Soundfield technology in an innovative learning environment

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ABSTRACT

The Ministry of Education in New Zealand has a policy of upgrading all classrooms into Flexible Learning Spaces (FLSs) or Innovative Learning Environments (ILEs) by 2021. These are open-plan learning spaces where multiple 'classes' operate under the same roof and teachers cooperate with one another to task-share their lesson plans and the students can carry out set tasks in a range of environments. Careful acoustic design is required for these new spaces, with large amounts of acoustic absorption to manage reverberant build-up of activity noise. New Zealand schools invested significantly in soundfield technology over the past 15 or more years. The aim was to apply amplification technology to raise the teacher's voice well above the background noise, so it can be clearly heard by all students in the class. A significant number of studies have shown the benefits of this technology for a wide range of students. However, this technology cannot be deployed in the ILEs because these are shared spaces and the use of sound reinforcement in one area of the space results in an increased background noise level in other areas of the shared space. While there are many attributes promoted for flexible learning spaces, problems of high noise levels, distraction and over sensory stimulation, are a significant issue. This paper also considers technical solutions that can help restore the benefits of soundfield technology or at least mitigate the negative acoustics of ILEs. Possible solutions include assistive sound technology, were a wirelessly linked teacher's microphone, directly transmits their voice to a hearing aid like device worn by the students.

1. INTRODUCTION

Soundfield is the commonly used name to describe classroom amplification technology. This technology has become widely used in New Zealand over the past decade or more, in primary school classrooms and to a lesser extent, high school classrooms. Typically it consists of a head-mounted wireless microphone worn by the teacher and a receiver-amplifier connected to a set of strategically placed speakers around the classroom. When a teacher speaks into the microphone, their voice is amplified through the speakers. The purpose of a soundfield system is to raise the level of the teacher's voice in a classroom, relative to the background noise level, thus improving the speech intelligibility.

1.1 A brief history of soundfield in New Zealand

One of the first soundfield systems to be installed in New Zealand was in a primary school located on the edge of a large busy arterial highway intersection. Following very favourable feedback from early installations, soundfield technology was adopted by many schools through fund-raising activities and charitable grants. The systems were also found to benefit children classified with moderate learning needs who were present in the classroom and learning alongside their peers. Children with special education needs, including hearing impairment, attention deficit hyperactivity disorder, autistic spectrum disorder, Asperger's Syndrome, Down syndrome, visually impaired, and those experiencing development delay, were thought to benefit from the use of soundfield systems.

A considerable number of studies evaluated the efficacy of the use of soundfield systems, through direct testing of the children, as well as questionnaires from teachers. In general, positive education outcomes were claimed. These include studies by Vickers *et al.* (2013), McLaren and Humphries (2009), Heeney (2007) and Flexer (1997).

1.2 Open-plan classrooms

Open-plan classrooms are not a new concept. They were popular in some jurisdictions in the 1960s and 1970s because of education reasons and reform movement at the time (Shield *et al.*, 2010). However, difficulties were encountered with noise and visual distractions and in some cases remedial work was undertaken to convert them to single cell designs. There has be international resurgence in interest over the last decade in open-plan classrooms, under a number of different names, such as 'flexible learning spaces', 'modern learning spaces' and 'innovative learning environments'. These modern open-plan classrooms are large spaces where multiple teaching activities can occur at the same time and which can also be divided by partitions into smaller, more cellular spaces. A joint Organisation for Economic Co-operation and Development (OECD) and Department of Education and Skills (2006) publication stated that the need for flexible education learning spaces is required to accommodate the increasing range of teaching and learning methods, and technologies, which should include spaces for group as well as individual learning. However, these authors pointed out, when designing inclusive schools for students with special education needs, that:

All existing and future design should cater to students with special needs, but designers also need to consider *special schools for those children which require greater care.*

This is to ensure equal access to facilities and services.

2. CURRENT STANDARDS AND GUIDELINES FOR CLASSROOM ACOUSTICS

The current Australian and New Zealand standard for the acoustics of building interiors, AS/NZS 2107:2000 (Standards New Zealand, 2000) recommends a reverberation time of 0.4 – 0.6 seconds with 0.4 seconds recommended for students with special hearing requirements. This is identical to the recommendations of the design criteria for classrooms produced by the Ministry of Education (Building Research Association of New Zealand and Ministry of Education, 2007). Although these documents do not specifically identify the mid-frequency range reverberation time (T_{mf}[1]), other standards such as United Kingdom's Building Bulletin 93 (Department for Education and Skills (UK), 2004), do use this important parameter. Many standards and guidelines confirm that for children with special hearing requirements or for learning activities such as speech language therapy, a T_{mf} of 0.4 seconds is needed.

3. REVIEW OF SOUNDFIELD STUDIES

The study by Heeney (2007) is the most wide reaching study of soundfield systems in New Zealand. It involved 30 classrooms from five different schools and a representative control group. Heeney reported that the typical standard equipment was a boom microphone worn by the teacher whose voice is transmitted to an amplifier connected to four speakers. The use of this system improved the aural learning conditions which lead to enhanced learning outcomes and benefits in school aged children. Improvements were observed in aural comprehension, which resulted in increased achievements of all students, with a strong link to mastery of literacy.

In a more recent study in the United Kingdom, Dockrell and Shield (2012) predicted that if soundfield improved the audibility of the teacher's voice in the classroom, it would result in greater achievement over all subjects. They found no differences between students in amplified and non-amplified classrooms. Neither did they find evidence to support claims made about the way in which amplification could improve the learning environment. These authors rightly emphasize that these systems should be installed in acoustically optimal rooms. In many installations, the acoustic conditions of the room were not considered. In the study by McLaren and Humphries (2009), the room acoustics were evaluated as part of the trial and the classroom had a reverberation time of 0.4 seconds (including the T_{mf}) when measured in two locations in the room. As indicated by Dockrell and Shield, it is widely accepted that in learning environments with excessive reverberation, the ability of student to understand the teacher would be compromised and speech intelligibility would be reduced. They have presented the argument that soundfield systems may not be necessary in rooms which had optimal acoustics. However, the findings of McLaren and Humphries (2009) tend to discount this argument. Their pilot study involving children in a classroom from an economic deprived area, measured phonological discrimination with and without the use of soundfield in ambient conditions, and in the presence of introduced white noise, used to simulate the effects of heavy rain and similar types of noise. In degraded listening conditions, the use of the soundfield systems showed a substantive increase in students listening ability and performance.

3.1 Children experiencing special education needs

Soundfield systems have been promoted to benefit those with special education needs, especially those with auditory function difficulties, learning difficulties and those with sensory processing and/or auditory processing disorders. Children with these kinds of special education needs are now being referred to as those with '*special hearing requirements*'. These have been listed in a recent design guide for acoustics in schools (Institute of Acoustics and Association of Noise Consultants, 2015) and include students experiencing:

- Hearing impartment
- Language speech and communication difficulties
- English as second language speakers
- Visual impairment
- Sensory processing disorder
- Auditory processing disorder
- Global Developmental delay

This list encompasses a wide variety of specific disorders or impairments including: autistic spectrum disorder (ASD); Asperger's Syndrome; developmental verbal dyspraxia; attention deficit hyperactivity disorder (ADHD); Down

[1] The reverberation time, averaged over the octave frequency bands: 500 Hz, 1 kHz, 2 kHz

syndrome and even a cohort of giftedness (who like those experiencing ASD, can experience extreme sensitivities to noise and other sensory stimulation).

A number of studies have indicated that soundfield systems are beneficial to these students. Bennetts and Flynn (2002) conducted a small study with four children experiencing Down syndrome. Hearing loss is common in those with Down syndrome, most frequently presenting as mild conductive bilateral hearing loss. Bennetts and Flynn referred to a study by (Miller *et al.*, 1999) who found that one third of these children had a hearing loss at all times, with another third who never experienced hearing loss, and the remainder having fluctuating hearing loss. Any level of hearing loss in children is significant as it affects speech and language development. The use soundfield systems were found to improve the speech perception of the children in this study even, though it was not conducted in a real life classroom situation.

Arnhold and Canning (1999) indicated that many classrooms (of the time) were of a hostile acoustic environment for listening. Flexer (1997) stated that children were often expected to hear meaningful word/sound distinctions in unfavourable acoustic environments. This is disadvantageous to children, especially those with hearing impairments and other auditory function difficulties. The reference to a 'hostile environment for listening' was due to the unfavourable acoustic conditions, such as poor reverberance, high background noise levels, and distance from the teacher to the student. However, some of these issues could be of significance in the modern flexible learning environments with shared teaching spaces.

4. MINISTRY OF EDUCATION ADVICE ON FLEXIBLE LEARNING SPACES

The New Zealand Ministry of Education has issued a clear directive that all teaching spaces must progressively move to 'flexible learning spaces' (Minsitry of Education, n.d.). The directive states that schools need to upgrade learning spaces so they are flexible learning spaces. They must plan for any upgrades in their "*10 Year Property Plan*" and pay for upgrades using their "*5 Year Agreement funding*". Flexible learning space upgrades are 'priority 3' projects, which sits them below Health and safety (priority 1) and Essential infrastructure (priority 2).

Evidence provided as to the efficacy of these 'flexible learning spaces' in any school setting is very sparse and this is supported by Bisset (2014) who stated that despite a major drive to these environments, there is a paucity of literature into the perceived benefits or otherwise of the introduction of 'modern learning environments' to secondary schools in the New Zealand context. The Ministry of Education conducted a small learning studio pilot review with five schools in 2008, to develop a learning hub of the future. The review is available online (Ministry of Education, 2008). This publication was produced as a reference document for new and remodelled facilities. Initial feedback on the publication was reported as positive, with teachers and pupils reporting good quality acoustics for these new spaces. In the same publication under 'design guidance', it was reported that achieving the required sound isolation rating between the spaces, is difficult, whist providing the visual and spatial links. Further details were not given. The other comments in the publication related to quiet operating equipment such as mechanical ventilation and noise from rain on the roof.

Shield *et al.* (2010) have cited several studies where occupant density is the major factor in the mitigation and control of distraction from noise. They state that in open-plan classrooms,

> *…it is likely that intrusive noise arising from activities in neighbouring classbases, is critical is causing disturbance, distraction, and interfering with children ability to hear their teacher in an open-plan classroom.*

They conclude that this is far more significant than the type of acoustic insulation used, or the total area of space. They also state in a separate publication, that limiting the numbers of classbases in the unit to a maximum of three (and therefore reducing the numbers of students) significantly reduces the level of noise (Greenland *et al.*, 2009).

The Ministry of Education does not address the issue of noise distraction in its studio pilot review (Ministry of Education, 2008). Furthermore, there is no mention of whether any children with special education needs were involved in the pilot study and whether their needs and learning efficacy were assessed.

4.1 Teaching and learning for children with special education needs

The Ministry has also published a factsheet document (Minsitry of Education, n.d.) for support of students with special education needs in flexible learning spaces. This document appears to largely ignore the issues that a cohort of students with special education needs will face. Evidence provided in the document is sparse, with practically no information given on the research that the document claims to summarise. This document claims that soundfield amplification can be used to increase the signal-to-noise ratio, and quotes a New Zealand study with Down syndrome subjects to support the claim. While no reference is given, this is almost certainly the study published by Bennetts and Flynn (2002). This research was done in 2002 and not in a flexible learning environment. Therefore such claims of efficacy cannot be made unless a study is carried out in the real life situation of a flexible learning space. The Ministry document appears to assume that soundfield technology can be operated effectively in these learning environments. Practically, they cannot be used due to spill-over of sound into other learning activities running simultaneously in these environments. Furthermore, a significant limitation of the Bennetts and Flynn (2002) study is clearly articulated in the study itself, where it was done with only four students and in a clinical setting. The Ministry of Education document also indicated that an American study found that students with developmental special education needs, made fewer errors in a word identification tasks using a soundfield system. Again, no reference was given for this statement but it is likely to be from a one of a number of publications around the turn of the century, such as Flexer (1997). Studies of this period were not carried out in flexible learning environments but in typical cellular classrooms of the time, and therefore claims of their efficacy in flexible learning environments are not based on evidence.

4.2 Noise issues in flexible learning environments

An extensive report on noise in open-plan classrooms was conducted by Shield *et al.* (2010), which stretched back to the 1960s and 70s when open-plan classrooms first became popular. They were developed alongside new educational methods known as a child-centred pedagogic approach (where emphasises was placed on the child rather than that of the teacher). In 1976 these authors report that 10% of all primary school classrooms in the United Kingdom were open plan and in the USA, 50% of newly built schools were of open or semi open-plan design. However, in the later period around the 1970s – 80s, due to difficulties encountered in teaching in these spaces and criticism of the child-centred approach, there was a change in educational philosophy (to more traditional values). This led a trend back to conventional, cellular classroom design. However, by the early 21st century, open-plan classrooms were starting to become popular again.

Shield *et al.* (2010) points out that there have been very few rigorous studies that examined the effects of noise on learning performance in open-plan schools when compare to evaluations in single cell classrooms. While there were many advantages attributed to open-plan classrooms, these authors cited noise levels as being a significant disadvantage. Early studies were reported on by Shield *et al.* (2010), but care needs to be taken when comparing these historical noise levels as the sound level meter technology of the time was not nearly as advanced as it is today. Integrating sound level meters that measured time-average levels did not first appear until around 1987 and so any studies conducted before then would have not used a sound level meter which could measure time-average levels (dB $L_{Aeq\ (t)}$), the sound descriptor that is the basis for most modern standards. It was more common in those early studies to use what is known as centile or exceedance levels such as $L_{A10,}$ L_{A50} , L_{A90}, or L_{AS} (A weighted sound pressure, slow response time) depending on what was measured. These are quite different descriptors from the modern time-average descriptor (dB $L_{Aeq\ (t)}$) and therefore levels measured by these two different descriptors cannot be reliably compared. It was also common to quote sound levels in 'dBA' without a descriptor, which can be confusing in determining what was actually being measured. The measurements were often done manually by a read/write survey, as sound level meters of the time did not have logging functionality. For example, average levels as reported in a 1977 study by Weinstein and Weinstein (1977) were not the modern time-average level (dB$L_{Aeq(t)}$) descriptor. While the sound level meter and settings were not explained in the paper, it was probably set to dB L_{AS} which was commonly used at the time. A series of spot measurements were taken at 15 second intervals and these values arithmetically averaged. Such read/write methods were prone to high levels of human error when compared to using modern integrating sound level meters. Furthermore, when values of sound levels are stated, the time component is very import, as monitoring done over a short burst such as a few minutes can vary greatly from one taken over an hour or a working day. In addition, recognition of the importance of good acoustics in learning spaces, may mean that recently constructed learning spaces are more likely to have a high level of acoustic treatment to reduce reverberance to mitigate noise levels and to enhance speech perception and communication.

Intrusive noise, such as meaningful but extraneous speech was shown to be the most distracting type of noise, even when compared to similar noise levels of different sources (Knez and Hygge, 2002). Shield *et al.* (2010) have indicated that criteria for background noise levels in flexible learning environments must take into account distraction and annoyance, as well as effective speech intelligibility between the class bases (a huddle or group of students engaged in a particular learning) as opposed to others in the same spaces engaged in different activities.

Mealings *et al.* (2014) published a study on noise levels and related indices, such as speech transmission index (STI) scores and signal-to-noise ratio, in both flexible learning spaces (open-plan) and enclosed single cell classrooms, in early education. The STI scores and signal-to-noise ratios dropped dramatically in flexible learning spaces, to levels well below those recommended for the age group. These indices deteriorated further when noise from other activities increased. While there was a higher than recommended reverberation time in flexible learning environment they accessed (0.7 seconds compared to 0.5 seconds in the single cell learning space), the authors strongly question the use of flexible learning spaces in the education of young children.

4.3 Emerging flexible learning space configurations in New Zealand

Three distinct configurations of flexible learning spaces have been noted from initial investigations of recently constructed classrooms.

1. Rectangular - can be partitioned into three separate spaces
2. Cluster style with a central (common area) hub with class bases on the side
3. Split-level – with a large connected adjacent common space

Shield *et al.* (2010) have indicated that arranging classrooms in a linear rather than square or cluster configuration has been shown to achieve a greater level of attenuation because of the increased distance between adjacent sources of noise when compared to the other configurations.

The Ministry of Education explicitly states that schools will be free to design their own site specific solution that blends with their buildings and therefore a number of different styles can be expected in future.

4.4 Preliminary investigation of flexible learning space acoustics

In a preliminary investigation, reverberation times were measured in several unoccupied flexible learning spaces, by the integrated impulse response method (Bolund, 1978). This was carried out using a *01 dB Solo real time analyser* sound level meter with the trigger level set to 90 dB and a cap starter-gun used to generate the impulsive sound. All the environments had acoustic treatment applied to the walls and ceiling, and the measured reverberation times all fall into the optimal range of 0.3–0.5 seconds, especially in the T_{mf} band. Based on this, there appears a good recognition that quality acoustics are essential in these environments.

However, Shield *et al.* (2010) state occupant density is the major factor in the control of noise distraction and not acoustic insulation, or the total space provided. While there will be attenuation from acoustic insulation, they reported greater reductions in noise from the reduction of student numbers in the space. This means that acoustic treatment alone, cannot be relied on to effectively attenuate noise levels and improve indices such as STI and signal-to-noise ratio.

4.5 Soundfield technology in flexible learning spaces

In considering how soundfield systems might be used in flexible learning spaces, the following needs to be considered. Soundfield systems were designed for use in single cell classrooms and were never envisaged to be used in flexible learning environments. While authors (Shield *et al.*, 2010) reported on noise in open-plan classrooms, the same authors later reported on soundfield systems in classrooms (Dockrell and Shield, 2012) but did not include any open-plan classrooms with soundfield installations, in their later study. This was probably due the lack of cases to evaluate.

While a teacher can clearly move around, speaking as s/he goes, the installed speakers remain fixed. How will this work in a flexible learning environment? Are the amplifier-speakers to be made mobile and the teacher expected to move them from area-to-area in the learning hub or classbase? If each teacher had a mobile soundfield system, it is difficult to conceive how multiple units could work a flexible learning space due to sound spillage and each system picking the voices of the other teachers and also amplifying them. Practically, successful deployment of soundfield systems has only been demonstrated in single cell classrooms.

The Charlton-Smith Partnership (2005) stated that:

> *Hearing impaired pupils will be disadvantaged even more than normal hearing pupils in all of the tested schools given the responses to assessments of communication conditions, recorded period levels and reverberation times. This suggests that consideration should be given to methods of improving received signals for the hearing impaired including FM and sound-field / speech reinforcement systems.*

4.5.1 Assistive sound technology

It is clear that existing soundfield technology cannot be used in flexible learning spaces because it adds more noise to an already noisier space. This degrades the speech intelligibility for other groups/classes working in the same space that are not using the technology. So are there any technological solutions to this that can reinstate the benefits of soundfield systems for classes in flexible learning spaces? Many modern hearing aid devices have the ability to wirelessly connect directly to electronic sound sources, enabling the wearer to directly receive the sound without having to play it back through external speakers. Almost all of these wireless systems use Bluetooth technology but this is limited to one-to-one connections, rather than one-to-many (broadcast) connections required in classroom settings. However, some makers of hearing aid devices produce hearing assistance devices for children with normal hearing (Phonak, n.d), but who are easily distracted by background noise, such as those with unilateral hearing loss (UHL), auditory processing disorder (APD), autism spectrum disorder (ASD) and attention deficit hyperactivity disorder (ADHD). These devices are discrete and are worn behind the ear; they enable the teacher's voice to be sent directly to the wearer's ear. Once the devices are paired with the wireless microphone worn by the teacher, the teacher can be anywhere within the class and be heard by the wearer. Although there are limitations to the current implementations of this technology, they demonstrate a potential way forward for reinstating the benefits of soundfield technology in flexible learning spaces.

5. DISCUSSION

There is a generally held belief that the new flexible learning spaces will benefit a great many children, especially those who can exploit the attributes that these facilities provide. Few would argue with this statement and those flexible learning spaces that have been observed, are attractively decorated with a very pleasant, homely atmosphere.

However, there is emerging evidence that the flexible learning space concepts come with their own set of adverse consequences, such as noise and increased level of distraction. Soundfield systems were introduced as an assistive technology in regular cellular classrooms and on balance these systems have been found to assist student learning. This was notably the case for those experiencing hearing deficits or other special requirements along with studying in environments with less optimal listening conditions.

A number of studies have demonstrated that young children are immature listeners and do not perform as well in noisy settings when compared to older children and adults. Furthermore, children who are non-native speakers of the language being used, as well as those experiencing learning and hearing impairment, developmental delay and deficits in speech and communication (i.e. special hearing and learning requirements), will perform poorly in flexible learning spaces. This is because they have not or cannot develop the necessary strategies to understand speech and communication in noisy settings (Nelson and Soli, 2000) (McLaren, 2008) (Vickers *et al.*, 2013). A study by Soli and Sullivan (1997) found that effective listening in the presence of noise does not completely develop until adolescence.

A number of questions have been raised about those children with high and complex needs in modern classrooms. Children on the autistic spectrum and others experiencing sensory processing disorder, are known to have major issues in noisy and over-stimulating environments. This is an issue which has not been addressed in the information provided by the Ministry of Education. Furthermore, aspects of the information provided by the Ministry are clearly incorrect with respect to the use of soundfield system in flexible learning spaces. It is very concerning if policy decisions are being made based on flimsy evidence when the most vulnerable of children are not adequately considered.

There have been discussions about the delivery of education being 'person-centred', where Breakley (2006) promoted the provision of education being matched to the needs of the person. However, McLaren (2013) questioned if it was ever reasonable to expect a child with serious sensory processing difficulties to be able to manage in a noisy, unpredictable and over-stimulating environment. He suggested that to place a child with such level of need in a noisy and over stimulating environment cannot match the definition of being person-centred in any form. Is this another case in which these students are expected to be slotted into a readymade provision?

The Minister and Ministry of Education have a duty and responsibility to ensure that any radical changes in education delivery are carefully considered and especially as to how it will affect the most needy and vulnerable children. Investigation and pilot studies must investigate the full range of children that will use these new spaces, how their needs will be met and how any assistive technologies that they need, can be used in these new environments. There is little reported evidence of this being done from the literature or information provided by the Ministry or in the international literature.

Unless the Minister and Ministry are going to provide an increased number of special education or alternative facilities for any children which cannot learn or cope in these new environments, their future in the education system could be in jeopardy.

6. CONCLUSION

The New Zealand Ministry of Education has embarked on an aggressive policy to require schools to progressively convert all learning spaces into the new modern learning environments. This policy has been implemented with little regard for the very large investment in sound field technology made by many school boards and charitable grants over the years. These systems, which were only ever designed to operate in single cell classrooms, cannot be used with multiple systems operating in the same environments .

Studies and literature on these systems has found on balance substantial benefits in the use of these systems which will be lost unless technological solutions can be found implemented in these modern learning environments. Concerns have also been raised about the effects on children with a wide range of auditory and intellectual impairments to cope and effectively learn in noisy and overstimulating environments.

REFERENCES

Arnhold , P & Canning, D 1999. 'Does classroom amplification aid comprehension', . *British Journal of Audiology,* 33**,** 171-178.

Bennetts, L & Flynn, M 2002. Improving the classroom listening skills of children with Down Syndrome by using sound-field amplification. *Down Syndrome Research and Practice,* 8**,** 19-24.

Bisset, J-A. 2014 *The move to modern learning environments in New Zealand: Step forward or smokescreen?* Master of Educational Management and Leadership, Unitec Institute of Technology.

Bolund, K 1978. On the use of the integrated impulse response method for laboratory reverberation measurements. *Journal of Sound and Vibration,* 56**,** 341-62.

Breakley, C 2006. Inclusion, being person centred and further education. *Awares Online Conference.* Online at http://www.awares.org/conferences.

Building Research Association of New Zealand & Ministry of Education 2007. *Designing quality learning spaces: Acoustics.,* Wellington, Ministry of Education. Available: http://www.minedu.govt.nz/NZEducation/EducationPolicies/Schools/PropertyToolBox/StateSchools/Design/ModernLearningEnvironment/MLEDQLSStandards.aspx.

Charlton-Smith Partnership 2005. Design for educationally appropriate acoustic characteristics in open plan schools: Research report to The Scottish Executive. Carnoustie, Scotland: Charlton-Smith Partnership. Available: http://www.gov.scot/Resource/Doc/920/0020505.pdf.

Department for Education and Skills (Uk) 2004. *Acoustic design in schools: Building Bulletin 93,* London, The Stationery Office.

Dockrell, J & Shield, B 2012. The impact of soundfield systems on learning and attention in elementary school classrooms *Journal of Speech, Language and Hearing Research* 55**,** 1163-1176.

Flexer, C 1997. Individual and sound-field FM systems. Rationale, description, and use. *Volta Review,* 99**,** 133-162.

Greenland, E, Shield, B & Dockrell, J. Control of speech intellgiblity in open plan classrooms. Euronoise 2009 2009 Edinburgh, Scotland.

Heeney, M. 2007. *Classroom soundfield amplification, listening and learning* PhD, Unversity of Newcastle.

Institute of Acoustics & Association of Noise Consultants 2015. *Acoustics of schools: A design guide.,* United Kingdom., Institute of Acoustics (IOA) and Association of Noise Consultants (ANC). Available: http://www.ioa.org.uk/sites/default/files/Acoustics%20of%20Schools%20-%20a%20design%20guide%20November%202015_1.pdf.

Knez, I & Hygge, S 2002. Irrelevant Speech and indoor lighting: Effects on cognitive performance and self-reported affect. *Applied Cognitive Psychology,* 16**,** 709-18.

McLaren, S. 2008. *Noise in early childhood education centres - the effects on the children and their teachers.* PhD, Massey University.

McLaren, S 2013. Is inclusive education right for every child? An account by a parent of a child with high and complex needs due to autism spectrum disorder. *Kairaranga (A New Zealand journal of education practice),* 14.

McLaren, S & Humphries, S 2009. A pilot study of a soundfield system and acoustical quality in a New Zealand school classroom. *New Zealand Journal of Educational Studies* 44.

Mealings, KT, Buchholz, JM, Demuth, K & Dillon, H. An investigation into the acoustics of an opn plan compared to enclosed kindergarten classroom. . Inter-noise 2014, 2014 Melbourne, Australia. Available: https://www.acoustics.asn.au/conference_proceedings/INTERNOISE2014/.../p821.pdf.

Miller, JF, Leddy, M & Leavitt, LA 1999. *Improving the communication of people with Down syndrome,* Baltimore, MD, USA., Brookes Publishing Co.

Ministry of Education 2008. Learning Studio Pilot Review. Wellington Ministry of Education.

Minsitry of Education n.d. Flexible learning spaces in schools Wellington: Ministry of Education. Available: http://www.education.govt.nz/school/property/state-schools/design-standards/flexible-learning-spaces/.

Nelson, PB & Soli, S 2000. Acoustical barriers to learning: Children at risk in every classroom. *Language Speech and Hearing Services in Schools,* 31**,** 356-361.

Organisation for Economic Co-Operation and Development (Oecd) & Department of Education and Skills, U 2006. *Twenty first century learning environments.* , OECD Publishing. Available: http://www.westernsprings.school.nz/New%20School/becoming_a_new_school/Resources/21st%20Century%20Learning%20Environments%20-%20OECD.pdf.

Phonak. n.d. *Rodger Focus* [Online]. Available: https://www.phonakpro.com/com/en/products/wireless-accessories/roger-focus/overview-roger-focus.html.

Shield, B, Greenland, E & Dockrell, J 2010. Noise in open plan classrooms in primary schools: A review. *Noise and Health,* 12**,** 225-234.

Soli, S & Sullivan, J 1997. Factors affecting children's speech communication in classrooms. *Journal of the Acoustical Society of America.,* 101.

Standards New Zealand 2000. *Australian and New Zealand Standard AS/NZS2107:2000 - Recommended design sound levels and reverberation times for building interiors,* Standards New Zealand.

Vickers, DA, Backus, BC, Macdonald, NK, Rostamzadeh, NK, Mason, NK, Pandya, R, Marriage, JE & Mahon, MH 2013. Using personal response systems to assess speech perception within the classroom: An approach to determine the efficacy of sound field amplification in primary school classrooms. *Ear and Hearing* 34**,** 491-502. Available: DOI 10.1097/AUD.0b013e31827ad76f.

Weinstein, D & Weinstein, CS 1977. Noise and reading performance in an open space school. *Journal of Educational Research,,* 72**,** 210-13.