Classroom Acoustics

And

The Benefits of

Sound Field Amplification

Administration and
Supervision of Elementary
And Secondary Schools

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When a school facility does not have proper wheelchair accessibility, structural modifications are made. If a student with learning disabilities does not have the appropriate/qualified providers or educational plan, alterations will be made to the IEP. If classroom lighting is inadequate, changes will be addressed by school personnel. However, children are in poor listening conditions in American schools every day and it is often overlooked because, until recently, there was no national standard for classroom acoustics. This is alarming considering children may spend up to 45% of their school day engaged in listening activities (Palmer, 1997).

Since the Mainstream Amplification Resource Room Study (MARRS) began nearly thirty years ago, there has been a lot of research examining the effects of poor classroom acoustics and the possible solutions. The MARRS project is considered to be the original investigation on sound field FM amplification and followed two groups of students with learning disabilities (with normal hearing or minimal hearing loss) over a three year period. Some students were placed in a resource room setting and others were in regular classrooms equipped with sound field amplification. During that time, all students showed improvement in standardized test scores. However, those in regular classrooms with amplification had significantly higher scores, especially in reading and language arts. Younger children and students with minimal hearing loss (less than 40 dB HL) showed the most benefit (Crandell, 1998). The project continued to monitor student progress for several more years after the original study was published and showed that students in amplified classrooms showed gains at a faster rate, to a higher level, and with less cost to the school district than students in unamplified classrooms (ASHA, 2005). The MARRS project has raised questions and spurred research about classroom listening environments. Years of research regarding room acoustics and the effects on listening and learning in the classroom (Crandell & Smaldino, 1999; Nelson, 2000) have led to certain tenets regarding classroom acoustics.

1. There are children in every classroom, especially in the early grades that either cannot hear well and/or cannot process speech and language well.
2. Not hearing and/or processing well negatively impacts student listening and learning, especially learning to read.
3. Low teacher voice level, excessive background noise level, and excessive reverberation exacerbate listening and learning problems.
4. Improvements in classroom acoustics may require solutions involving architectural design and/or acoustic modifications, and in special cases, hearing assistive technologies. (ASHA, 2005)

This paper will address those tenets and the related studies. It is important to note that all research cited here involves normal hearing subjects, unless otherwise stated. In order to better understand the effects of the classroom listening environment, the aspects of room acoustics must first be considered.

Classroom Acoustics:

In order to predict whether students will have difficulty listening in a classroom environment, there are acoustic elements that need to be understood. These acoustic elements (or acoustic variables) are the level of the background noise, reverberation time, the signal to noise ratio, and the distance from the speaker to the listener (Crandell & Smaldino, 2000). ***Background noise*** can be external, internal, or room noise. External noise is just that – coming from outside of the building from traffic, airplane noise, construction, playgrounds, etc. Internal noise is generated inside the building, but outside of the classroom (noise from cafeterias, music rooms, gymnasiums, hallways, etc). Sources of room noise may be sliding of chairs and tables, individuals talking, noise on hardwood floors, and heating, ventilating, and air-conditioning (HVAC) systems. Background noise levels in a classroom will vary as a function of time (Crandell & Smaldino, 2000). Decades of research have examined the levels of background noise in occupied and unoccupied classrooms. This may be considered the most serious acoustical problem because it masks the teacher's voice (Berg, Blair, & Benson, 1996). Crandell and Smaldino (2000) summarized several previous studies and noise levels in unoccupied classroom ranged from 41 to 51 dB and 48 to 68 dB in occupied classrooms. Berg, Blair, and Benson (1996) reported:

> "Classroom noise levels have been found to be 30-35 dB at night or over a weekend, 40-50 dB when the heating, ventilating, and air conditioning (HVAC) system is turned on, and 55-75 dB when a teacher and 25 or more students are in the room. The typical noise level of school classrooms is 60 dB, which is greater than the conversational voice level of many teachers, making it difficult for the students to hear the teachers. At certain during the school day, the noise level of occupied school classrooms can reach 75-85 dB causing a very difficult, if not impossible, listening environment for the students."

A more recent study by Knecht, Nelson, Whitelaw, and Feth (2002) examined 32 unoccupied classrooms chosen randomly from three different school districts in Ohio. The results were similar to those previously noted, with noise levels ranging from 34.4 dB to 65.9 dB. Only four of the classrooms had background noise levels below the 35 dB recommendation by ANSI/ASA. The largest single source of noise in one classroom (1D in Fig. 2) was a fish tank that produced a noise level of 65.9 db. Their findings are summarized in Figure 2 on page 5.

Reverberation occurs when the spoken message or background noise bounces off surfaces in the room. In a closed space, reverberation is always present. It will mask the signal (in this case, the teacher's voice) and increase the background noise. Reverberation is measured as a function of time (how long it takes for the sound to decay). It increases with the volume of the room and decreases with the amount of sound absorption (Nabelek & Nabelek, 1985). The preceding studies summarized by Crandell and Smaldino (2000) also measured reverberation times between 0.35 seconds and 1.2 seconds. Knecht, Nelson, Whitelaw, and Feth (2002) measured reverberation times from 0.2 to 1.27 seconds. In the 32 unoccupied classrooms they examined, 13 exceeded the ANSI recommended time of 0.6 seconds. The rooms having the shortest reverberation times were those with smaller volumes and ceilings of 10' or less, suggesting the positive effects of proper sound absorbing materials on ceilings and walls (see results in Figure 3).

The effects of background noise and reverberation on speech perception skills in normal hearing and hard of hearing students were studied by Finitzo-Heiber and Tillman (1978). When tested in an audiometric booth, the normal hearing students had mean speech recognition scores of 95% and the hard of hearing students had mean scores of 83%. In an experimental classroom with varying levels of noise and reverberation, speech perception skills were again measured. The scores of the normal hearing students ranged from 30% to 83% and those of the hard of hearing students ranged from 15% to 60%. It was concluded that "both noise and reverberation degraded speech recognition, and the combination of the two was especially detrimental".

Regardless of the level of background noise in a classroom, the ***signal-to-noise ratio (SNR)*** is the most relevant to effective communication (Palmer, 1997; Crandell & Smaldino, 2000). It is the comparison of the signal (the teacher's voice) to the level of the background noise. For example, if the speech signal is 70 dB and the noise is 60 dB, then the SNR is + 10 dB. A positive classroom SNR means the teacher's voice is louder than the noise and can be easily heard. Reports of SNR's for a variety of classrooms have ranged from +5 dB to -7 dB (Crandell & Smaldino, 2000). For maximum performance, adult listeners require an SNR of +6 dB or greater, however; young listeners (with normal hearing) require higher SNR's to achieve equivalent speech recognition scores (Palmer, 1997). The recommended SNR is +15 dB.

The ***distance from the speaker to the listener*** also influences the perception of speech in the classroom. Loudness of a direct sound decreases in proportion to the distance and the effects of noise and reverberation further impact the signal. Ideally, a student should be seated within close proximity to the teacher, however; this is not possible for all students in a single classroom (Palmer, 1997).

As stated earlier, there was no national standard addressing these variables until recently. The Americans With Disabilities Act (ADA) and Individuals With Disabilities Education Improvement Act (IDEA) guidelines are developed by the U.S. Access Board, an "independent federal agency whose primary mission is accessibility for people with disabilities" (Sorkin, 2000). In 1996 the parents of a child who was unable to hear classroom instruction and discussion, even with preferential seating and use of an FM amplification system, filed a complaint with the Access Board (Nelson, 1998). At that time, a task force was formed to address the problem. Since 2003, the U.S. Access Board has supported classroom acoustics standards developed by the Acoustical Society of America (ASA) however; in most states the standard is still voluntary. The New Jersey School Construction Board has adopted the standard (known as ANSI S12.60-2002) but it only applies to new construction (U.S. Access Board, 2006). Existing classrooms with poor acoustics still remain the same. The ANSI/ASA standard gives criteria similar to those recommended by the American Speech-Language-Hearing Association (ASHA) in their position statement on acoustics in educational settings (ASHA, 1995) and in "Guidelines for Addressing Acoustics in Educational Settings" (ASHA, 2005). The ANSI standard and ASHA recommendations are summarized below:

	ANSI	ASHA
Unoccupied background noise	35 dB	30 dB
Reverberation time	0.6-0.7 sec*	0.4 sec
Signal-to-noise ratio	+15	+15

*Based on volume (cubic ft) of classroom

Who Is At Risk?

"All children need good, clear signals and low background noise (good signal-to-noise ratio [SNR]) for full understanding." (Nelson & Soli, 2000) Considering all of the previously discussed research regarding classroom acoustics, that statement may not be achieved as often as we think. There are several groups of children with so-called "normal hearing" who experience significant difficulties hearing in classroom noise and reverberation. They are young students, children learning English as a second language, children with otitis media, and children with minimal hearing loss.

Studies have shown that ***young children*** have more difficulty hearing in noisy situations than adults. Soli and Sullivan (1997) reported "the ability to listen in noise is not completely developed until a child reaches adolescence". Stelmachowicz, Hoover, Lewis, Kortekaas, and Pittman (2000) found similar results with "typically developing" 5-7 year olds. When words were presented in low noise levels (high audibility), both children and adults understood essentially all of the words. In high noise levels (low audibility), adults understood most of the words but the children understood very little. Another study examined children's sentence recognition in noise. It found that "performance of 9 year olds was significantly poorer than that of 11 year olds, who also performed significantly poorer than 15 and 17 year olds" (Nelson & Soli, 2000). A recent article in *Parents* (2006) even reported possible hearing and listening difficulties in preschool boys when compared to girls of the same age. It claims that "preliminary studies suggest" that girls tend to have better hearing than boys which "may make a difference in classroom behavior: Experts say an inability to hear clearly could explain why boys have a hard time focusing on what the preschool or kindergarten teacher is saying".

Children learning English as a second language are also at risk for listening in a noisy classroom. The ability to understand spoken English in noise is related to the listener's proficiency and experience with the English language. There may be subtle phonemic differences in the languages (for example, "b" and "v" are two different sounds in English, but are pronounced the same in Spanish) and specific word knowledge is necessary to "fill in the blanks" when portions are missed. Research shows that students who were speakers of other languages perform significantly poorer in noisy conditions than their English-only speaking peers in various word and sentence perception tests (Crandell & Smaldino, 1996; Nelson, Kohnert, Sabur, &Shaw, 2005). Statistics show that "by the year 2020 over 60% of the students in public school classrooms will be children of color, many of whom will speak a dialect or language that differs from the teacher's" (Hoy & Hoy, pg. 25). Therefore, this is an essential classroom dynamic for teachers and administrators to consider.

Otitis media is a temporary middle ear infection that often occurs with fluid in the middle ear. ***Children with otitis media*** can experience a temporary and fluctuating hearing loss of 25 dB (but can be more or less, depending upon the stage of the disease). While 25 dB is only a mild hearing loss, it can cause significant hearing and processing difficulties for students in the usual classroom listening environment (Davis, 1986). Even children with first-year histories of recurrent otitis media have been found to have long term, subtle effects on phonological perception and working memory (Moody, Schwartz, Gravel, & Ruben, 1999). In 2000, Nelson & Soli reported that the incidence of otitis media (OM) in children is “at an all-time high”. In a hypothetical group of 100 students, they estimated 70 bouts of OM annually along with the following:

> “Only half of the bouts of OM will clear within a month, whether treated or not. During that month (or more), the child’s hearing loss fluctuates, varying between 0 to 40 dB (normal to mild hearing loss). One can easily do the math and figure that, for 30 children in a grade 1 class, there will be 20 bouts of OM over the course of the year, averaging 3-4 weeks each. It can be expected that every week, there are children with hearing loss due to OM in the earlier grades.”

Nelson & Soli (2000) also reported on the incidence of ***minimal hearing loss in children***. They compiled recent research indicating that 13-15% of school age children studied had hearing losses of 15 dB or more along with “major educational consequences”. Many children with this degree of hearing loss may go undetected for some time, as routine hearing screenings do not test below 25 dB (which is the upper limit for adult normal hearing). Of the children with mild hearing loss studied, 37% had repeated at least one grade, as compared to 3% of their normal hearing peers and obtained markedly lower scores on academic achievement subtests. These children were usually not aware of their hearing loss, “yet they exhibited significantly greater dysfunction than children with normal hearing on several tests of behavior, energy, stress, social support, and self-esteem”. Hoy & Hoy (2006) also support these findings as they address student motivation. They state that anxiety (which may be caused by any of those factors) “can interfere with motivation and learning by affecting attention, information processing, and performance” (pg. 126).

Other children that may be considered at risk for speech recognition difficulties in the classroom include those with articulation and language disorders, dyslexia, learning disabilities, auditory processing disorders, and attentional deficits (Crandell, 1998). Thus, all students that fall into these categories require more favorable listening conditions in order to understand classroom conversations and reap the benefits of education.

The Solution:

There are several options available to improve the listening, learning, and teaching environment in a classroom. After identifying the nature of the problem, installation of sound absorbing room and ceiling tiles, replacing old doors and windows (which may also improve the energy efficiency), and insulating or replacing existing HVAC systems may be some of the choices to consider (U.S. Access Board, 2006). However, in existing classrooms many of these options may be costly.

One cost effective way to improve classroom listening environments is through the use of sound field amplification systems. The purpose of the system is to amplify the teacher's voice evenly throughout the classroom so every student hears every word all the time. The teacher wears a microphone that transmits to a receiver/amplifier. The voice is amplified through speakers (mounted on the wall or in the ceiling) for the entire class to hear, overcoming any background noise and poor room acoustics (improving the signal-to-noise ratio). All students receive the advantages of an improved signal regardless of where they are seated in the classroom or if they are having hearing difficulties on any given day (especially with students in the younger grades).

There two most prevalent types of sound field amplification for classroom use are FM and infrared systems. ***FM*** technology has been on the market for many years and it transmits sound via radio waves. Each room uses a specific channel (or FM frequency) and the signal is not interrupted by physical objects in the room. However, this type of system can be susceptible to radio frequency interference (from other types of wireless technology) and the signal can transmit through walls, which could compromise confidentiality. ***Infrared*** systems are the most widely used for a group or classroom setting today. This type transmits sound in the form of invisible infrared light waves, similar to a television remote control. The more modern technology is immune to electromagnetic interference and the signal will not transmit through walls, ensuring privacy (Waldowski, 2002).

Enhancing the signal-to-noise ratio in a classroom provides obvious benefit to those children in "at risk" categories. However, it also provides educational benefits to virtually *all children* in a classroom. While research shows improved performance in all academic areas, significant improvement has been documented in vocabulary, reading comprehension, listening/attention skills, mathematics, phonological awareness, and spelling (Zabel & Tabor, 1993; Flexer, 2000; Long & Flexer, 2001; Crandell & Kreisman, 2002; Heeney, 2004). Darai (2000) found remarkable gains in literacy skills of first grade students in amplified classrooms, especially for bilingual and special education students. Heeney (2004) also noted improvement of classroom behaviors, such as increased on-task behavior, less disruptive behavior, lower classroom noise levels, improved student cooperation, and reduced student fatigue. Hoy & Hoy (2006) state that "the first step in learning is paying attention" (pg.89). Improving the signal-to-noise ration can contribute to a student's ability to maintain attention, as they are expending less energy on blocking out other distractions.

Feedback from students includes hearing the teacher's voice clearer, being able to hear more easily when sitting at a distance, and easier to hear over competing noises inside and outside of the classroom. Students willingly accept sound field amplification and pass around the microphone for oral reports, oral reading, and asking/answering questions. Students themselves have reported “improved classroom interaction and participation” (Crandell & Kreisman, 2002).

Classroom teachers that use sound field amplification consistently have reported having less vocal strain. Since they are speaking at reduced volume levels, they felt “less tired” and “noted reduced irritability in themselves and in their students” (Heeney, 2004). This author also surveyed teachers in a local elementary school in southern New Jersey. After having sound field amplification in their classrooms for one to two years, 80% of the teachers reported using it consistently during the school day and feel very comfortable with the system. They also observed the following behaviors in their students: Increased on-task behavior (40%), less disruptive behavior (40%), better understanding of directions (50%), more student involvement (40%), and improved phonological skills (20%). Consistent with research findings, 90% reported having less vocal strain and 50% reported feeling less fatigue or stress. These are very important factors to consider, as teachers are the largest professional group to use their voice as the “primary tool of their trade”. They rely on it almost exclusively to earn their living and, in turn, are at a higher risk for voice disorders (Mosheim, 2004). With amplification, teachers don’t have to strain or overuse their voice as often, or speak over excessive background noise.

Sound field systems can also be used to enhance other instructional equipment, such as televisions, interactive white boards, and CD/audio equipment to make the output more audible in the classroom (Crandell & Kreisman, 2002).

Cost:

Compared to the benefit that sound field amplification systems provide to students and teachers, they can be the most inexpensive technology purchased for a classroom. Up to date costs from leading manufacturers average $1200 for a complete system. When this is divided by 25 students per class, it is a cost of $48 per student. The estimated life span for each system is 10 years; therefore the annual unit cost per student is $4.80 ($6.00 for a class size of 20 students).

Since budgets are a primary concern in most school districts, it is important to show teachers, administrators, and school board members the secondary savings that can result by using sound field system. A two-year study of a school district in Oconto Falls (WI) which amplified all 37 of their regular elementary education classrooms documented a significant decrease in special education referrals. In those two school years, "an average of 4.6 percent of the student population was referred for special education evaluation, as compared to an average referral rate of 7.72 percent for the nine previous school years" (Long & Flexer, 2001). These researchers also encouraged administrators to wear earplugs during the day (and take a spelling test) to demonstrate how difficult even a minimal hearing loss can be! [Also see *Listening for Learning 3* in Appendix B]

Additional savings to a school district may be in the form of reduced sick days paid to teachers due to voice problems and fatigue. Of the teachers participating in a study examining voice disorders in the profession (Mosheim, 2004), 18 percent reported missing at least one day of work per year due to a voice disorder. Based on an average substitute teacher pay of $75 per day, every 16 sick days saved by a district would cover the cost of another amplification system.

In conclusion, the benefits of classroom amplification to listening and learning are numerous. As one study claims, “The concept of sound field amplification seems too simple to be so powerful” (Long & Flexer, 2001). Even though it is well recognized that listening is the primary modality for learning, the use of this technology for regular education classrooms is rarely considered. Throughout their book, Hoy and Hoy (2006) urge administrators to monitor student and teacher motivation and faculty morale, and keep up-to-date of the latest developments that support learning. A good administrator will understand that things happening *inside* the classroom have the greatest impact on learning (pg.3). The research presented here demonstrates improvement in teaching, learning, motivation, and classroom management through a simple, and very cost-effective, addition to the classroom.

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APPENDIX A:

Sound Field Amplification: Teacher Questionnaire

1. Do you utilize classroom amplification consistently during the school day? If not, for selected lessons? (which ones?)

2. Do you feel comfortable using the system?

3. Have you noticed any of the following behaviors in your students:
    a. Increased on-task behavior (less distraction)
    b. Less disruptive behavior
    c. Improvement in phonological skills
    d. Better understanding of directions
    e. Less fatigue or stress
    f. Other (please note)

4. Do you feel:
    a. Less vocal strain
    b. Less fatigue or stress

APPENDIX B: