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CLASSROOM MODIFICATIONS WITH IMPROVED ACOUSTICS MODELED FOR CEHIC, A SCHOOL FOR THE DEAF, IN KELANIYA, SRI LANKA

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CLASSROOM MODIFICATIONS

WITH IMPROVED ACOUSTICS

MODELED FOR CEHIC, A SCHOOL FOR THE DEAF,

IN KELANIYA, SRI LANKA

By

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Declaration

I hereby declare that the work contained in this report has never been submitted for a degree in any other university. To the best of my knowledge, this report contains no material previously published or written by another except where due reference is made within the report itself.

I further declare that the ethical procedures and principles determined by the University of Montana's document on human research and experimentation have been adhered to in the preparation of this report.

Signed ……. Date ……

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Classroom Modifications with Improved Acoustics Modeled for CEHIC, a School for the Deaf, in Kelaniya, Sri Lanka

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Abstract

The purpose of this study was to model a typical classroom in a school for the Deaf in Kelaniya, Sri Lanka. Intense effort by teachers provides intervention for students with significant hearing impairment. The school is an oral school, and the philosophy is to utilize the residual hearing of each student through the use of high-powered hearing aids. Like many schools in Sri Lanka, the Centre for Education of Hearing-Impaired Children (CEHIC) has many classrooms that have both high ambient noise with long reverberation times. Both noise and reverberation interfere with the sound signal, the teacher's voice, and provide a poor learning environment where speech discrimination is critical.

Before actually modifying a classroom, it is now possible to virtually model a classroom using architectural design software. The modified design can then be assessed through the input of sound into the classroom modelling construction materials used in acoustic modeling, and then generating a sound output that would be nearly equivalent to an actual modified classroom. A room was selected at CECIH, and the modeling process was applied using relatively low cost materials. Word intelligibility was measured with normal listeners for sound files created before and after the modifications. The results indicated a 21.8 percent improvement ($p<.0001$). Reverberation time for the modeled classroom decreased from 1.96 seconds to .32 seconds.

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CHAPTER ONE

Introduction

Children learn primarily through listening. From Kindergarten through 12th grade, the majority of the education relies on oral communication (Classroom Acoustics, 2013). Children need a learning environment in which they can hear fully and comfortably, and can clearly understand the instructions given by the teacher (Flexer, 1995).

A child's ability to learn in a classroom largely depends on hearing and understanding the teacher clearly (InformeDesign Research Desk at the University of Minnesota, 2009; TeachLogic (1999-2015).; Ostergren, Anderson, Iglehart, Johnson, Nelson, Smaldino, & Thibodeau, 2011). A child's ability to hear clearly and understand diminishes as the classroom becomes noisier (McCarthy & Rollow, 2005; InformeDesign Research Desk at the University of Minnesota, 2009; Wilson, Valentine, Halstead, McGunnigle, Dodd, Hellier, Wood, & Simpson, 2002; Berg, Blair, & Benson, 1996). Studies have shown that the majority of classrooms in schools have poor acoustics which do affect the efficiency of children's learning (Ostergren et al., 2011; Berg et al., 1996). Poor classroom acoustics have a more adverse effect on children with hearing loss, including hearing loss in one or both ears, than on their normal-hearing peers. In addition to children with hearing impairment, poor classroom acoustics may affect the following:

- Children with learning disabilities
- Very young children who are unable to predict from context
- Children with speech and language delays
- Children with auditory processing disorders
- Children with a foreign (different) native language

- Children having problems with paying attention in the classroom, and
- Children with temporary hearing losses due to fluid in the middle ear and children with ear infections (Berg, 1996; Classroom Acoustics, 2013; Ostergren et al., 2011).

With poor classroom acoustics, there is greater likelihood for breakdowns in communication to occur. Communication breakdown hinders chances for achieving the best academic prospects for any child. In addition, communication breakdowns can also affect the health of the teacher's voice. Since voice is the main tool used for giving instructions (InformeDesign Research Desk at the University of Minnesota, 2009), teachers must use more vocal effort to overcome poor classroom acoustics. Due to the strain on their voices, teachers tend to have more trouble with their vocal health than people in other similar occupations (ScienceNordic, 2012; Berg et al., 1996; TeachLogic (1999-2015). Poor acoustic learning environments with excessive ambient noise can lead to the following:

- Decrease in speech recognition
- Decrease in academic performance
- Delay in language acquisition
- Increase in reading and spelling deficiencies
- Increase in disruptive behavior (Koszarny, 1978).

Studies have shown that the average noise levels in most classrooms can range between 66 decibels (dB) and 94 dB (Rosenberg, 2010; Picard & Boudreau, 1999). According to the American National Standards Institute (ANSI), which has set standards for classroom acoustics, noise levels for an unoccupied classroom should not exceed 35 dB (American Speech-Language-Hearing Association, 2014). The signal to noise ratio

(SNR) is used to express in dB the relative difference between the signal you are listening for and the interfering background sounds. Picard and Bradley (2001) found that in most classroom settings, the SNR was -6 dB. Preferred SNR in a classroom is between +15 dB to +30 dB.

The main factors that contribute to poor classroom acoustics are:

- The distance between the child and the teacher
- The level of ambient noise (external to the building, external to the classroom and internal to the classroom)
- The reverberation time (RT) in the classroom
- Ratio of the speech signal relative to the background noise levels
- Poor planning (physical location of the school and placement of the classrooms)
- Poor selection of building construction materials and finishing materials for floor, walls and ceiling (i.e., having reflective surfaces for sound to bounce back and forth; not using sound absorbent materials to line the interior of classroom surfaces).
- Lack of knowledge and funds

In many developing countries, such as Sri Lanka, India, and Nepal, consideration was not given to classroom acoustics when schools were built. This research could not find any present national standards for what constitutes an acceptable acoustic environment for listening and learning in Sri Lanka, India, Nepal, Pakistan, or Bangladesh. Due to non-existent architectural acoustic design requirements in developing countries, acoustically substandard classrooms are still being constructed, even in new schools which are yet to be completed. This is mainly due to the lack of awareness and

very low funding available for school projects. Almost all permanent school buildings have been built using materials of concrete, brick and mortar. In many developing countries in South East Asia, the climate is hot, there is no air conditioning, and the school buildings have no insulation/thermal barriers, which help to insulate classrooms from ambient sound. To improve ventilation, buildings and classrooms often have large windows which are left open. Some classrooms have no ceilings; therefore, ambient sounds from outside the classroom can encroach on the classroom. Other classrooms, with classrooms directly above, usually have a concrete surface for the ceiling. The classrooms are normally overcrowded. Specific construction materials are available with acoustic parameters that attenuate outside environmental sounds as well as those that reduce deleterious reverberation within the classroom. With respect to acoustical properties, inappropriate surfaces and materials are used to separate classrooms and line the walls. Some schools have been built as long concrete buildings with no partitioning between classrooms. While classroom conditions such as these make learning very challenging for normal-hearing children, learning becomes much more difficult for children with a hearing loss.

Speech intelligibility has been used to assess communication systems. It is expressed as a percentage correct. Consonants, words or sentences can be assessed using a number of test instruments. Speech intelligibility is very poor in classrooms with excessive noise and high reverberation. Studies using speech intelligibility tests have shown that children with normal hearing in classrooms in developed countries, understand about 75% of the words that were read from a list (McCarthy, & Rollow, 2005; Acoustical Society of America, 2000; Colleran, 2010; Classroom Acoustics, 2013).

The issue of speech intelligibility becomes more difficult for children with a hearing loss. To date, there is no literature concerning speech intelligibility and classroom acoustics for classrooms in developing countries.

Modifying classrooms to improve acoustic properties can be accomplished with relatively little extra cost. The benefits of having improved acoustics in classrooms would far outweigh extra expenditure if they were to be considered and compared. Even in existing classrooms, acoustics can be vastly improved by carrying out simple, inexpensive modifications, with locally available materials, which would reduce the reverberation time (RT), increase the signal to noise ratio (SNR), and decrease ambient noise levels. Education and awareness from students, parents, educators, and authorities are the keys to improving classroom acoustics. In addition, it is essential to build national standards and develop acoustic design requirements for schools and all forms of educational institutions.

The Center for Education of Hearing Impaired Children (CEHIC) in Sri Lanka

The History of CEHIC

This information in this section is taken from documents available from the Center for Education of Hearing Impaired Children (CEHIC). The CEHIC emerged out of two founding principles – free education for all hearing-impaired children and an ethos of inter-religious and inter-ethnic cooperation and harmony. The school started from small and difficult beginnings in 1982. Its Founder and present Director, Rev. Sr. Greta Nalawatta of the Sisters of Perpetual Help, began her unique work, the first of its kind in Sri Lanka, nearly thirty-two years ago. Sr. Greta believed that hearing-impaired children

should be treated like normal-hearing children, and that their aural habilitation (not re-habilitation) should begin from pre-school age, even as early as six to eight months old.

The Sisters of Perpetual Help in Sri Lanka are the pioneers of “deaf” education and training in Sri Lanka. The famous St. Joseph's School for the Deaf in Ragama, was founded in 1935 by the Belgian Missionary Sisters. This school helped youths and young adults by concentrating on the traditional methods of putting "deaf and dumb" children into the “ghettos” of residential institutional care. Within the St. Joseph’s residential school, those who were deaf were taught sign language, and trained in a vocational skill in order to earn a basic living in adult life.

Sr. Greta felt uneasy with this approach. Amidst disagreement and opposition from her superiors, she advocated that hearing-impaired children could be taught to hear and speak. With the help of hearing aids, children could be given a holistic education with integration into the mainstream school system at the normal school-going age of around five to six years. She insisted that hearing-impaired children could go on to higher academic and social achievement, and become equal creative partners with normal-hearing people to build a better society.

Sr. Greta first started a pre-school class using these new ideas at St. Joseph’s School for the Deaf in Ragama, but she didn’t continue for long. After a period of training in Japan, Sr. Greta found, on return to Sri Lanka, that she was unable to continue with her vision at St. Joseph's School for the Deaf. With just the teaching materials she had made with her own hands, Sr. Greta gathered a few children by going from house to house in the village searching for “deaf and dumb” children who were being kept at home and not sent to school. Through various well-wishers, she ensured that each child had

proper hearing aids and also insisted on the daily attendance of one parent, usually the mother, with the child. Sr. Greta first concentrated on training teachers to help her. Sr. Greta realized that, next to the parent, the teacher is the most important person in the life of the hearing-impaired child. Using the small amounts of money she earned from giving English tuition, Sr. Greta trained a small team of young women teachers to assist her in her work with the children and their parents.

It was only later that the steady evolutionary process began in the establishment of a permanent school. With the help of various donor-institutions and individual well-wishers, a pre-school, educational center, and a parents' association were organized. This has resulted in the specialized educational center of excellence today which is known as the Centre for Education of Hearing Impaired Children (CEHIC).

CEHIC Today

The Center for Education of Hearing Impaired Children (CEHIC) is administered by the Association for Hearing Impaired Children (a registered charity) and by its legal arm, the Hearing Impaired Children's Trust. It is neither a private school nor a state school. It is a multi-ethnic, multi-religious community school managed by the parents. There are two patrons of CEHIC. The first is the Ven. Kusaladhamma Nayake Thera, a high ranking prelate of the Buddhist Sangha who heads the Peliyagoda Vidyalankara Privena (the seminary for Buddhist monks). He is also the Chancellor of the University of Kelaniya. The grounds of the university border the grounds of CEHIC. The other patron is the Rev. Fr. Aloysius Pieris, s.j., the world renowned Jesuit theologian and Buddhist scholar. He is the Founder and Director of the Tulana Research Centre for Encounter and Dialogue. Both patrons are members of the Board of Trustees for CEHIC.

Educational and other services at CEHIC are provided to the highest standards possible and offered free of charge, thus making education and services accessible to the very poor. This is a unique institution in Sri Lanka. In 2003, Kanchana Rajapakse, one of the first profoundly deaf children from a poor background who was educated by Sr. Greta, successfully passed her university entrance examination and was admitted as an undergraduate to Kelaniya University to read for a Bachelor of Arts degree offering the subjects Library Science, Buddhist Culture and Sinhala Language. This is the first time in Sri Lanka that a "deaf" student was admitted to a university in Sri Lanka.

As CEHIC is nearly thirty-two years old, many former students are now young adults who are facing life in the real world with all of its challenges. These students represent one of the oldest groups of deaf adults who have received education and training. Those who have the ability are encouraged to go into higher education and some, like Kanchana, to enter university. Extra tuition is provided by CEHIC for these students. For those who wish to enter the world of work, CEHIC has developed a Vocational Training and Aftercare Centre. At present, full-time staff members consist of eight teachers, three office staff, and one domestic staff. There are also ten part-time teachers. The driving force of CEHIC is the hope that it instills in every hearing-impaired child the knowledge that he or she can have a positive future as an equal partner with every other member of society in building a just, prosperous and peaceful Sri Lanka.

Achieving the Objectives of CEHIC

Early identification.

At CEHIC, the vital importance of early identification of a child's hearing loss is stressed. Parents are encouraged to bring their child for testing and assessment at the

earliest moment they suspect a child has a hearing problem. The pre-school admits children below the age of 12 months. Prior to enrolling in CEHIC, an individualized program is created to suit the needs of each child as well as the child's primary caregiver (usually the mother). The child and the primary caregiver then attend the pre-school and begin the process of auditory and oral habilitation.

The Auditory-Oral method at CEHIC.

At CEHIC, it is proposed that children with hearing loss can learn to listen and talk. This is the main goal of the educational programs at CEHIC. Children who develop spoken language have options to participate more fully in the community. Spoken communication facilitates all aspects of life – at school, at home, and at the workplace. Children who are educated with the oral approach, compared to other methods used in deaf education will hopefully develop listening skills with the use of auditory technology, including hearing aids, along with specific teaching, and speech reading. Using this combination, hearing-impaired children, especially those with moderate and severe hearing losses (as opposed to a profound hearing loss) can learn to speak much as children with hearing do, given the right intervention.

Every encounter at CEHIC, however informal between a child and an adult, is a teaching and learning experience. The teachers and other staff constantly engage the children in developing their hearing and verbal skills in order to improve their knowledge of the world around them. In this way, the parents who attend the school every day also learn how to re-create such a world of sound for their children in their own homes and local communities.

Language acquisition and the hearing-impaired child.

The central nervous system of a human is tuned by nature to process spoken language patterns and other meaningful sounds like music (Cole and Flexer, 2010). During the early years of life, a child with normal hearing has an abundant experience with communicative speech and other sounds of the world around him or her. Through this constant immersion in sound, children learn the basic rules which govern meaningful use of spoken language and other sounds. At birth, a hearing impairment does not change this basic nature of the child's central nervous system but with intervention it is able to improve and how it deals with verbal and other auditory material.

Therefore, for the hearing impaired child, the problem is how best to supply the child with clear and frequent verbal, musical, and other sound patterns to activate this processing capability and to develop it. Total deafness is extremely rare. Most hearing-impaired children have some residual hearing, which allows for language acquisition. They can hear some sounds if adequate amplification is provided for them. This is achieved by using powerful hearing aids. Much like wearing spectacles, each child needs hearing aids individually prescribed for his or her particular impairment.

But simply hearing speech and other sounds is not enough. The hearing-impaired child, parents, siblings, and everyone around this child needs to understand that a hearing-impaired person needs a special approach and technique to understand all sounds. Acquiring the ability to speak and use the language of communication of the child's society also needs specialist assistance. This is what is provided at CEHIC.

Pre-school education.

The founder and the present Director recognized the importance of a specialist pre-school education for hearing-impaired children at the very beginning of her mission. The heart of CEHIC is its pre-school. Over the years, Sr. Greta has developed a method of pre-school education suitable for the Sri Lankan context. Educational techniques from the Montessori method have enhanced Sr. Greta's own ideas and discoveries relating to hearing-impaired and deaf education. Today, CEHIC has eight classrooms with an average of about six to eight children in each class. The ages of the children range from about eight to 12 months, up to the school-going age of about five or six years. Pre-school classes are held on weekdays from 7:30 am to 12.30 pm

Integrated education.

The successful integration of the hearing-impaired child into the mainstream educational system, and ultimately into society, is one of the primary goals of CEHIC. At the school-going age of six years, children are admitted into a primary school of the parents' choice, but preferably into a school close to CEHIC. The purpose is to enable the children to return to CEHIC in the afternoons to attend the afternoon classes which are conducted by part-time trained professional teachers. The subjects taught are those included in the mainstream national educational curriculum. CEHIC offers extra instruction from Year/Grade one through Year/Grade12 for the following subjects: Mathematics, Art, Social Studies, Science, Sinhala language, English language, Buddhism and Home Science. The classes for integrated children take place from 2:00 pm to 5:30 pm every weekday.

Holistic education.

Education at CEHIC is not restricted to the “three R's,” but also includes arts and crafts (painting, woodwork, pottery, sculpture), music and singing, dance and ballet, sports and gymnastics, and sewing and cooking (for both girls and boys). The rationale behind this holistic education is that the development of hearing-impaired children as whole, rounded individuals is vital for their entry into civil society as creative and contributing citizens. These classes are held on Saturdays, and are taught by skilled part-time teachers as well as the CEHIC teaching staff.

Parent Education

Daily program.

At CEHIC, the classroom is considered a home, and the child's home is considered a classroom. This is an essential aspect of the auditory-oral educational process adopted by Sr. Greta. It is made possible by the daily attendance of one parent, usually the mother, who accompanies the child. The parent sits with the child in the classroom, and takes part in all the educational activities and other activities of the center. The mother learns educational techniques, especially those used for voice, language and speech therapy, and continues the exercises with the child at home. In many cases, especially for families of low socioeconomic status, the mothers often have little formal education themselves. Working alongside their own children in the classroom also provides these mothers with an education. It further improves their knowledge, communication skills, parenting skills, and social skills, as well as increases their personal confidence.

Pre-school parents' seminars.

A series of one-day seminars are held at least twice a year for the parents of the children attending the pre-school. The seminars are conducted by Sr. Greta and various visiting specialists in the fields of education, pediatric health, family counseling, and child psychiatry.

Parent's day.

The annual Parent's Day is a big event in the regular CEHIC calendar. This is held in July every year, and, apart from a variety of entertainment by the children and staff and the festive lunch, talks on various important themes such as those concerning family values and the psychology of children are given by the invited guest. These talks are followed by questions and answers and a discussion.

Teacher Training

The ongoing teacher training program at CEHIC is carried out mainly by Sr. Greta Nalawatta in the practical setting of the pre-school classrooms. Teachers also spend about three months working alongside Sr. Greta in her Year One integrated class conducted in the CEHIC annex house at Dalugama. Every year, an intensive full-time workshop is conducted for the teachers by Sr. Greta and guest lecturers are invited to discuss various educational, clinical and social aspects of teaching the hearing-impaired child. Each October, the annual Teachers' Day is held at CEHIC, giving students and parents the opportunity to show appreciation for CEHIC teachers’ dedication and commitment. Plans have been drawn up to conduct a comprehensive training course for teachers of hearing-impaired children at the university level.

Propagation of Teaching Methods.

CEHIC has formalized this in the Propagation of Sr. Greta's Educational Methods (PROGEM) Project. The first program under this project is the design and publication of a complete Language Teaching method for pre-school children from the ages of one year to the school-going age of about five or six years. A second program, the Mathematics Teaching method for pre-school children is currently being designed and produced.

Primary school.

As stated above, CEHIC has commenced discussions with a state-assisted school to set up a primary school branch in Dalugama where hearing-impaired children will be educated alongside normal-hearing children. In this way, under guidance of Sr. Greta and CEHIC, hearing-impaired children can be integrated into mainstream classrooms.

Vocational training.

CEHIC is currently in the process of developing a fully-equipped and comprehensive Vocational Training Centre on the annex site in Dalugama, which is located about a kilometer from the main site in Lumbini Mawatha. The house and land were recently received as a generous donation, and facilities are envisaged for teaching a range of craft and technical training courses, including English language competence and computer skills. This facility will be open to CEHIC students as well as to all youth of the area.

The Community School Ethos

The practice of making education available to children free of charge according to the community school ethos is a concept central to the existence of CEHIC as the school is neither a private school nor a state school. The parents of the children currently

attending CEHIC have formed themselves into an association called the Association for Hearing Impaired Children (AHIC). AHIC is a legally-constituted charitable organization, and at the Annual General Meeting of the membership, the Management Board is appointed which oversees the day-to-day running of the center. Parents in AHIC hold their meetings once a month.

A Board of Trustees, the Hearing Impaired Children's Trust (HICT) is the Centre's legal and financial supervisory body. This body also meets monthly. A Board of Education, made up of a variety of eminent experts in the various professional fields aligned to hearing impairment and education of children in general is also part of this community school ethos. They advise and consult with Sr. Greta and meet twice a year. Three members from the Board of Management, three from the Board of Education (nominated by the AHIC board), two patrons (Ven. Kusuladhamma Thera and Fr. Aloysius Pieris, s.j.), and Sr. Greta constitute the nine-member Hearing Impaired Children's Trust board.

CHAPTER TWO

Review of Literature - Classroom Acoustics

In order for students in a classroom to achieve the best academic prospects, the acoustical information received from the teacher should be accurate and complete. Speech perception ability in a typical classroom can be adversely affected by acoustical characteristics and the environment. Acoustical variables that will affect the perceptual abilities include the distance of the student from the teacher, amount of background noise, the ratio between the teacher's sound level and the background noise, and echo or the reverberation time (RT) of the classroom.

In addition to the acoustical environment, speech perception in a classroom can also be decreased by reductions in the hearing sensitivity, as well as auditory processing abilities, of the child. It is documented that the major consequence of sensorineural hearing loss (SNHL) is the speech perception difficulties encountered especially in noisy or reverberant listening conditions.

Major Acoustical Variables in Classrooms

- Ambient or background noise level
- Level of the speech signal relative to the level of background noise
- Reverberation time (RT)
- Distance from the teacher (or the speaker) to the student (or the listener).

Ambient or Background Noise Level.

Ambient, or background, noises are the undesired sounds in a classroom which mask the teachers voice (direct instructions) and the voices of the peers (indirect instructions). Some of the undesirable background noises that exist in a typical classroom in a developing country are (a) interior to the classroom; (b) exterior to the classroom but

interior to the building; and (c) exterior to the building. Each of these will be described below.

Interior to the classroom.

This type of noise includes noise from classroom equipment such as computers; fixtures such as light fixtures (florescent lightening); electric fans; individuals talking and whispering; chairs or tables sliding across floors; hard-soled shoes shuffling on non-carpeted floors; and cloth, bags and paper rustling in the classroom.

Exterior to the classroom but interior to the building.

This type of noise includes sounds of children talking; shouting outside the classroom in the corridors; sounds from classroom adjustments; loud rooms such as classroom without teachers; and the sound of children reciting/learning in neighboring classes. There are usually no gyms or cafeterias in most schools in developing countries. Also, there are usually no heating, ventilating, or air-conditioning (HVAC) systems in these schools.

Exterior to the building.

This type of noise includes traffic sounds from the adjoining roads and intersections; sounds of airplanes and trains; busy building sites that are close by; public announcements through loudspeakers; sounds from Mosques, Temples (Hindu and Buddhist), and churches; and sounds from rain and thunder.

Since there are very little, or, in most cases, no thermal or acoustic insulations used in these school buildings, sound can easily travel into the classroom through the walls from adjacent rooms, or from outside through exterior walls. When sound strikes a wall, the sound energy sets the wall in vibration, much like a radio signal to a speaker.

The wall then becomes the transmitter and relays the signal to the opposite side of the wall at a reduced intensity. Sound also travels through doors and windows; around frames and under doors; and over ceilings from adjacent rooms, hallways and outside.

It should be noted, however, that background noise in a classroom often fluctuates considerably as a function of time. This variability often makes it difficult to measure classroom noise reliably in a simple manner. In spite of this difficulty, most studies of classroom noise report background noise levels via single number descriptions (Crandell, 1995). The most common single number descriptor of classroom noise is the measurement of the relative sound pressure level (SPL) of the background noise at a specific point, or points, in time on an A-weighting scale (dBA). Such measures are usually conducted with a sound level meter. The A-weighting network is designed to simulate the sensitivity of the average human ear. However, a single number obtained from a sound pressure measurement performed with the A-weighting scale can be obtained with a number of very different acoustic spectra.

As mentioned above, the ambient sound in a classroom affects a child's ability to understand speech by masking acoustic and linguistic cues that are contained in the teacher's instruction. The energy of consonant sounds is much less than the energy of vowel sounds. Ambient sounds in the classroom largely affect the consonant sounds that have less energy, which reduces consonant perception. Unfortunately, even minimal decreases in consonant perception can significantly influence speech perception because the vast majority of a listener's ability to understand speech is the result of consonant energy (French & Steinberg, 1947; Licklider & Miller, 1951).

The most effective maskers for speech are usually those noises with a long-term spectra which are similar to the speech spectrum because they affect all of the speech frequencies to the same degree. Consequently, noises generated within the classroom, such as children talking, often produce the greatest decrease in speech perception because the spectral content of the signal, usually the teacher's voice, is spectrally similar to the spectra of the noise. Low-frequency noises in a classroom, such as low humming of a ceiling fan, are usually more effective maskers of speech than high-frequency sounds because of the upward spread of masking (i.e. low frequency sounds will tend to be effective maskers of higher frequencies). Due to the upward spread of masking, noise tends to produce greater masking for signals, such as speech, that are higher in frequency than the noise. Classroom noises that are continuous in nature are generally more effective maskers than interrupted, or impulse, noises. These differences in masking occur because continuous noises more effectively reduce the spectral-temporal information available in the speech signal. Continuous noises in the classroom include the sound of ceiling fans, faulty fluorescent lighting, and the long-term spectra of children talking.

As discussed above, there are a number of potential noise sources, and classrooms often are filled with excessive levels of background noise. The American National Standards Institute (ANSI, 2010) recommends that ambient sound levels not exceed 35 dB for an unoccupied classroom. But studies have shown that in a typical classroom, the ambient sound levels far exceed 35 dB (Smaldino and Crandell, 1995). In developed countries, ambient sound levels for a typical classroom are generally between 45 dB to 75

dB (Smaldino & Crandell, 1995). Because of construction materials and this ambient sound level could be much higher in a typical classroom in a developing country.

This is not the most critical factor. Based upon the literature, the most critical factor is the ambient sound level in the occupied classroom. Studies have shown that in occupied classrooms, sound levels can rise as high as 70 dB (Smaldino & Crandell, 1995). To overcome these levels of ambient sound, the teacher has to raise his or her voice in order to reach a desirable signal to sound ratio (SNR). Therefore, it is imperative that the occupied classroom sound levels are kept to a minimum, which is below 50 dB, so that speech communication is not masked. All the noises within the classroom, within the school, and outside the school, have to be identified, measured, and either isolated or reduced. It is possible to reduce ambient sounds levels using locally-available, inexpensive materials such as rugs on the floor, drapes, curtains, as well as wall hangings on the walls, doors and windows. In addition, teachers and students can be instructed to move silently in the corridors.

Level of the Speech Signal Relative to the

Level of the Background Noise, or Signal to Noise Ratio (SNR)

The ratio of the speech signal (teacher's voice) relative to the ambient noise level, also known as Signal to Noise Ratio (SNR) at the student's ear is the most important consideration for accurate speech perception in most learning environments. This component of acoustics in a classroom is most critical to understanding the acoustic environment and a child's hearing ability. The SNR is basically how much louder the teacher's voice is when considering other noises in the room. As an example of the SNR,

if the teacher's voice is at 70 dB, and background noises (student chatting, fans, noise from outside, etc.) are at 60 dB, the SNR would be calculated at +10 dB.

Two components, ambient noise and reverberation time, that are discussed in this chapter, affect the SNR. An increased background noise will lower the SNR. An increased reverberation time will also lower the SNR. But the SNR includes one other component – the teacher's voice. The teacher's voice is the signal.

In a learning environment, SNR is the most critical component because it determines speech intelligibility, or, the ability to understand what a person hears. This is where the difference between a child's ability to hear and an adult's ability to hear becomes most evident. Normal-hearing children require a SNR of +15 to +20 decibels for good speech understanding (Smaldino & Crandell, 1995). Therefore, a child must have the teacher speaking at least 15 dB louder than the background noise in the room in order to fully comprehend what is being heard. In comparison, an adult with normal hearing requires a SNR between +6 and +10 dB. Conservatively speaking, children with normal hearing need a teacher to speak at least 9 dB louder than adults in order to fully comprehend speech. (Smaldino & Crandell, 1995). Understanding of auditory closure for children who are developing speech allows for an understanding of how detrimental poor acoustics can be to auditory learning, which again, makes up a significant portion (up to 75%) of a child's day in school. For children with hearing loss, the reduction in SNR has more adverse effects than for the normal-hearing children.

Due to the excessive noise levels found in many learning environments, it is not surprising that unfavorable SNRs have often been reported in classrooms. Specifically, as can be noted from Table 2, the range of SNRs for classrooms has been reported to be

from approximately +5 dB to -7 dB. The effects of poor SNRs on the perceptual abilities of children in classroom settings will be addressed later.

Table 1

A summary of studies examining classroom signal-to-noise ratios

Study	***Signal-to-noise ratio***
Sanders (1965)	+1 to +5
Paul (1967)	+3
Blair (1977)	-7 to 0
Markides (1986)	+3
Finitzo-Hieber (1988)	+1 to +4

Note. Adapted from Crandell & Smaldino (2000).

Effects on Academic Performance of the Children and Performance of the Teacher Due to Excessive Noise Levels in the Classrooms

Background noise can adversely affect speech recognition which may result in poor academic performance. This could influence reading skills and pronunciation, spelling, attention deficits and concentration issues, and, importantly, behavioral issues in a child (Berg et al., 1996; Bradly, 1986; Finitzo-Hieber, 1988). Crandall and Smaldino (2000) stated that there is a direct negative relationship between high background noise levels in classrooms and reading scores of elementary school-aged children. Reading scores decreased with the increase of background noise level in the classroom. Koszarny (1978) reported that background noise has a serious adverse effect on concentration and

attention in children with lower IQs and/or in children with high anxiety levels. Significant improvement including increased concentration, attention, and participatory behavior in children were reported by Lehman and Gratiot (1983) by reducing the classroom noise levels through acoustic modifications.

The American Speech-Language-Hearing Association (ASHA, 2014) has set a standard for acceptable acoustics which are to be no louder than 30-35 dB in an unoccupied room. Reverberation time should not exceed 0.4 seconds and the SNR should be no lower than +15 decibels, which is what a normal-hearing child requires for intelligible comprehension. The authority on acoustic standards is the American National Standards Institute (ANSI). In 2002, ANSI adopted standards that were developed by the Acoustical Society of America (ASA) regarding acoustic performance criteria and design requirements for classrooms and other learning spaces. These standards are referred to as ANSI S12.60-2002, "Acoustical Performance Criteria, Design Requirements and Guidelines for Schools." The general guidelines are based on two acoustic performance factors: background noise and reverberation. ANSI specifies that average-sized core learning spaces should have background noise levels which do not exceed 35 dB. Maximum reverberation times are not to exceed 0.6 seconds for small rooms, and 0.7 seconds for large rooms. Unlike ASHA, ANSI fails to address the signal to noise ratio, the most critical component.

A teacher's performance can also be affected due to excessive classroom noise levels (Ko, 1979; ScienceNordic, 2012). In a study of 1,200 teachers conducted by Ko (1979), it was shown that teachers experienced increased levels of tension, discomfort, and fatigue due to excessive noise levels, which included both internal and external noise.

These excessive noise levels did interfere with both teaching and speech comprehension in the classroom. Many studies have shown that teachers have a higher incidence of vocal problems than people of other professions (Smaldino and Crandell, 1995). To maintain a higher SNR, teachers must raise their voices in order for the children to hear them over background noise levels. A survey conducted by the Danish National Research Centre for the Working Environment (NFA, Feb 25, 2012) has found that teachers who work in schools with good acoustics are much happier than the teachers who work with excessive background noise levels. According the Jasper Kristiansen of the NFA (Feb 25, 2012), about one quarter of unhappy teachers were considering quitting their jobs. This survey by the NFA showed that teachers who worked in classrooms with excessive background noise levels were not satisfied with their jobs, were tired and lacking in energy, and were demotivated. These teachers' wishes to change their jobs were six times higher than teachers who worked in classrooms with good acoustics. Other studies have also reported that teachers tend to have significantly higher incidence of vocal problems than the general population (Smaldino and Crandell, 1995). It is suggested that these vocal ailments are caused, at least in part, by having to talk louder in order to be heard in the classroom over background noise levels.

A pioneer-study was done to measure classroom sound levels in a student-occupied classroom, which provided new evidence on the noise level in the classroom and discounted the ANSI background noise standard of 35 dB. This study, referred to as the Los Angeles Unified School District (LAUSD) study by McCarty and Rollow (2005), investigated the Los Angeles student-occupied 4th grade classroom through a two-day recording and statistical analysis of the recorded sound data. Classroom activities such as

silent reading, working together, talking, and out-of-class activities such as lunch and recess, were recorded by the teacher so that classroom activities could be correlated with varying sound levels. Actual sound levels were recorded at 10 second intervals in a class size of 30 children. The school was new and designed with good acoustic qualities. The classroom was not considered a noisy room, even though the noise of traffic and air-conditioning could be measured.

Until recently, efforts to reduce classroom noise have focused on reducing noise generated by ceiling fans and traffic. Because there was no information on noise generated by the occupants, their role in the problem was dismissed as an issue of classroom management. The LAUSD study concluded that background noise levels, ranging from 43 to 52 dB, exceeded the ANSI requirement of 35 dB by 8 to 17 dB. Given these results, present ANSI standards cannot be expected to make improvements in the student-occupied classroom.

Noise generated from heat, ventilation, or air conditioning (HVAC), previously thought to be the main source of background noise, had little to no effect on background noise. Rather, it was noise generated from the children themselves that had the greatest impact (Smaldino and Crandell, 1995). "Working together and talking" activities were measured at 67 to 72 decibels, "Silent Reading" activities were measured at 45 dB, only one to two decibels louder than the unoccupied room. Unoccupied levels during lunch, before and after school were between 43 to 45 dB. This study raised the question, if the ANSI background noise levels are not achievable, how is it possible for a teacher to generate the +15 dB signal to noise ratio in all areas of the classroom?

Looking at the results of the LAUSD (2005) study, combined with information about acoustics, leads to a suggestion that the classroom may be a poor environment for auditory learning to take place. It is not possible for a teacher to project his or her voice to the back of the room all day, in order to achieve the signal to noise ratio of +15 dB in all areas of the classroom, for all students, at all times.

The other factor that affects the SNR is the distance between the teacher and the child. As the distance between the teacher and the child increases, the SNR becomes less favorable, which suggests that different locations within the classroom may have different SNRs. Typically, the back of the class has the lowest SNR. Also, children sitting close to noise sources, such as open windows and under ceiling fans, experience unfavorable SNRs. Children with hearing loss require up to +30 dB for optimal speech understanding according to Bess (1999). Children with hearing loss require amplification. Usually this is achieved with the use of hearing aids or personal amplification devices. Oftentimes, hearing aids and amplification devices which are available today cannot distinguish between the speech signal and the noise; therefore, the hearing aid, or the personal amplification device, boosts all sounds available at speech frequencies making both the speech and noise louder. The result may be that desired speech sounds are masked by noise. Markides (1986), in his study of speech levels and signal to noise ratios, suggests that that in order to get the optimum benefits from personal hearing aids and personal amplification devices in the classroom, the speech signal must be presented at a very high level (up to 80 to 90 dB SPL), with a high SNR of +30 dB or more. Bradly (1986), in his study of speech intelligibility studies in classrooms, confirms the above by demonstrating that, in a classroom which measures

300 m^3, the most desirable results are obtained with the SNRs between 25 to 35 dB with reverberation time (RT) being less than 0.6.

Reverberation Time

Reverberation, along with ambient noise, are the two elements most frequently blamed for poor speech intelligibility. Sound propagates spherically in all directions at the speed of 770 miles an hour (1132 feet per second) in the air. When sound waves come into contact with hard surfaces in a room (walls, floor, and ceiling) most of the sound is reflected back (unless these surfaces are treated for sound absorption) over and over again until the energy in the sound has dissipated. In continuous speech, reflections which arrive at a child's ear milliseconds after the direct speech sound tend to reduce the clarity of the speech signal. Toward the back of the classroom, reflected sounds can be louder than the direct speech signal. Reverberation, which consists of the sum of the original sound and its reflected sounds, also causes a buildup of sound, which effectively increases the noise level in a room. Excessive reverberation does not distort words equally; consonant sounds are more affected than vowel sounds. Consonant sounds are important for speech intelligibility, yet they are weaker in intensity compared to vowels (Kent & Read, 1992). Vowel sounds, which have more energy, mask the weaker consonants sounds

In simple terms, reverberation is the overall effect of reflected sound in a room commonly known as the echo. The time taken for reflected sound to decay, and become inaudible, is known as the Reverberation Time (RT). In any room, short RTs (less than 0.4 seconds) are considered good as they do not affect speech intelligibility much. A room with long RTs (over 0.4 seconds) can detrimentally affect speech perception in the

classroom. The RT is often calculated with the room unoccupied. When occupied, people and their clothing provide additional sound absorption; an unoccupied room is the worst case scenario for RT. In a complete study, RT has to be measured for each octave band as RT can vary widely at different frequencies. But for quick estimates, the RT of a classroom can be calculated by using just one octave band representative of speech frequencies, such as 1000 Hz; alternatively, an RT can be calculated by using a few representative bands of speech frequencies such as 500 Hz, 1000 HZ, and 2000 Hz.

Reverberation refers to continuation of sound in a room as the sound bounces off hard surfaces and sound waves are reflected back into the room (Nabelek & Pickett, 1974). The most important acoustic feature which contributes to the acoustic climate of a classroom is the reflected continuation of sound. The definition of the RT is the time taken (in seconds) for the sound from the source to decay by 60 dB after the sound has ceased. A decrease of 60 dB represents a reduction of 1/1,000,000 of the original intensity of the sound. A common formula to calculate RT was described by Sabine (1964):

$$RT_{60} = \frac{0.049V}{\Sigma S\alpha}$$

This formula states that RT60 = reverberation time in seconds, 0.049 is a constant (use 0.161 if room volume is stated in meters), V = room volume in cubic feet (ft^3), and $\Sigma S\alpha$ = the sum of the surface areas of the various materials in the room multiplied by their respective absorption coefficients at a given frequency where S = surface area in feet squared (ft^2) and α = the absorption coefficient of material(s) at given frequency. The two variables which affect RT in the formula described above are the amount and the rate of sound absorption in the room (increased surface area of good sound absorbing

materials shorten the RT), and the volume of the room (the smaller the volume of the room, the shorter the RT).

Studies have shown that in unamplified rooms with typical reverberance (between 0.5 and 1.0 seconds), and typical background noise levels (over 40 dB), children with and without hearing problems have difficulty understanding what is being said. The following table illustrates the results of the Finitzo-Hieber and Tillman study of 1978. The table reports speech recognition scores in percent correct for children with normal hearing and for children with mild to moderate degrees of hearing loss under various controlled classroom listening conditions.

Table 2

Mean speech recognition scores, in percent correct of children (age 8-12) with normal hearing and hearing impairment for monosyllabic words across various signal to noise ratios S/N and reverberation times.*

Reverb. Time = 0.00 Sec			**Reverb. Time = 0.4 Sec**			**Reverb. Time = 1.2 Sec**		
S/N	**Normal Hearing**	**Hearing Impaired**	**S/N**	**Normal Hearing**	**Hearing Impaired**	**S/N**	**Normal Hearing**	**Hearing Impaired**
Quiet	94.5	83.0	**Quiet**	92.5	74.0	**Quiet**	76.5	45
+12 dB	89.2	70.0	**+12 dB**	82.8	60.2	**+12 dB**	68.8	41.2
+6 dB	79.7	59.5	**+6 dB**	71.3	47.7	**+6 dB**	54.2	27.0
0 dB	60.2	39.0	**0 dB**	47.7	27.8	**0 dB**	29.7	11.2

*Note: +12 dB S/N means that speech level is 12 dB greater than background noise level. Adapted from McCarthy & Rollow (2005).

The common method of calculating the RT as the mean decay time uses three frequencies of 500, 1000, and 2000 Hz. Different frequencies exhibit different reverberation times in rooms. As noise is not limited to just 500, 1,000 and 2,000 Hz, this measurement standard may not produce accurate results. In order to identify the

reverberant characteristics of a room, greater reverberation calculations might reveal more accurate data using frequencies ranging from 125 to 8000 Hz as recommended by Crandell and Smaldino (2000) – especially if excessive reverberation is affecting clear communication. Adding frequencies to reverberation calculations would allow for selection of the most effective sound-absorption materials to treat the room.

Reverberant energy can mask direct and early-reflected energy hindering speech perception (Nabelek & Pickett, 1974). Speech perception is diminished when refracted sound waves cloak, or mask, speech. This creates an overlap of sounds, which especially affect the less energetic consonant sounds and their perception. In a worst-case scenario, temporal pauses between words and sentences may be filled with reverberant sounds. This makes speech understanding very difficult, especially for young children, who have not yet gained auditory closure to fill in gaps for comprehension of speech Nabelek and Pickett, 1974). The below table offers a comparison of studies from 1960 to 1994 which examined reverberation time in classrooms.

Table 3

Comparison of studies examining classroom reverberation times

Study	***Reverberation time in seconds***
Kodaras (1960)	0.40 to 1.10
Nabelek & Pickett (1974)	0.50 to 1.00
McCroskey & Devens (1975)	0.60 to 1.00
Bradley (1986)	0.39 to 1.20
Crandell & Smaldino (1994)	0.35 to 1.20

Note. Table 3 adapted from Crandell and Smaldino (2000).

Combined Effects of Noise and Reverberation

Excessive noise levels and reverberation, by themselves, are detrimental to the speech signal. When these two are combined, or if a classroom has both excessive noise levels and reverberation times over 0.4 seconds, there is a greater adverse effect on speech perception (Finitzo-Hieber & Tillman, 1978; Nabelek & Pickett, 1974). The following example is given by Crandell and Smaldino (2000), who stated that if an individual is listening to speech in a quiet room, the addition of a specific noise, such as the starting of a ceiling fan, might reduce that listener's perception by 10%. In another quiet room, the presence of some reflective surfaces, which encourage reverberation, might reduce perpetual abilities also by 10%. However, if both noise and reverberation were present in a room, their combined effects on speech perception might actually equate to a 40% to 50% reduction in speech perception. These synergistic effects appear to occur because when noise and reverberation are combined, reflections fill in the temporal gaps in the noise, making it more "steady state in nature" (Finitzo-Hieber, & Tillman, 1978).

There are three methods to reduce RT in the classroom. First, sound levels can be reduced. If ambient noise levels are kept to a minimum, reducing the speech signal will not help the children. In fact, the speech signal should be increased.

The second method is to reduce the volume of the room by either lowering the ceiling or reducing the floor area. This second method might be not be practical as it would require large funding. The third method is to modify a classroom is by lining

surfaces with sound-absorbing and sound-diffusing materials to reduce reverberation from hard, reflective, flat surfaces.

Distance from the Teacher (the Speaker) to the Student (the Listener)

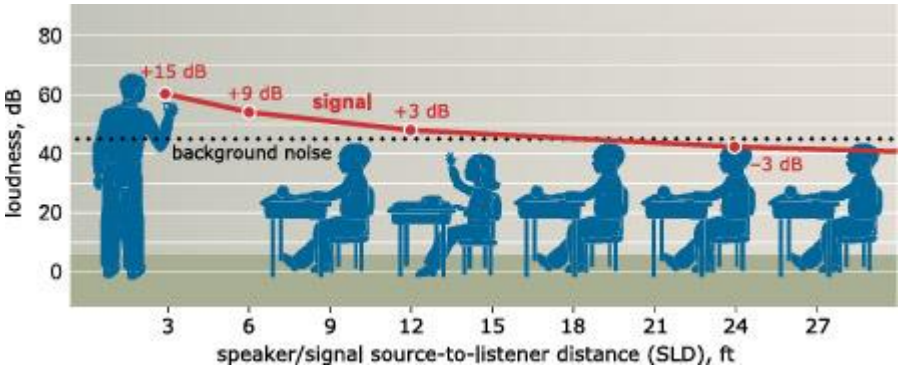

Figure 1. Distance from the teacher (the speaker) to the student (the listener). Adapted from McCarthy and Rollow (2005).

In a classroom, a major factor that affects speech perception is the distance from the teacher to the student. At close distances (less than two meters), the direct sound field (teacher's voice) predominates the listening field, which includes background noise. At close distances, sound waves are transmitted to the child from the teacher with minimal interference from surfaces in the room. The further the distance of the child from the teacher, the weaker the sound becomes, and the greater the probability that noise and reverberation will interfere with the speech signal.

Direct sound pressure follows the principal of the inverse square law, which states that sound level decreases 6 dB for every doubling of distances from the sound source. As the distance from the teacher to the student increases, the indirect, or reverberant field, begins to dominate the listening field. The following example will show how the distance from the teacher to the child affects hearing levels. With respect to distance from a teacher, if a student four feet away from the teacher hears the teacher's voice at a volume

of 70 dB, a student eight feet away would hear the sound at a volume of 64 dB, a student 16 feet away would hear the sound at a volume of 58 dB, and a student 32 feet away would hear the sound at a volume of 52 dB. As the decibel scale is a logarithmic scale, every 10 dB drop is perceived as a 50% drop in loudness. In the above example, with an almost 20 dB drop in sound level, children at the back of the class (32 feet away) would be hearing at about 25% of the volume level compared with children at the front of the class.

4 feet from the teacher	=	hearing at a volume of 70 dB
8 feet from the teacher	=	hearing at a volume of 64 dB
16 feet from the teacher	=	hearing at a volume of 58 dB
32 feet from the teacher	=	hearing at a volume of 52 dB

In most developing countries, the seating arrangements in classrooms are in rows (one behind the other). It is not uncommon to have eight to ten rows on either side of the class with a gap in the middle for the children and the teacher to move. A typical classroom would have anywhere between 35 to 60 children. The teacher usually stands at the front of the class near the blackboard when teaching. This type of seating arrangement may affect many children seated at the back who may have difficulties in understanding speech clearly. Children with temporary conductive hearing losses and children with permanent sensorineural hearing losses will be at greater disadvantage.

The indirect sound field begins to encroach on the direct sound field at what is known as the “critical distance” of the room. The critical distance of the room refers to the point in the room where the level of the direct sound and the level of the reverberant

sound are essentially equal. Operationally, critical distance (Dc) is defined by the following formula: $Dc = 0.20\sqrt{(VQ/nRT)}$.

In this formula, V = volume of the room in m^3, Q = directivity factor of the source (the human voice is approximately 2.5), n = number of sources, and RT = reverberation time of the enclosure at 1400 Hz. (Crandell & Smaldino, 2000). In an average-sized classroom (20' x 40'), with a commonly reported level of reverberation of 0.35 to 1.20 seconds, the critical distance of the room would be approximately three to four meters from the teacher (Crandell & Smaldino, 1994).

A student's distance from the teacher can have a direct impact on speech perception. Reverberation will have minimal effects on speech perception when the student is within the critical distance (the direct sound field). If there is sufficient intensity change in the reflected sound which interferes with the perception of the direct sound, these reflections can significantly reduce speech perception beyond the critical distance (the indirect sound field).

Speech perception scores decrease until the critical distance of the room is reached (Crandell & Bess, 1986). Beyond the critical distance, perception ability tends to remain essentially constant in the classroom. This finding by Crandell and Smaldino (1995), suggests that the only way to improve speech perception ability in a classroom is to bring a child closer to the teacher. The maximum speech perception is present only when a child is very close to the teacher. As a child moves away from the teacher, the speech perception ability is reduced. Having smaller classrooms, with fewer students per teacher, is not a possibility in developing countries without enough qualified and trained teachers. Other solutions include amplification either in the form of personal FM

amplification systems or a sound field system with several speakers strategically placed around the classroom. However, it is unlikely that schools in developing countries will have funds to implement either of these two systems.

In 2002 a study was conducted in New Zealand schools, coordinated by Oriole Wilson of the National Audiology center in New Zealand. The study included two groups of children. The first group of children, who had severe hearing losses, used FM systems; the second group of children, who had milder degrees of hearing loss, did not use FM systems. In speech tests, higher scores were achieved by the children with severe hearing losses using FM systems. The children with milder degrees of hearing loss scored worse. Using an all-classroom amplification system, such as a sound field system, will benefit all the children in the class, including children with mild hearing loss, children with auditory processing difficulties, children with learning difficulties, and children whose native language is different to the language taught in the school (Wilson et al., 2002).

CHAPTER THREE

Statement of the Problem

The two main factors which contribute to the auditory learning process of a child are the learning ability of the child, and the acoustical environment around the child. It is a well-researched fact that poor classroom acoustics cause difficulties in speech perception; hence, learning difficulties can ensue, especially in young school-aged children. The four main reasons that contribute to undesirable classroom acoustics are, a. excessive ambient/background noise levels, b. poor signal to noise ratios (SNR), c. extended reverberation time (RT), and d. inappropriate distance between the teacher and student. In classrooms, it is common to find evidence of more than one of these reasons affecting the academic progress of children. Speech perception becomes worse when there is a combination of these factors. Nearly all classrooms, especially those in developing countries, are not treated for acoustics. Especially classrooms in older school buildings, have inappropriate acoustic environments, particularly with respect to RTs and ambient noise levels (McCroskey & Devens, 1975). According to the Institute for Enhanced Classroom Hearing (n.d.), due to high levels of noise and reverberation, children with normal hearing only understand 70 to 75% of what is being said by the teacher. This can be considered as not hearing every fourth word of what is being said. Noise and reverberation can drastically reduce the ability to understand and learn as important contextual cues will be missed in the learning process, even by normal-hearing children.

In the case of hearing-impaired children, either with unilateral or bilateral hearing loss, poor classroom acoustics dramatically decrease the effectiveness of the learning

process. High reverberation and loud background noise levels can make learning very difficult in normal classrooms. For hearing-impaired children, both comprehension of speech, and understanding what is being said by the teacher and colleagues, are far below the 70% mark that was scored by their normal-hearing classmates. As the reverberation time increases and as the signal to noise ratio decreases, the speech recognition scores are affected dramatically for hearing-impaired children when compared with normal-hearing colleagues.

In addition to affecting speech perception of hearing-impaired children, poor acoustics can also be related to behavioral problems for children with auditory processing disorders, children with speech and language delays, children with attention deficits, children with a foreign native language, children with ear infections, and children with temporary hearing losses.

Developed countries have identified this problem and have started to implement standards to detect problematic classrooms, to design acoustic improvements, and to monitor classrooms. New school buildings must meet strict criteria with respect to reverberation time, ambient noise levels, and placement of special classrooms. Some schools are installing sound field systems and providing hearing-impaired children with personal FM systems. In developing countries, there are no standards with respect to acoustics in schools. Neither schools nor governments have funds to equip classrooms with sound field systems or provide personal FM systems.

The Center for Education of Hearing Impaired Children (CEHIC) in Dalugama, Kelaniya, Sri Lanka is a school for hearing impaired children, which is managed by the parents of these hearing-impaired children. The school is funded by charitable

organizations and individuals. Every month is a struggle to find funds to pay the teachers' wages and utility bills. Buildings are constructed of concrete, brick, and mortar, which all contain reflective surfaces. There are no treatments for sound absorption. No attention was given to classroom acoustics when this school was built. The classrooms have high slanting roofs without ceilings, thereby making the volumes of the classrooms large. There are only partial walls which separate classrooms, and classrooms have large windows. There are florescent lights and each classroom has a ceiling fan hanging from the roof. There are loud exterior noises from three sides of the property since the school borders the grounds of a university. On one side is a hostel for the undergraduate university students, and on another side there are university classes that conduct local dancing with loud chanting and drums.

The main purpose of this thesis was to study the acoustic properties of a classroom at CEHIC, and offer inexpensive and simple ways to reduce reverberation and ambient noise levels in this school for hearing-impaired children. To do this, room-modeling software, ODEON Room Acoustics**,** was used to virtually create a typical classroom from CEHIC. A recorded speech test was played in the virtual classroom and acoustic properties were measured along with speech intelligibility. The same classroom was then virtually modified using locally available materials which are inexpensive and widely available. Recorded speech was played back in order to measure the acoustic properties again, and also to test the speech intelligibility in the improved environment.

ODEON is a software program that has been specifically designed to simulate the interior acoustics of surfaces, rooms, and buildings. The software allows the user to change parameters of the room, such as the dimensions of the rooms, and also allows for

virtual changing of materials on present surfaces. Further, the software allows the user to change the placement and angle of the voice and sound source. Rooms and buildings can be precisely drawn using most Computer Aided Design (CAD) programs. The output of these programs, can be imported to ODEON acoustical architectural software in a universal .DXF or a .3DS format. Sound sources can be located in a variety positions, with added effects such as sound delay and decay times to replicate an individual speaking, either with or without an amplification system. Accurate results are calculated in real time making use of highly optimized hybrid algorithms. Early and late reflections are simulated and calculated. This software is able to handle scattering and diffractions of sound accurately. The surfaces in the room can be assigned different materials with absorption coefficients for frequencies ranging from 63 Hz to 8,000 Hz, as well as scattering and transmission properties for specified materials. Sounds can be played in the virtual room and listened to either by using headphones, or in the sound field by using speakers which offer surround sound reproductions. This offers the listener an understanding of how sounds would sound in reality. The software will also allow the user to view sound which escapes from the room, sound which enters into the room, and sound with both direct and indirect propagation in the room. The software will allow the user to measure reverberation times. It allows the user to visually see the interaction of the sound with surfaces, along with sound transmission and absorption by the surfaces. ODEON is a tool that can be used when designing buildings and classrooms in order to study acoustic properties. This software will allow designers to virtually study acoustics in a room, and then virtually modify the room and surfaces to achieve the most desirable results. Designers can experiment with different materials and placement of walls,

partitions, columns and objects so that reverberation time and ambient noise levels remain at a minimum, while SNRs are optimized.

Statistical Hypotheses

Null Hypothesis: The mean speech intelligibility score for the unmodified room will be equal to the mean intelligibility score for the virtually modified room.

Alternative Hypothesis: The mean intelligibility score for the modified room will not be equal to the mean intelligibility score for the virtually modified room.

CHAPTER FOUR

Method

Classroom

Photographs of the selected classroom at CEHIC are shown in Appendix D. The classroom is typical of all other classrooms. The classroom acoustics of this classroom were studied using the Acclastica (Scott & Yonovitz, 2000) program to measure acoustic variables.

Sketch-Up (Trimble Navigation, 2014) was used to render a three dimensional (3D) drawing of the classroom. The 3D drawings were then submitted to the Odean software architectural acoustics program which was able to model acoustic consequences of using various materials for the floor and ceiling, and walls (See Appendix D).

Acoustic Speech Testing Materials and Process

The Modified Rhyme Test (MRT) was recorded by a speaker of standard American English. English is the language of instruction in schools in Sri Lanka. The recordings were made in a sound-treated room. The recordings were made using a Sony (EC condenser) microphone and Cool Edit software. The MRT is a 50 word test given with a carrier phrase "mark the ---". The answer sheet contains six rhyming words for each of the test words. Two forms of the test were created (see Appendix B). These were WAV files.

Generation of the control and experimental test words.

Control: Materials used were those currently in existence.

Floor: Concrete

Ceiling: Asbestos Roof

Walls: Plaster board

Experimental: Materials were selected in Odean

Floor: Carpet

Ceiling: Acoustic ceiling panels

Walls: Curtains on windows

Two WAV files were generated using the ODEAN architectural software. These files were played to eight listeners who responded by marking the forms for the two conditions.

Listeners.

The research was approved by the University of Montana (UM) Institutional Review Board. Listeners were ten UM college students (ages 21-28, Mean=24.1, S.D=2.3). After receiving a hearing examination to confirm normal hearing (20 dB HL or better) each subject listened to the stimuli with TDH-39 earphones and MX-41 AR cushions. The stimuli were presented at 60 dB HL. Each subject marked on the answer form the word that was heard. The control and the experimental conditions were counterbalanced such that four subjects heard the control list fist and four other subjects heard the experimental list first.

CHAPTER FIVE

Results and Discussion

The classroom was measured for a number of acoustic parameters. These included the reverberation time, and the signal to noise ratio at different locations in the room.

No special problems occurred in the listening portion of the study. Each 50 word list took 12 minutes to administer for a total of 24 minutes. The percentage correct for each subject for the two conditions were calculated. A total of ten subjects participated. Half of the subjects responded to the control condition first, and half of the subjects responded to the "after room treatment" first.

Acclastica is a program that was written to measure classroom acoustics. The primary basis for the use of this software was to measure the noise levels and the teacher's voice. The Acclastica description of the actual classroom is shown in the following figure. Each of the numbered positions is a measurement location in the room.

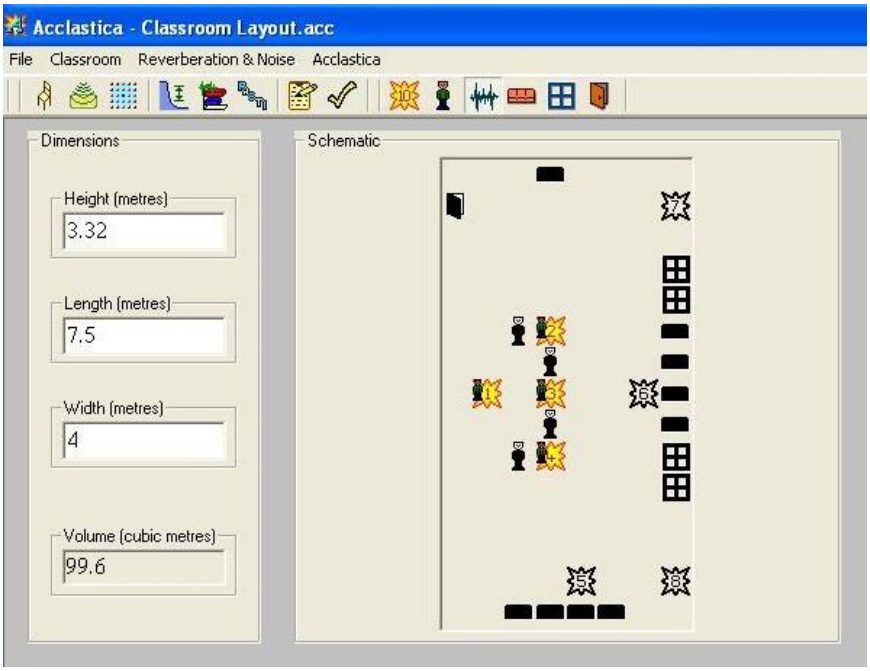

Figure 2. Example of Acclastica Classroom Layout screen.

For the listening condition the basic statistical measures are shown in the following table (Table 4). Figure 3 shows the graphic results of the intelligibility of the treatment condition. There was dramatic improvement in the fidelity of the speech stimuli. The overall discrimination improved from 74.6% to 96.4%. The reverberation time was significantly reduced from 1.96 sec to .32 sec. With informal listening the improvements were quite audible with respect to the reverberation time. Background noise would be significantly reduced with the acoustic treatments that were modeled and this would be expected to improve the signal to noise ratio even to a greater extent. The levels of improvement would likely allow a signal to noise ratio of better than +5 dB. The Acclastica measures indicated a signal to noise ratio of approximately -4 dB in the actual classroom.

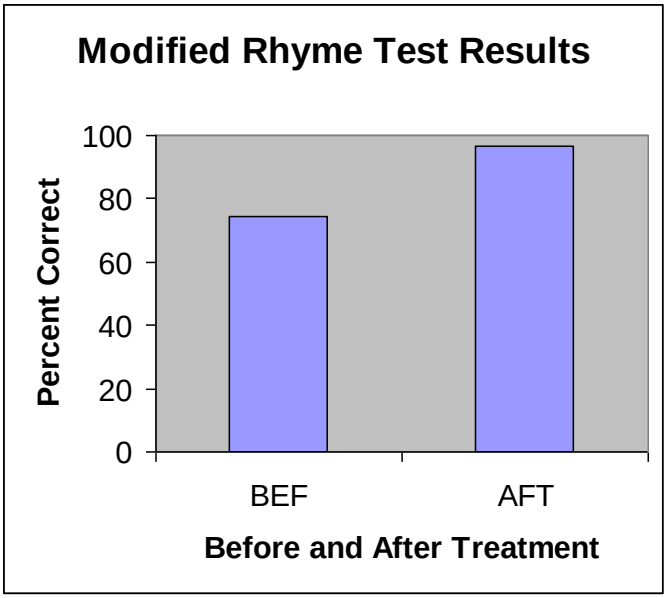

Figure 3. Speech Intelligibility of the Modified Rhyme Test for the Original and Modified Room

Table 4

The Central Tendency Statistics shown for the two conditions

	Before Treatment	After Treatment
MINIMUM	72.000	94.000
MAXIMUM	80.000	98.000
MEAN	74.600 *	96.400 *
S.D.	2.675	1.578
STD. ERROR	0.846	0.499

*p<.0001

The purpose of this study was to demonstrate the virtual improved speech intelligibility that can be achieved with relatively low cost materials to modify classroom acoustics. Expenditures in developing countries could be minimized using predictions from this type of model allowing the best cost-benefit.

Individual rooms may in fact require separate modeling scenarios because the acoustic characteristics of the room may change, especially where external noise occurs. A thorough analysis of the acoustics of the school and not a single room would be of great benefit for the determination of the overall expectation of improvement. In addition, the real benefit of improved acoustics is not just in speech intelligibility, but instead, in improved academic achievement of students, improved speech production and perception students. Methods of these assessments should be put in place.

CHAPTER SIX

Summary

This study has reviewed the literature on classroom acoustics and provided a rationale for improved learning through better hearing and audibility in the classroom. A real classroom at a School for the Deaf in Sri Lanka was used. This thesis has provided a basis for virtual modeling of a classroom and testing through the production of sound files (wav) before and after a classroom modification. The sound files were a speech discrimination task based on a word intelligibility test, the Modified Rhyme Test. The following conclusions can be made.

1) Both poor signal to noise ratios and long reverberation are detrimental to satisfactory intelligibility in the classroom.
2) Research has shown that this poor intelligibility has a very negative effect on learning.
3) A classroom can be drawn in 3D and submitted to a modeling program such as ODEAN. The speaker and listeners may then be placed into the virtual room and sound qualities, such as a speech intelligibility may be generated with the acoustic characteristics of the modeled room.
4) With relatively low-cost materials the room acoustics were significantly changed. The speech intelligibility increased from 74.6% to 96.4%.

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APPENDICES

APPENDIX A

Name of Principal Investigator Polwatte Krishantha Silva
Department Communicative Science and Disorders
University of Montana

Introduction

I am a graduate student from Sri Lanka who works with Hearing Impaired Children. I am a full time volunteer at Center for Education of Hearing Impaired children (CEHIC) in Dalugame Kelaniya, Sri Lanka. I would like to invite you to take part in this research. You can ask me any question(s) that you have and I will be more than happy to provide you with all the information you need. Before deciding to take part, if you have any doubts, I would prefer you talking to anyone that you feel comfortable with about this research. If you do not understand any part of this please ask me. Also you are very welcome to stop me at any time, as I explain, for further clarifications. If you have further questions later, you can ask me or Dr Yonovitz. I can be reached through the department at anytime.

Purpose of the Study

The aim of my thesis is to improve the acoustical challenges faced by the hearing impaired children in their classroom environment in Sri Lanka (which is a typical developing country). The classrooms are made from brick and mortar with a concrete floor. No special considerations were given when these classrooms were designed and built. They are not sound treated nor any special sound absorbing/non reflective materials used to build these classrooms. To learn under these conditions, it could be a challenge for any "normal hearing" child, but for a hearing impaired child with hearing aids this could be a nearly impossible situation

Interventions to be used

To find the best locally available materials at a low cost to sound treat classrooms in developing countries to improve the acoustics in classrooms for the hearing impaired children.

Reason for selecting you to participate in my study

I need "normal hearing" people to listen to a sound recording of untreated and treated classroom and let me know if there is a change in the acoustics of the classroom. Your participation is entirely voluntary. Your personal details will not be used outside this study. I will not share your identity or any information regarding you with anyone else.

Procedure and Duration of your participation

A psychoacoustic speech test called 'Modified Rhyme Test' will be used to measure the changes / improvements in the classroom. This is a multiple choice, easily scored speech test. It was found that the speech intelligibility scores obtained with this test remain consistent for a given communication system when tested nearly daily for a period of one month of one month using enlisted personnel as test listeners. The testing procedure only takes about 30 minutes per person, untrained listeners, record play back machine test

sheet and a pencil. Essentially, the test sound files will be played through the modeling software and normal hearing listeners will be used to determine optimal improvements.

A word at a time is spoken or played back from a recording. The listener has to pick the spoken word from a list of six words in front of him / her (example - mark the word heat and the following six words will be given to select the spoken word - meat, feat, heat, seat, beat, neat). The listener will be presented with two sets of 50 monosyllabic words, each word with six choices. The first set of 50 words will be recorded in the simulated untreated class room and the second set of 50 words will be recorded in the simulated sound treated classroom. In addition, a sound quality judgment will also be made. The accuracy of the selected words will be computed before and after the sound treating the classroom to show the benefits of sound treating the classroom.

Consent for Participation in Research

I volunteer to participate in a research project conducted by Polwatte Krishantha Silva from the University of Montana. I understand that the project is designed to gather information about classroom acoustics. I will be one of approximately 20 people being asked to participate for this research.

1. My participation in this project is voluntary. I understand that I will not be paid for my participation. I may withdraw and discontinue participation at any time without penalty. If I decline to participate or withdraw from the study, no one will be ever told.

2. If I feel uncomfortable in any way during the test, I have the right to decline to answer any question and/or to end my participation.

3. Participation involves listening to two sets of recording and answering few questions regarding the sound quality of the recordings. I am expected to spend approximately 35 to 45 minutes

4. I understand that the researcher will not identify me by name in any reports using information obtained and that my confidentiality as a participant in this study will remain secure. Subsequent uses of records and data will be subject to standard data use policies which protect the anonymity of individuals and institutions.

5. Faculty and administrators from my campus will neither be present at the test nor have access to raw notes or transcripts. This precaution will prevent my individual comments from having any negative repercussions.

6. I understand that this research study has been reviewed and approved by the Institutional Review Board (IRB) for Studies Involving Human Subjects: Behavioral Sciences Committee at the University of Montana.

7. I have read and understand the explanation provided to me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study.

8. I have been given a copy of this consent form.

_____	_____
My Signature	Date
_____	_____
My Printed Name	Signature of Polwatte Krishantha Silva

For further information, please contact:
Polwatte Krishantha Silva
(406) 552 - 9330
Dr Yonovitz
Department of Communicative Sciences and Disorders

APPENDIX B

Modified Rhyme Test
Word List

1	bat	bad	back	bass	ban	bath
2	bean	beach	beat	beam	bead	beak
3	bun	bus	but	buff	buck	bug
4	came	cape	cane	cake	cave	case
5	cut	cub	cuff	cup	cud	cuss
6	dig	dip	did	dim	dill	din
7	duck	dud	dung	dub	dug	dun
8	fill	fig	fin	fizz	fib	fit
9	hear	heath	heal	heave	heat	heap
10	kick	king	kid	kit	kin	kill
11	late	lake	lay	lace	lane	lame
12	map	mat	math	man	mass	mad
13	page	pane	pace	pay	pale	pave
14	pass	pat	pack	pad	path	pan
15	peace	peas	peak	peal	peat	peach
16	pill	pick	pip	pig	pin	pit
17	pun	puff	pup	puck	pus	pub
18	rave	rake	race	rate	raze	ray
19	sake	sale	save	sane	safe	same
20	sad	sass	sag	sack	sap	sat
21	seep	seen	seethe	seed	seem	seek
22	sing	sit	sin	sip	sick	sill
23	sud	sum	sub	sun	sup	sung
24	tab	tan	tam	tang	tack	tap

25	teach	tear	tease	teal	team	teak
26	led	shed	red	bed	fed	wed
27	sold	told	hold	fold	gold	cold
28	dig	wig	big	rig	pig	fig
29	kick	lick	sick	pick	wick	tick
30	book	took	shook	cook	hook	look
31	hark	dark	mark	lark	park	bark
32	gale	male	tale	bale	sale	pale
33	peel	reel	feel	heel	keel	eel
34	will	hill	kill	till	fill	bill
35	foil	coil	boil	oil	toil	soil
36	fame	same	came	name	tame	game
37	ten	pen	den	hen	then	men
38	pin	sin	tin	win	din	fin
39	sun	nun	gun	fun	bun	run
40	rang	fang	gang	bang	sang	hang
41	tent	bent	went	dent	rent	sent
42	sip	rip	tip	dip	hip	lip
43	top	hop	pop	cop	mop	shop
44	meat	feat	heat	seat	beat	neat
45	kit	bit	fit	sit	wit	hit
46	hot	got	not	pot	lot	Tot
47	nest	vest	west	test	best	rest
48	bust	just	rust	must	gust	dust
49	raw	paw	law	jaw	thaw	Saw
50	way	may	say	gay	day	pay

APPENDIX C

Noise Questionnaire

The scale comprised 16 items translated from the original scale and some additional items reflecting general attitudes toward noise. The initial questionnaire consists of 24 questions broken up into 3 sections as listed below using a 4-point likert scale.

- not at all (1)
- a little (2)
- quite a bit (3)
- very much (4)

The 12 sensitivity to noise questions are as follows;

1. Do you get annoyed by loud music?
2. Do you get annoyed by people speaking loudly?
3. Do you get annoyed by noise from others in your class?
4. Are you sensitive to noise?
5. During a usual day do you often think that it is noisy?
6. Do you try and not cause any noise?
7. Do you get annoyed by noise that you are causing?
8. Do you get annoyed by other people causing noise?
9. Are you more sensitive to noise than other people?
10. Do you have to accept some noise in a classroom?
11. Do you consider your class as noisy?
12. Does the noise level ever worry you?

The 7 annoyance by noise questions are as follows;

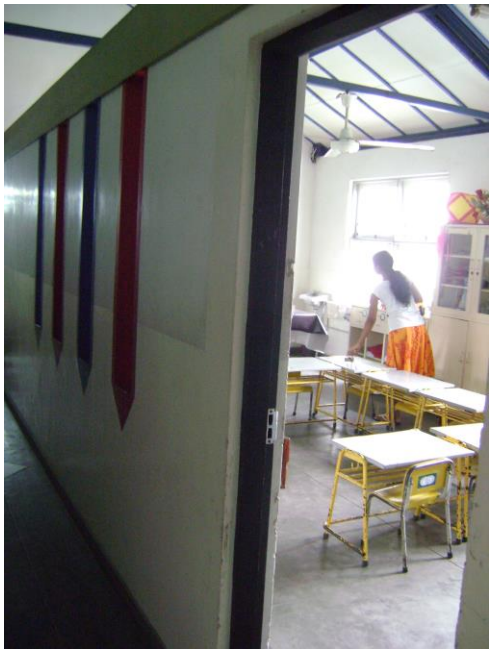
13. Do you ever get annoyed by noise during lessons?
14. Do you hear noise from other classrooms?
15. How often do you feel the level of noise in the classroom is too great?
16. Do you ever experience headaches at school?
17. Do you get upset by the noise from outside the classroom?
18. Do you ever look forward to going home to get away from the noise at school?
19. How often do you feel there is a lot of noise in the classroom?

The 5 questions about students hearing are as follows

20. Do you have problems with your hearing?
21. Do you hear the instructions clearly from the teacher?
22. Is the teacher's voice easy to hear from where you are sitting?
23. Does where you sit effect how well you hear the teacher's voice?
24. Do you find it difficult to hear the teacher's voice?

APPENDIX D

Selected Classroom Photographs








APPENDIX E

Odean Rendered Images (3D)