. The lower T_{60} improves recognition of unfamiliar sentences by about 3% to 4% for normal listeners, and even more for listeners with communication disabilities. The benefit is even greater at low SNR.

Cost Benefit Ratio for an Upgraded Classroom Acoustical Ceiling

The cost for educating a child in a mainstream classroom is about $7000 USD per year per student. With the better ceiling, about 3% more unfamiliar sentences are understood correctly by normal students. A measure of the economic value of this improvement is (0.03)* $7000 or $210. The additional $1 cost for the better acoustical ceiling is relatively insignificant. By this measure, the economic value of the better ceiling exceeds its cost by a factor of 200. That is surely a good investment! But unless value-engineering reviewers are told the economic benefits, they are likely to reject the better ceiling on costs alone.

Acoustical Access to Education

A metric is proposed by which the annual economic value of quiet can be estimated. Assume that AAE (Acoustical Access to Education) is nil when classroom ambient noise levels are 65 dBA and over. Also assume that AAE is 100% when classroom ambient noise is 35 dBA or less. Assume a linear relationship between AAE and noise level over the 30 dB range. Then every 3 dB of noise reduction between in this range improves AAE by 10%. If the annual cost of education is $7000 per student, the value of a 3 dB classroom noise reduction is $700 per student. The value for a class of 20 students is thus $140,000 USD per year. This argument can be used to justify paying more for quiet HVAC or other noise-making products. It can also guide purchasing decisions when quieter but more expensive products are available alternatives.

Benefits of Reduced Teacher Absenteeism due to Vocal Strain

There were 2.9 million public school teachers in the US in the Year 2000 (National Center for Education Statistics) Teachers lose an average of 2 days/year for vocal fatigue caused by raising their voices to talk over noise. Recently, the cost for substitute teachers was about $220 per day. The national cost for teacher vocal fatigue is estimated at $638M USD. A large fraction of that cost could be saved each year if schools were quieter. Teacher satisfaction and the amount of verbal interaction between teachers and students would also improve. Dividing $638M among the 85000 US Public Schools would provide an annual budget of $7500 per school for educational purposes.

Conclusion

Current methodologies for estimating the costs and benefits of good acoustics are inadequate. Studies are needed to determine the full impact of acoustics on learning, the full social costs of poor acoustics, and the cost benefits of good acoustics. In the absence of methodical economic studies, crude estimates were made here. (Other examples will be shown in the oral presentation). By standardizing and proliferating such measures, good classroom acoustics can be given the economic foundation it now lacks.

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17th Meeting of the International Commission for Acoustics, Rome, Italy, Sept. 2-7, 2001
The Impact of Classroom Acoustics on Scholastic Achievement

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What are the relationships between scholastic achievement and acoustics in learning spaces? Answers to this difficult question are needed to support setting objective limits for noise and reverberation. Good acoustics is necessary in classrooms and learning spaces whenever speech communication is important to the learning process. It is clear that excessive noise and reverberation interfere with speech communication and thus present acoustical barriers to learning. Acoustical allowances are needed to accommodate differences in student abilities, health, and scholastic preparation. This paper reviews speech communication criteria and studies that have linked scholastic performance with acoustical noise or reverberation. Some studies link aircraft noise with delayed language acquisition, reading deficiencies, reduced motivation, and long-term recall of learned material. Others link ground transportation noise with reduced academic achievement. Aside from reduced speech intelligibility, little data were found to gauge the impact on learning achievement from heating, ventilating, and air conditioning noise; from the noises of students interacting in cooperative learning environments; or from reverberation. Despite their incomplete nature, some useful inferences can be drawn from these studies. For example, evidence for cumulative impact of poor acoustics on scholastic achievement suggests that good acoustics be made a high priority for children in lower grades.

INTRODUCTION

The ability to understand isolated speech material consisting of single words or sentences in an acoustic environment with varying amounts of background noise and reverberation has been well studied in laboratory settings and documented in the literature for persons with normal hearing[1-3], persons with impaired hearing[4, 5] and students for whom English is a second language [6] All of these auditory challenges exist in the school classroom with an environment for which the most significant speech communication can be connected discourse or, for the youngest learners, new words or phrases containing unfamiliar sounds or phonemes. Criteria for speech intelligibility as measured under laboratory conditions are clearly related to speech reception in this classroom acoustic environment but direct correlation between laboratory testing of speech intelligibility and student achievement in school environments is more tenuous. For example, Evans [12] has shown evidence for adverse effects on children's health and learning due to chronic noise exposure. Development of the link between acoustics and learning is vital to support improvements in classroom acoustics. The classroom serves as a communication channel for learning essential academic, social, and cultural skills for all students. All knowledge-based societies should do what is necessary to eliminate acoustical barriers to learning.

Noise as an acoustical barrier to learning

Noise level and teacher vocal strain

Excessive noise can only be partially ameliorated by a teacher raising his or her voice level and then only at the potential cost of voice fatigue. From a study by Pearson, et al[7], the average A-weighted sound level, LA at 1 meter from male and female teachers was found to increase from a level of 60 dB in quiet (average for normal and raised voice effort) to a level of about 62 dB in an A-weighted background noise level of 35 dB to 67 dB in a background of 45 dB and then increasing approximately dB for dB as the background noise level increased above 45 dB. Thus, while the teacher attempts to maintain approximately the same signal to noise ratio in a noisy room, the strain on the teacher's voice increases causing voice fatigue and results in teacher absenteeism. [8]. In addition; there is evidence of a reduced number of verbal interactions between teachers and students in noisy classrooms, although its impact on student achievement is not known.

From measurements of background noise in 56 classrooms in 5 different studies in the U.S., the average A-weighted background noise level was roughly normally distributed with a mean of 45 dB and a standard deviation of 8 dB. Thus, statistically, these very limited data suggest that 28% of the nations' schools may have background noise levels in excess of 50 dB. This 28 % figure is cited as a crude basis for comparison with results from a US Government Accounting Office survey [9] which found that 28% of the nation's schools reported "acoustics for noise control" as their top environmental problem. This suggests that the 28% figure from this survey may be a substantial understatement of the problem of acoustic barriers in schools since a background noise level of 50 db is 15 dB above the recommended limit included in a US standard for classroom acoustics now approaching a final draft. [10] It also suggests that the average voice level for a teacher in many classrooms could be 10 dB or more above their average (normal and raised) level in quiet - further validation of the prevalence of voice fatigue for teachers.

A teacher cannot effectively compensate for the acoustical barrier of excessive reverberation in a classroom. Raising the voice level provides little compensation. What, now is the link between the classroom acoustic environment and the scholastic achievement of students - i.e., what is the effect of the acoustic barriers?

Scholastic Achievement and The Acoustical Environment

Educational research studies[11] show that learning is dependent on the ability to communicate with spoken language and that perception of spoken language is the foundation for the ability to read and write.12 As much as 60% of classroom learning activities typically involve listening to, and participating in, spoken communications with the teacher and other students. It would be fully expected, therefore, for disruption of this communication to affect students' scholastic achievement.

For this paper, we mention, but make no attempt to document, the added acoustical barriers in the classroom for students with hearing impairments, learning disabilities or for those who are not learning in their native language. These added burdens simply compound the negative effects of these barriers to scholastic achievement. This omission is not meant to minimize their importance. Concern for the hearing handicapped, was an important motivating force that inspired much of the current effort to improve classroom acoustics. [10]

In one pioneering study of noise and reading in a home setting, Cohen, et al[13] measured reading and auditory processing among children living on different floors of an apartment building located over a busy highway in New York City. They found that for socio-economically-equivalent children, the higher the floor of residence, the lower the background noise level and the higher the reading scores.

In a series of three studies carried out on a school located within 67 m (220 ft.) of an elevated urban train track, Bronzaft and McCarthy[14] and Bronzaft [15] studied the reading scores of 2nd to 6th grade children in classrooms facing the tracks and in classrooms on the other side of the building facing away from the tracks. In the first study[14] (1975), it was found that children in the lower grades exposed to the noisy side were three or four months behind in reading scores relative to the children on the quieter side and as much as 11 months behind for the higher grades.

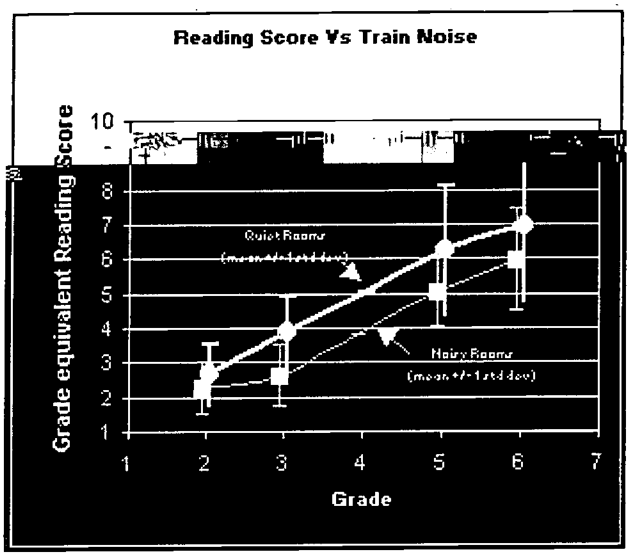

FIGURE 1. A study by Bronzaft and her colleagues showed that children exposed to the noisy side of a school building achieved lower reading scores than students on the quiet side.

After a subsequent effort succeeded in reducing the track noise by 3 to 8 dB on both sides of the school, further tests were conducted to determine if the achievement differences diminished.. [15] As shown in Fig, 1, a substantial difference remained in the reading scores between "noisy" and "quiet" classrooms. The students in each classroom were comparable in all respects and were receiving the same type of instruction. The data in Fig. 1 indicate that the reading scores for the children in "noisy" classrooms are approximately one year behind those in the "quiet" rooms - the rooms away from the rail track. There is some indication in the data that this time lag in reading scores may be slightly less for the lower grades, which is consistent with the 1975 study. There may be two plausible explanations of this effect: 1) it was observed that the teacher spent more one-on-one time with the students in the lower grades thus tending to minimize the detrimental effects of noise on their speech communication - a trend just the opposite of what might be expected for background noise effects on learning for younger vs. older children or 2) a hypothesized compounded effect of reduced learning for children in noisy classrooms as they progress through their grades. There are no known data to validate either possibility.

Another classic study on noise effects on scholastic achievement was carried out by Lukas, et al[16] in 14 schools in Los Angeles, California, located at different distances from freeways. The differences in distance from the freeway caused the background noise in the classrooms to differ by up to 19 dB between the noisiest and quietest classrooms. Reading and math grade-equivalent scores and general classroom behavior patterns were evaluated in 74 classrooms, approximately 19 in each of the "noisy" and "quiet" schools in third and sixth grade classes. The results of this study for reading scores are shown in Fig. 2 in terms of the grade equivalent reading scores as a function of the C-weighted background noise level in the classroom.

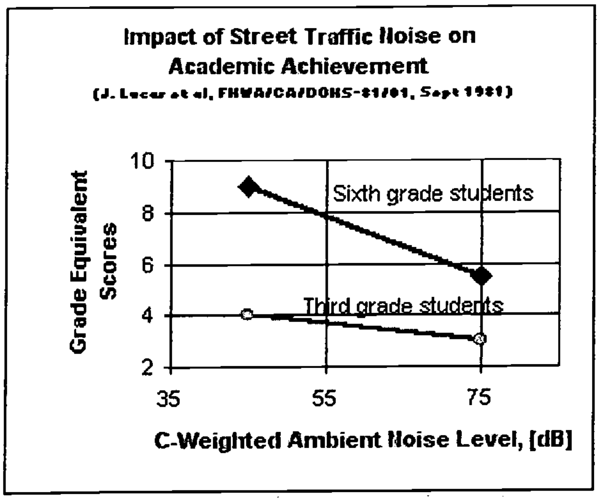

FIGURE 2. A study by Lucas et al showed that academic achievement was higher for students exposed to lower levels of noise from freeways.

Lukas, et al, used the C-weighted level because it provided the best correlation with the reading scores. However, the average difference between the C- and A-weighted noise levels was approximately the same, (14 to 15 dB) for the "noisy" and "quiet" locations. The data in Fig. 2 show, in this case, a much greater decrease in reading scores for the 6th grade classes than for the 3rd-grade classes. This is a more prominent effect of grade differences in scholastic effects of noise than was shown by the Bronzaft data. [14, 15] The explanation for this pattern is still uncertain - either differences in teaching style between grades or cumulative compounded effects of poor acoustics on learning still seem to offer plausible explanations. If it were the latter, however, the loss to the learning process would be more critical. Carefully executed prospective educational research studies may be needed to resolve this enigma. It is not just an academic question to be resolved since it has significant implications for placing priorities on improving classroom acoustics at various grade levels.

Not addressed in this paper is the more insidious effect on scholastic achievement that has been attributed to poor classroom acoustics - the tendency for students who can't hear a teacher's instructions to withdraw from active participation in class activity and potentially develop a decreased sense of self-worth. [12]

Other research, including unpublished anecdotal studies, have linked aircraft noise with delayed language acquisition, reading deficiencies, reduced motivation, and long-term recall of learned material. Aside from reduced speech intelligibility, little data were found to gauge the impact on learning achievement from heating, ventilating, and air conditioning noise or from the noise of students interacting in cooperative learning. This seems to be another fruitful area for study.

One other study on classroom acoustics worthy of note for this paper is the recent work carried at Heriot-Watt University in Scotland. [17] Sixty teaching spaces in 13 schools at various locations around the United Kingdom were evaluated for their acoustic environment and corresponding speech communication conditions and teacher satisfaction. The average A-weighted background noise level in the unoccupied classrooms, before any acoustic treatment was applied was 45 dB, identical to the average cited earlier for the sample of US schools. After acoustic treatment, consisting of the application of acoustic absorption materials on the ceiling, the unoccupied background noise levels dropped to 40 dB, presumably reflecting the decrease in the reverberant level with added acoustic absorption. The average reverberation in the unoccupied room dropped, after treatment, from 0.7 seconds to 0.4. While no testing of student achievement was carried out, predictions of improved speech intelligibility demonstrated the effectiveness of the acoustic treatment. As stated by the researchers: "subjectively, classrooms with acoustic treatment were favored by the teachers and pupils, who reported a greater ease of communication and increased performance." [17]

SUMMARY

Limited data strongly indicate that poor classroom acoustics in the form of excessive background noise are indeed barriers to learning, as demonstrated by reduced scholastic achievement. The vital necessity of maintaining a proper acoustic environment while students are acquiring language skills seems especially significant and self-evident.

Further research is called for to more accurately define the magnitude of this degradation in learning and to more clearly define the various confounding factors, especially the potential significance of cumulative loses in learning over time as a child progresses through a school with less than an optimum acoustic environment. Having said that, the existing evidence for adverse effects on learning of poor classroom acoustics provides ample motivation to press on as rapidly as possible to improve the acoustic environment in classrooms and eliminate the acoustic barriers to learning.

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