

Open Plan Classrooms, Noise & Teacher Personality

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Contents

Foreword	4
Executive summary	5
Glossary	12
1.0 Introduction to report	13
1.1 Objectives	13
1.2 Approach	13
2.0 Teacher personality profiles	15
2.1 Early studies	15
2.2 Personality trait studies	15
2.3 Teacher personality and noise	17
2.4 Conclusions of teacher personality	17
3.0 The changing nature of pedagogy	19
3.1 New thinking	19
3.2 New classroom activities	20
4.0 Classroom design progression	23
4.1 The rise and fall of open plan classrooms	23
4.2 Innovative Learning Environments	26
5.0 Classroom acoustics	32
5.1 Development of acoustic standards	32
5.2 National standards for traditional classrooms	32
5.3 Additional requirements for open plan	35
5.4 Acoustic design of future schools	38
6.0 Impact of noise in classrooms	39
6.1 Effect on students	39
6.2 Effect on teachers	40
7.0 Impact of open plan classrooms	42
7.1 Acoustic field measurements	42
7.2 Effect on teacher performance	45
7.3 Effect on student performance	46

8.0	Open plan classroom solutions	49
8.1	Multiple solutions	49
8.2	Management & behaviour solutions	50
8.3	Layout solutions	52
8.4	Furniture solutions	54
8.5	Absorption solutions	56
9.0	Conclusions and next steps	58
10.0	References	59

Foreword

In response to recent research identifying that deep learning and student fulfilment is most likely to occur in innovative open and semi-open learning spaces, many schools are now increasingly likely to be designed to reflect this ongoing approach. The success of this modern approach to learning spaces is dependent on several factors, but two most commonly affected are the teachers and the acoustic environment.

This report by Workplace Unlimited is an important addition to existing literature exploring the need for optimal acoustic design and teacher change. This includes an investigation into the research undertaken so far regarding: traditional classrooms, open learning spaces, noise and the potential implications of different teacher personalities.

The importance of good acoustics in learning spaces has long been recognised. Studies have shown that teachers' well-being and student behaviour, and resultant attainment, can be correlated to the quality of the acoustic environment. Ecophon have commissioned this report in the belief that good acoustics, and therefore excellent speech intelligibility, is essential to the success of these large volume learning spaces. We also believe that we need to develop a deeper understanding of the broader human centric design aspects, to ensure these learning environments are sustainable long-term. This is especially true from the teacher perspective, in what can be an exciting, but challenging ongoing pedagogic change.

As classrooms adapt to the ongoing pedagogic evolution worldwide, traditional teacher lead instruction moves, instead, to student centred learning activities. The result is usually greater teacher student collaboration and engagement. This change, whilst positive, can, if not planned for, lead to higher noise levels, which has been proven to increase stress and reduce concentration.

Based on previous evidence in the workplace, around different personality profiles in offices, we would now like to understand more about the potential influence of teacher personality profiles. We are particularly interested in the context of increased requirements for collaborative teaching and learning activities in open learning spaces.

As an important resource, teaching has some clear challenges and needs to address issues around workload and teacher well-being. Focusing on this personality aspect and how the operating effectiveness of teaching can be better understood, may be a missing but, important part of creating a teaching harmony.

We believe this report can help to give a broader understanding of the potential impact of teacher personalities, which can provide future school leadership and management with insightful knowledge when the time comes to organise and design future learning environments. We believe this, combined with an activity based acoustic design approach, will support future learning environments which can deliver sustainable learning outcomes, health and wellbeing of all occupants not only the teachers.

Colin Campbell

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Executive summary

Introduction

The uptake of the Innovative Learning Environments (ILE), the modern adaptation of open plan schools, is increasing in parts of Europe (particularly Scandinavia) and the Antipodes (Australia and New Zealand). The new learning environments have resulted in mixed success due to issues with: acoustics, teaching practices, coordination of activities, and the management of the space, teachers and students.

Ecophon commissioned Workplace Unlimited to conduct a literature review (of Circa 200 papers and reports), to understand the key issues of open plan classrooms and how they may be resolved, with a focus on acoustic solutions. In our recent study of psychoacoustics, related to office noise, it was found that personality affects how well office workers can tolerate noise. Ecophon was therefore interested to know if that is also the case for teachers in classrooms, both traditional and open plan.

This literature review is aimed at testing several pertinent hypotheses:

1. Any identified issues with noise in open plan classrooms can be partially mitigated through design improvements and acoustics solutions.
2. A teacher's personality profile, in particular extroversion, will enable them to better cope with noise in the (open plan) classroom.
3. Organisational factors such as teacher training, coordination of the space, timetable administration, changes in pedagogy, and managing student behaviour will help resolve any identified issues with open plan classrooms.

Whilst there are studies of the personality of teachers and studies on open plan classrooms, we found no research exploring the overlap between the two subjects. We did however find a few studies linking personality of teachers to teaching style, and a few exploring the impact of personality on voice control in the classroom.

Teacher personality profiles

The impact of teacher personality has been discussed for some time. Some believe that teacher personality profiles need to be recognised to allow educators to be proactive in determining a better fit for students and teachers. For example, Reid (1948) notes that when he asked university students what they thought were the characteristics of the best lectures, "the answers often reflected opinions about the character and personality of the lecturer" rather than the environment *per se*.

The Big Five Inventory (BFI) is often referred to as OCEAN because it has five dimensions: Openness, Conscientiousness, Extroversion, Agreeableness and Neuroticism. Studies have shown that, when assessing their teachers, students predominantly favoured Conscientiousness, followed by Emotional Stability (the antithesis of Neuroticism) and Agreeableness. In terms of teacher performance there are mixed research results. Teachers scoring higher on Extroversion and those low in Neuroticism are more efficient than their counterparts. However, Extroversion is not a definite requirement for teachers as introverts can adopt coping strategies and tap into "free traits" i.e. the ability to act out of character for a limited period of time. Students achieved higher Texas Assessment of Knowledge and Skills (TAKS) scores when instructed by teachers rating higher in Conscientiousness and/or Agreeableness whereas the more Neurotic teachers resulted in lower student TAKS scores. In lay terms, it appears that teachers who are diligent, more able to deal with stress and more approachable are more successful.

Our own research in offices, building on that of others, revealed that those higher in Extroversion and Emotionally Stability fared better in noisy and stimulating environments than those higher in Introversion and Neuroticism. The current literature search did not reveal any significant studies exploring the impact of teacher personality on dealing with noise in the classroom. Many studies showed an effect of noise on teachers, but personality was not considered as a significant factor. Nevertheless, in combination with the broader requirements stated previously, teachers high in Conscientiousness and Emotional Stability traits appear to be at an advantage.

The changing nature of pedagogy

Pedagogy, the theory and practice of teaching, has evolved over time. The discipline and practice of rote learning in Victorian schools has been replaced by alternative teaching styles, even though 'chalk and talk' style teaching is still prevalent in many UK classrooms. Scholars such as Maria Montessori in Italy and John Dewey in the USA supported the notion of child-centred learning and developed educational theories that form the basis of modern education.

Pedagogical theory can be framed as three key stages: behaviourist, cognitivist and constructivist (Dovey & Fisher, 2014). Behaviourist approaches are traditional didactic teacher-centred pedagogy, whereas cognitivist approaches involve moving from lower-order to higher-order thinking, and constructivism is largely based on the application of knowledge in the student's world. Constructivist pedagogies were developed in the 1970s, after the early adoption of open plan schools failed. The constructivist approach, now often referred to as student-centred learning, is increasingly being adopted by educational institutions, particularly in parts of northern Europe and the Antipodes. Furthermore, the Gradual Release of Responsibility (GRR) model, developed in the 1980s, is a structured method of pedagogy which gradually shifts learning responsibility from the teacher to the student, creating autonomy and independence.

Many educational commentators have categorised the types of activity that take place in the modern classroom. For example, Dovey & Fisher (2014) developed a list of six key teaching practices based on a constructivist (student-centred) pedagogy. Their typology, is a continuum of group size and activity: presentation (25-150 students), large interactive (25-75), medium interactive (10-25), creative Interactive (10-25), small interactive (2-5) and reflection (1 student).

Classroom design progression

Open plan classrooms gained popularity in the 1960s to 1970s following the post-war educational reform movements. "Before this time, pedagogy largely consisted of didactic teaching, with the teacher speaking in a fixed position at the front of the class and the pupils listening from formal rows of desks. The years following the second world war witnessed a breakdown of this formality, as education began to focus on the individual needs of the pupils rather than the 'convenience' of teachers." (Shield, Greenland & Dockrell, 2010).

There were many supporters of the evolving change in pedagogy and by the mid-1970s, 10% of all primary schools in England and Wales were open plan, whereas in the USA over 50% of new build schools were either fully or semi-open plan. These classrooms were found to be difficult to teach in, so there was a return to the more traditional enclosed classroom and many open plan schools reverted to conventional classrooms. The reason for failure of the early open plan schools is not just due to a poor or noisy setting for teaching but also due to: cost and space constraints, an unwillingness to change the pedagogy, lack of teacher training, poor timetabling and student behaviour.

Successful open plan design and teaching style are interrelated. A physical change alone will not instigate a change in pedagogy and the physical change is unlikely to succeed without first

changing the teachers' approach to education. As well as the recorded pitfalls of open plan, there are also success stories. Studies show that open plan schools lead to increased interaction among teachers and increases their autonomy, satisfaction and ambition. Teachers also say they enjoy teaching in open-plan schools and would not return to a conventional building. From a student perspective, open plan appears to enhance students' feelings of autonomy, willingness to take risks, and persistence at a task plus "Students also tend to meet with more teachers during the day to engage in a greater variety of activities and to move around more" (Weinstein, 1979).

De Werkplaats Kindergemeenschap (The Workplace children's community) in Bilthoven is one success story. Teachers like that that they can see at a glance what all the children are doing, and the pupils in the various classes switch around, which enhances their feeling of togetherness. Open plan schools in Finland have not always proved successful but the country's desire for more open plan classrooms is a direct reflection of its national curriculum, which rejects traditional academic silos and instead favours more student autonomy and cross-curricular connections, whilst eschewing standardised tests.

Some open plan classrooms have higher densities of students, probably for economic reasons, and the higher densities result in lower student achievement (Glass & Smith, 1979). Barrett & Zhang (2009) note several key considerations in classroom design: 1. identify the proposed activities that are likely to take place, 2. size based on determining the average number of children involved with each activity, and 3. the layout will need to be planned to accommodate activity modes.

Early open plan schools often confused flexibility with openness and were poorly matched to new learning practices. We are now seeing a substantial re-emergence of student-centred pedagogy. Instead of simple open there are assemblages of different spaces grouped in clusters with meeting rooms, learning commons and traditional classrooms in a myriad of new arrangements (Dovey & Fisher, 2014). Such hybrid spaces are termed Innovative Learning Environments (ILEs).

Just like in offices, classrooms and school layouts can no longer be simply categorised dichotomously as enclosed or open plan. The five cluster types of learning spaces, developed by Imms, Cleveland, & Fisher (2016), have been adopted in a number of recent research studies. Their framework of five cluster types are a loose continuum from the traditional to the fully open plan: A) traditional closed classrooms entered by a corridor, B) traditional classrooms with breakout space, C) traditional classrooms with flexible walls and breakout space, D) open plan with the ability for separate classrooms, and E) open plan with some adjoining spaces.

Traditional classrooms are Types A and B whereas open plan is Type E and ILEs tend to be Types C and D. As a school becomes more open (Types C, D and E) it also becomes more exposed and possibly noisy, which may constrain the activities it was originally designed for. Dovey & Fisher (2014) found that "the most open of plans are often not the most adaptable because they constrain choice" but "for budgetary rather than pedagogical reasons, are more likely to be supported." The semi-enclosed and more flexible cluster types (C and D) appear to be the optimal solution in terms of construction, cost, use and success.

A study of 12 learning environments with a mixture of the five cluster types found that all the learning environments were supportive of a range of teaching practices (Cleveland, Soccio & Love, 2016). However, small group work was challenging in the more traditional classrooms (Type A and B) and they were found to be less supportive of teacher supervision. In contrast, whole class work was identified as challenging in the more open plan schools (Type E).

A survey was carried out on the mind frames of 6,000 teachers in Australia and New Zealand (Imms *et al*, 2017). A teacher's mind frame reflects how they think and act when engaged in

teaching. The study found that teachers in schools with a higher prevalence of traditional classrooms had a lower mind frame. Furthermore, students in traditional classrooms also exhibited less deep learning characteristics. They also discovered that in traditional schools where the teacher-centric approach dominates there are much lower teacher mind frames and student deep learning. In contrast, in traditional schools where other teaching approaches dominate, the teacher mind frames and student deep learning are much higher. So, both the type of space and the type of activity affect teacher performance and student learning.

Classroom acoustics

Many books were written on the design and construction of schools at the turn of the 20th century, but Baker (2012) suggests that architects did not devote time to designing classrooms for acoustic performance until the late 1940s. For example, Baker refers to Luce (1949) who states that four basic acoustic conditions are required for schools: 1. sufficiently low level of background noise, 2. adequate separation of successive sounds (reverberation control), 3. proper distribution of sound within the space, 4. sufficient loudness of sounds. Unfortunately, Luce reported that these acoustic principles were not implemented by the designers of schools constructed at that time. The acoustic mantle was picked up again when research conducted in the 1980s and 1990s greatly contributed to industry understanding of the necessity of good acoustical conditions in classrooms (Baker, 2012). Since then many countries have introduced national standards for acoustics in schools and more recently more detailed and/or stringent best practice guidance has been introduced through BREEAM, LEED, WELL and by the IoA and ANC.

National standards use different acoustic criteria, but in general ambient noise levels need to be maintained at a reasonable level (L_{Aeq} 35-40 dBA), reverberation times minimised ($RT < 0.5$ s), speech intelligibility improved in the classroom ($STI > 0.6$), but reduced between classrooms (< 0.2), and speech-to-noise ratio should be increased ($SNR + 15$ dB). However, noise is commonly defined as 'unwanted sound'. So, in the classroom, the sound level is only considered noise if found distracting by the teacher or students for the task in hand. Similarly, higher sound levels are likely to be more acceptable for group work or less focussed tasks. It is a pedantic point, but nevertheless whilst most standards and research refer to noise levels they actually mean sound level (and L_{Aeq} is defined as a sound level, not noise, measurement).

Despite the introduction of various guidelines over the years, many schools continue to be built which are acoustically 'unfit for purpose'. Even after the introduction of *Building Bulletin 93 Acoustic Design of Schools – A Design Guide (BB93)* some new schools are failing to comply with minimum statutory requirements on acoustics. One study found that the L_{Aeq} in 67% of the surveyed classrooms in 12 UK schools had noise levels above the BB93 recommendation.

"From an acoustic perspective it is quite straightforward how to secure a good acoustic environment in traditional classrooms, depending on the volume, geometry and construction of the materials ... However, moving from traditional cellular classroom creates more challenges around the sound environment when doors and walls are removed" (Campbell, 2017a). The USA standard on classroom acoustics, *ANSI 12.60*, actively discourages the use of open plan classrooms. In contrast, the New Zealand MoE (2016) offers four key acoustic parameters for open plan schools: 1) RT of 0.5-0.8 seconds for flexible learning spaces and 0.4-0.5 for breakout and meeting spaces, 2) a Sound Transmission Class (STC) value of 50 between walls of separate flexible learning spaces and breakout spaces. 3) a minimum Impact Insulation Class (IIC) performance of 55 between floors and 4) 35-45 dBA L_{Aeq} for flexible learning, breakout and meeting spaces.

Impact of noise in classrooms

The effect of noise on student behaviour and attainment is complex, depending not only on classroom conditions and individual factors concerning the child but also on the task being

undertaken and the corresponding cognitive demands (Shield *et al*, 2015). Whilst one study found no differences in reading performance under quiet and normal background noise levels, other researchers have found classroom noise to negatively affect students' mental focus, memory and recall time, and exam performance.

The majority of studies which have examined the impact of noise on teachers, mostly find an effect on teacher voice disorders, or dysphonia, with some teachers experiencing problems so severe that their working ability is questionable. Very few studies of noise in classrooms refer to personality, one study found that the majority of those with functional dysphonia are introverts. However, an earlier study did not find any significant correlation between the Extroversion and voice problems.

Impact of open plan classrooms

In a detailed review of historic studies carried out over 40 years, four studies made a direct comparison between noise levels in open plan and enclosed classrooms (Shield, Greenland & Dockrell, 2010). Only one found significantly higher average noise levels in open plan classrooms and that was in a fully open plan area with 100 students, which is not typical of today's open plan designs.

In a study of 12 UK primary schools including 42 open plan classbases (classes taking place within open plan), the mean intrusive noise level increased with increasing activity in the adjacent classbases. There was a significant increase in noise level when the number of classbases increased above three, whereas the STI was significantly better, so limit the number of classbases to three in one open plan area (Greenland & Shield, 2011). Research has shown that the number of students, volume of space and occupational density of the open plan classroom all affect noise distraction. Densely populated classrooms do not allow for sound sources to be placed far enough apart, hence provide at least 6-7 m between working groups in the same space (Pavčková, Rychtáriková & Tomašovič, 2009). One study found the ambient noise level in classrooms to be significantly correlated with student numbers, with an increase of 0.33 dB (LAeq) per student (Mydlarz *et al*, 2013).

There are a number of case studies highlighting the success of modern Innovative Learning Environments (ILEs). Two Danish semi-open plan schools, Hellerup School and Absalon School (Holbæk), underwent acoustic improvements including more absorption on surfaces and through free-moving panels. As a consequence, the RT and sound level was reduced in the teaching areas, and also the staff perceived less noise (Møller Petersen & Rasmussen, 2012). Glass screening, storage walls, plasterboard barriers in the ceiling void, and side-on and staggered entries to the classbases was introduced in to the Berufliche Schulen Witzenhausen, which has a large plenary area with smaller rooms coming off it. The school design resulted in an RT of 0.48 s and STI >0.7, both good results, and the design inhibited sound transmission across the space despite the open plan layout (Mahat & Campbell, 2017).

Studies of how open plan schools affect teacher performance, indicate that their success is mostly dependent upon a change in teacher's attitude, teaching style and training, along with better timetabling. The impact of open plan classrooms on student performance have shown mixed results, with coordination of quiet versus noisy activities being a key factor.

Open plan classroom solutions

ILEs, the modern adaptation of open plan classrooms, are gaining popularity on some countries as they facilitate a change in pedagogy. However, some of these new spaces are less successful, and can result in noise and distraction, due to their design and use. Several authors have therefore offered practical solutions which we have broadly categorised as: 1. management, 2. layout, 3. furniture and 4. absorption solutions.

1. **Management & behaviour solutions** – Teachers need to coordinate and plan activities between classbases, so that work involving movement and interactions does not conflict with those involved in critical listening activities. Success requires a strong commitment from the end-users and decisions around curriculum delivery and timetabling. This requires an investment in time and planning in advance. Success is not due to optimised acoustics alone, but the combination of pedagogy, architecture and acoustics with good will from sponsors, teachers, students and parents.
2. **Layout Solutions** – Sound transmission can be reduced between classbases by staggering/overlapping entrances to semi-open plan areas, and introducing cupboards and wall absorption, without the need for doors and walls. The 'Fat L' layout provides three distinct zones facilitating large group seated teaching, project activities and quiet group working. The modern classroom has to be flexible enough to allow the continual reorganisation of the whole class into various sizes and number of small learning groups.

The New Zealand MoE (2016) recommends providing 3-4 m² floor area per learner to allow better acoustic separation, and provide a range of adaptable learning spaces, including spaces that can be acoustically separated. Also provide a range of spaces to allow teachers and students to choose where they learn which will help to reduce distraction from other activities. Movable screens, sliding doors and hinged partitions can divide larger spaces into smaller separate zones. Flexible partitions create nooks and alcoves for small group and individual work, and they also provide acoustic zoning in the space.

Nunes (2009) offers a number of specific solutions. The layout of the furniture in the space will affect the distance between student groups and help reduce the negative effect of large groups contained within a small area. As sound is reduced over distance, place teaching spaces further apart to increase separation and reduce speech interference. Breaking the line of sight between two points using screens can be an effective way of providing a small but effective acoustic break between two spaces. When high levels of separation are required, moveable and flexible partitions are seen to be the only solution.

Furthermore, a distance of at least 6.5 m between classbase openings will minimise noise transmission. Significantly more floor area is required for open plan classrooms than for enclosed classrooms, with 4-5 m² per child recommended in the literature. However, current UK guidance recommends 2.1 m² teaching area per primary school child, whereas 9 m² floor area per child is provided in the Hellerup School (Shield, Greenland & Dockrell, 2010).

3. **Furniture solutions** – Movable screens and furniture can be used to define zones, provide nooks and quiet corners, and provide acoustic separation if the screens are absorbent (a mass of at least 10 kg/m²) and a height of 1.7 to 2.0 m.

Nunes illustrates how it is possible to reduce the distance between the teacher and pupils by 1.25 m if a horseshoe seating (amphitheatre) arrangement is used. His freestanding 'banana seat' reduces the distance between the teacher and students to less than 2.6 m, and due to the size and absorbent materials used it can also be used to break up the open plan into smaller zones.

As well as tiered seating, Heppell, Heppell & Heppell (2015) propose several other furniture solutions for open plan schools. They propose family learning tables offering circa 12 seats for parallel quiet work. The attention square is an area marked out on the floor, usually with good line of sight to all the nooks and alcoves. A reading zone is a quiet, comfortable, reading corner where children can read whilst comfortably seated. Collaboration/conversation tables are 'coffee table' with two of three seats for small group activity. Finally, three-sided spaces, either constructed into the walls as 'nooks' or free standing, support quiet collaboration in small numbers.

4. **Absorption solutions** –The New Zealand MoE (2016) recommend that highly absorbent materials are added to floors, ceilings, and walls. Furthermore, the ceiling treatment should be as thick as practicable, ideally 50 mm or more with a noise reduction coefficient of 0.85. Others suggest a ceiling absorption of at least 90%, with a maximum ceiling height of 3.5 m, and the amount of glazing (reflective surfaces) should be below 16%. An absorbent ceiling has more of an impact on RT than carpet, reducing the RT by 0.3-0.4 s, but a carpet, absorbent ceiling and absorbent acoustic wall treatment (such as pin-boards or panels on all available wall surfaces equivalent to at least 20% of the ceiling area) should be incorporated into the open plan classroom design. Ceiling absorption can be in the form of rafts if a full ceiling of absorbent tiles is not provided.

Conclusion and next steps

Despite the introduction of standards, noise distraction in all classrooms appears to be an issue – affecting teacher and student performance. There are mixed results on whether noise is any worse in modern ILEs compared to traditional enclosed classrooms, or the large open plan classrooms of the 1970s. The impact of noise can be exacerbated in ILEs if the teachers do not embrace, or are not trained in, new constructivist pedagogy and if the classbase activities are not coordinated. However, adding absorption, using furniture (such as tiered seating) and considering the layout of the space (such as staggered opening to zones) can all help reduce noise distraction.

This literature review set out to test whether:

1. Any identified issues with noise in open plan classrooms can be partially mitigated through design improvements and acoustics solutions.
There certainly appears to evidence to support this hypothesis, especially in modern Innovative Learning Environments.
2. A teacher's personality profile, in particular extroversion, will enable them to better cope with noise in the (open plan) classroom.
Currently there is very little evidence to support this hypothesis and more research is required.
3. Organisational factors such as teacher training, coordination of the space, timetable administration, changes in pedagogy, and managing student behaviour will help resolve any identified issues with open plan classrooms

This also appears to be the case for all learning environments including ILEs.

Our next step is to further test hypothesis 2 initially through on-line surveys and field measurements, and later using intervention studies. Hypothesis 3 will be tested through more qualitative research including ethnographic observation, interviews and workshops.

Glossary

ANC	The Association of Noise Consultants
ANL	Ambient noise level (dBA)
ANSI	American National Standards Institute
ASA	Acoustical Society of America
<i>BB93</i>	<i>Building Bulletin 93</i>
BFI	Big Five Inventory
dBA	A-weighted decibels
$D_{nT,w}$	Airborne sound insulation
HR	Heart Rate (bpm)
IIC	Impact Insulation Class
ILE	Innovative Learning Environment
IoA	Institute of Acoustics
L_{Aeq}	Equivalent continuous A-weighted sound level (dBA)
$L_{Aeq,Nmin}$	Equivalent A-weighted sound level over N minutes
$L'_{nT,w}$	Impact sound pressure level
MoE	Ministry of Education
NUT	National Union of Teachers
RT	Reverberation Time in seconds (s)
RT_{mf}	Reverberation Time mid-frequency range (s)
SNR	Speech (or Signal) to Noise Ratio
SPL	Sound Pressure Level (dBA)
STC	Sound Transmission Class
STI	Speech Transmission Index

1.0 Introduction to report

1.1 Objectives

The uptake of the Innovative Learning Environments (ILE), the modern adaptation of open plan schools, is increasing in parts of Europe (particularly Scandinavia) and the Antipodes (Australia and New Zealand). The new learning environments have resulted in mixed success due to issues with: acoustics, teaching practices, coordination of activities, and the management of the space, teachers and students.

Ecophon commissioned Workplace Unlimited to conduct a literature review to understand the key issues of open plan classrooms and how they may be resolved, with a focus on acoustic solutions. In our recent study of psychoacoustics, related to office noise (Oseland & Hodsman, 2017, 2018), it was found that personality affects how well office workers can tolerate noise. Ecophon was therefore interested to know if that is also the case for teachers in classrooms, both traditional and open plan.

This literature review is aimed at testing several pertinent hypotheses:

1. Any identified issues with noise in open plan classrooms can be partially mitigated through design improvements and acoustics solutions.
2. A teacher's personality profile, in particular extroversion, will enable them to better cope with noise in the (open plan) classroom.
3. Organisational factors such as teacher training, coordination of the space, timetable administration, changes in pedagogy, and managing student behaviour will help resolve any identified issues with open plan classrooms.

Whilst the focus of the review is on teachers and classrooms, related articles on other learning environments, e.g. lecture theatres and lecturers, are also reported.

1.2 Approach

An on-line literature search was carried out using Google Scholar and the search engines made available to UCL academics. The initial key words searched on included: personality, teacher, noise, acoustics, open plan and classrooms. The key words were extended as the search progressed including voice, activity-based learning and student performance. In addition, any influential papers mentioned in the reviewed papers were then followed-up.

Circa 200 papers and reports were reviewed, but only the most relevant ones are reported here. The papers were categorised according to the following recurring topics:

1. **Acoustics (A)** – standards, controlling noise, design recommendations, impact of noise on student performance, measurement of "noise."
2. **Open-plan (O)** – history of school design, pros and cons of open plan classrooms, impact on student and teachers.
3. **Personality (P)** – personality profiles, teacher performance, student performance.
4. **Voice (V)** – stress on teacher's voice, coping mechanisms, treatment, microphones and sound field systems, voice and personality, teacher voice and performance.
5. **Teaching (T)** – changes in pedagogy, educational reform, managing student behaviour, teacher-student interactions, activity-based learning, student-centred learning, health and wellbeing.

Figure 1 illustrates the approximate proportion of papers reviewed according to the five identified topics. Note that whilst there are studies of the personality of teachers and studies on open plan classrooms, we found no research exploring the overlap between the two subjects. This raises the question of whether the impact of personality on noise in the open plan classrooms is of no interest (unlike research on psychoacoustics in office environment) or simply that it has not been considered.

We did however find a few studies linking personality of teachers to teaching style, and a few exploring the impact of personality on voice control in the classroom. Unsurprisingly, the main area of overlap was between classroom acoustics and open plan classrooms, including reviews of standards as well as, successful and less successful, case studies.

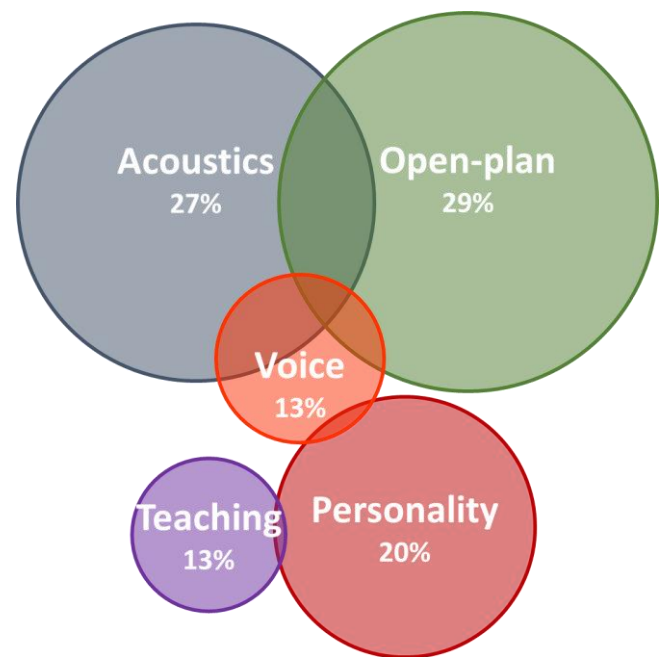


Figure 1. Papers reviewed by topic

2.0 Teacher personality profiles

2.1 Early studies

One of the most comprehensive reviews exploring the effect of personality on teaching is that of Göncz (2017). He believes there is a long-running consensus that teacher's personality is the most important and complex variable in the educational process. The impact of teacher personality has been discussed for some time, for example Cooper and Bemis (1967) remarked "If certain patterns of teacher classroom behaviour could be demonstrated to relate to pupil achievement (or the reverse) then we would be in a position to guide the development of that teacher's behaviour which leads to pupil learning." A more recent study by Richardson and Arker (2010) suggested that teacher personality profiles need to be recognised to allow educators to be proactive in determining a better fit for students and teachers.

Göncz commences his review by identifying a number of legacy typologies of teacher traits, starting with Caselmann (1949) who differentiates between 'paidotrop' teachers, emphasising upbringing and interest in individuals or groups, and 'logotrop' teachers, emphasising education and teaching. He continues with the typology described by Adelson (1961) which differentiates between teachers that place more importance on their profession, their students or their institution.

Göncz also reports on early research (Jersild, 1940; Witty, 1947) which asked students to note the preferred characteristics of their teachers and found they "referred to the following: personality traits, temperament characteristics, the physical features of teachers and their management style (students have a preference for kindness, readiness to help, sense of humour, natural behaviour, good mood, kind-heartedness, young looks and good health) and teaching (didactic) qualities." In his personal account, Reid (1948) notes that when he asked students what they thought were the characteristics of the best lectures, "the answers often reflected opinions about the character and personality of the lecturer" rather than environment." Furthermore, a good lecturer "has the interest of his listeners at heart ... good teachers use various methods of arousing the interest of their students." These three examples may reflect the Agreeableness (empathy) trait of the Big Five Inventory (BFI).

The BFI, developed by Berkeley University (John, Naumann & Soto, 2008), is often referred to as OCEAN because it has five dimensions: Openness, Conscientiousness, Extroversion, Agreeableness and Neuroticism. The BFI is the personality profiling method that was adopted by Ecophon in previous research (Oseland & Hodsman, 2018).

Gorgonia (1971) compared student comments on efficient and inefficient teachers. He found that students predominantly favoured Emotional Stability (the antithesis of Neuroticism) in an efficient teacher, followed by characteristics that might be associated with Conscientiousness. Furthermore, Suplicz (2009) found that students attributed emotional coldness and a lack of humour to the secondary school teachers they considered inadequate. Such comments may be related to the Agreeableness and Conscientiousness dimensions. Sánchez *et al* (2011) investigated the expectations of social sciences students at Andalusia universities. They found the students expected their lecturers to treat them with respect and understanding, which might be linked to Agreeableness.

2.2 Personality traits studies

According to Göncz, the first researcher to assess teachers using personality theory was Lamke (1951). Using Cattell's (1965) 16 Personality Factors (16PF), Lamke provided a description of the traits and behaviours of successful teachers. He found that teachers achieved above-average results for Cattell's Liveliness (F) and Social Boldness (H) factors. These two factors overlap with the Introversion/Extroversion dimension of other personality tests, such as the BFI and Eysenck Personality Inventory, or EPI (Eysenck & Eysenck, 1964).

Göncz also cites Petrović-Bjekić (1997) who demonstrated that teachers scoring higher on Extroversion and those more Emotionally Stable (the opposite end of the Neuroticism) are more efficient than their counterparts. Houlihan *et al* (2009) also report that university professors who suffer pronounced anxiety associated with teaching (so possibly high Neuroticism) prefer minimal interactions with their students, in both one-to-one sessions and lectures. So, it seems that Extroversion and low Neuroticism are key personality traits for teachers.

In contrast, Li and Wu (2011) found no differences on any dimensions of the EPI between 'good and poor' teachers. Furthermore, Bloom (2016) proposes that Extroversion is not a requirement and introverts also make good teachers: "Extroverts tend to gravitate towards large groups and free-flowing banter. Introverts, meanwhile, shun small talk, preferring the intimacy of one-to-one conversations. It is the introverted teacher, therefore, who will be more likely to stop an individual student and ask her pertinent questions about her life: how she is getting on with her new pet, for example, or whether she is still struggling with long division." Bloom points out that introverts find group situations overstimulating and are quickly exhausted by a busy, noise-filled environment and require restorative alone-time afterwards to re-energise. Teaching is therefore an eccentric career choice for an introvert, but it may be possible for introverted teachers to tap into 'free traits' i.e. the ability to act out of character for a limited period of time. Introverted teachers can develop other coping strategies, such as introducing one-to-one and small-group work instead of standing at the front of the class, thus reducing their level of stimulation. Other introverted teachers have allowed their students to listen to music through headphones to reduce 'noise and chaos'.

Several studies have profiled teacher personality using the BFI. For example, Aidla and Vadi (2010) established that teachers from Estonia scored higher on the Agreeableness and Conscientiousness scales and also had lower scores on the Neuroticism scale than the general population. The results were consistent with the features attributed to them by both the public and graduates. Genc *et al* (2014) found that students expected good teachers to have less Neuroticism and show more Extraversion, Openness, Agreeableness and Conscientiousness than the general population. In their own study, Göncz *et al* (2014) revealed that students of the social and humanistic sciences preferred lecturers that rated higher on Extroversion, Openness, Agreeableness and Conscientiousness. Three decades ago, Rushton *et al* (1983) investigated university professors who had opposing professional roles: lecturer versus researcher. They found that the teaching-orientated professors rated higher in Openness, whereas the research-orientated ones were higher in Conscientiousness.

Some studies then go on to determine if the BFI affects student performance. Garcia, Kupczynski & Holland (2011) studied whether there was a significant relationship between teachers' BFI traits and tenth/eleventh-graders' performance, measured using the Texas Assessment of Knowledge and Skills (TAKS). Their analysis is a little confusing, but their study indicates that students achieved higher TAKS scores when instructed by teachers rating higher in Conscientiousness and/or Agreeableness compared to teachers higher on Openness or Extroversion. The more Neurotic teachers also resulted in lower student TAKS scores. Conscientiousness has been found to be a good general predictor of job performance across a varied range of jobs, whereas more Neurotic individuals have a higher rate of burnout and job dissatisfaction.

Jiang (2012) compared 865 college teachers across 13 Chinese universities. They found that Extroversion, Emotional Stability (Neuroticism) and Conscientiousness positively correlated with research performance but there was no relation with teaching performance. However, they did report that the interaction of Agreeableness and Conscientiousness related to teaching performance.

Buttner & Pijl (2014) studied a cohort of 147 trainee teachers at the Hanze University of Applied Sciences in the Netherlands. They found that Conscientiousness and Emotional Stability

(Neuroticism) distinguished expert teachers from non-expert teachers. Furthermore, they discovered significant correlations between how well they taught students with behavioural difficulties and Conscientiousness, Neuroticism and Extraversion.

The impact of the student's BFI traits on their academic performance has also been investigated. For example, Geramian *et al* (2012) studied the relationship between the BFI and cumulative grade point average (CGPA) of 146 international postgraduate students at Universiti Teknologi Malaysia. They found that the CGPA was significantly correlated with Conscientiousness and Openness traits. Conscientiousness relates to diligence and planning whereas Openness relates to creativity – both useful traits from an academic perspective.

Rather than the BFI, several researchers have used the Myers-Briggs Type Indicator (MBTI, developed by Myers Briggs & Myers (1995)). The MBTI rates people on four dichotomous dimensions: Extraversion (E) or Introversion (I), Sensing (S) or Intuition (N), Thinking (T) or Feeling (F) and Judging (J) or Perceiving (P). For example, Lawrence (1979) studied teachers at all education levels and found that 63% of them had Feeling (F) and Judging (J) traits. Likewise, Macdaid *et al* (1986) examined a national sample of 804 teachers and found that nearly 50% were S and J types. Reid (1999) sampled 189 Florida elementary teachers and concluded that 57.7% favoured had S and J traits.

Rushton, Morgan & Richard (2007) administered the MBTI to 58 teachers who were members of the Florida League of Teachers (FLoT), deemed to be outstanding educators. They found that their sample of outstanding teachers were predominantly ENFP (32%) and ENFJ (12%) types, compared to the typical SFJ types reported in broader samples of teachers. They conclude that the personality traits of high performing teachers do not represent, nor share similar traits, with the majority of typical school teachers in the USA.

2.3 Teacher personality and noise

In our previous research (Oseland and Hodsman, 2017, 2018) both a literature review and our own survey research revealed that personality profiles affect the perception and tolerance of noise in the office. Our research, and that highlighted in the literature review, revealed that those higher in Extroversion and Emotionally Stability fared better in noisy and stimulating environments than those higher in Introversion and Neuroticism. Our study also showed positive results for the more Conscientious.

The current literature search did not reveal any significant studies exploring the impact of teacher personality on dealing with noise in the classroom. To be clear there are many studies showing the effect of noise on teachers (see Section 6.2) but personality was not considered as a significant factor.

2.4 Conclusions of teacher personality

Rushton, Morgan & Richard (2007) cite Getzels & Jackson (1963) who surveyed over 800 studies of teacher personality and concluded it was 'unproductive and chaotic'. Their conclusion was partly due to the lack of standard psychological tests applied during that time. Since then several standard personality inventories have been created, notably the EPI, BFI and MBTI. Hurtz & Donovan (2000) note that in office research, virtually all studies report strong correlations between the BFI and job performance.

So, it follows that teacher personality would affect their performance and corresponding student performance. In his extensive review, Göncz (2017) concludes that teachers' personalities profiled using tried and tested personality inventories, particularly the BFI, serve as the best starting point for exploring the impact of teacher personality on performance.

Nevertheless, to date the research on teacher personality have been mixed. In terms of studies using the BFI, this literature review indicates that teachers with higher ratings on the Conscientiousness, Emotional Stability (opposite to Neuroticism) and Agreeableness traits fare better than their counterparts. Surprisingly, studies highlighting the importance of Extroversion and Openness are less prevalent. In lay terms, it appears that teachers who are diligent, more able to deal with stress and more approachable are more successful.

Interestingly, our literature review did not reveal any research that explored if teacher personality affects tolerance to noise in either open plan or traditional classrooms. Our previous office-based research revealed that those higher in Extroversion, Emotionally Stability, and to some extent Conscientiousness, coped better in noisy and stimulating environments than their counterparts. In combination with the broader requirements stated previously, teachers high in Conscientiousness and Emotional Stability traits appear to be at an advantage.

3.0 The changing nature of pedagogy

3.1 New thinking

Pedagogy, the theory and practice of teaching, has always evolved over time. The discipline and practice of rote learning in Victorian schools has been replaced by alternative teaching styles, even though 'chalk and talk' style teaching is still prevalent in many UK classrooms. Baker (2012) notes that in the 1930s "a new generation of school reformers was emerging, through the leadership of such figures as Maria Montessori in Italy and John Dewey in the USA. These scholars supported the notion of child-centred learning and developed educational theories that form the basis for much current educational thought to this day." Dewey's (1916) student-centred model of learning highlighted the importance of social context and student interaction.

According to Dovey & Fisher (2014), the evolution of pedagogical theory can be framed as three key stages: behaviourist, cognitivist and constructivist. They explain that behaviourist approaches are traditional didactic teacher-centred pedagogy, whereas cognitivist approaches involve moving from lower-order to higher-order thinking through a hierarchy of activities, and constructivism is largely based on the application of knowledge in 'the student's lived world' i.e. "students construct their own meanings and they do so in a social context." Dovey & Fisher highlight that constructivist pedagogies were developed in the 1970s, after much of the early adoption of open plan schools which later failed. The constructivist approach, now often referred to as student-centred learning, is increasingly being adopted by educational institutions, particularly in parts of Europe and the Antipodes.

Lewinski (2015) takes an esoteric psychological approach to new pedagogies. He explains telic and paratelic motivation in the classrooms, where telic motivation is goal orientated, requiring relaxing (low arousal) environments, and paratelic motivation is focused on the activity itself, requiring stimulating (high arousal) environments. Lewinski assumes that students acquiring knowledge require a telic inducing classroom as those evoking paratelic states would not motivate occupants towards their learning goals. He concludes that "students ideally should experience a telic motivation state ... relatively unstimulating and non-arousing environments must therefore be provided" and "noise creates a distracting environment, which is not conducive to a telic state in students who wish to focus on a task." However, Lewinski also notes students prefer sociopetal seat arrangements that encourage social interaction and are more in-line with paratelic motivation. He concludes that because humans are such social animals and fear isolation, a lack of interaction creates uneasiness which in turn increases arousal. Lewinski misses the point that the required level of interaction is dynamic and dependent upon the situation, activity and personality, as per Altman's (1975) privacy model.

There is much (competing) literature on learning styles – the prominent style of learning assigned to an individual. Coffield *et al* (2004) identified 71 different models of learning style and categorised 13 of them as major models. They conclude "We have found the field to be much more extensive, opaque, contradictory and controversial than we thought at the start of the research process." They also found that there "is a dearth of rigorously controlled experiments and of longitudinal studies to test the claims of the main advocates." In regard to practical application for teachers they note "as students move from didactic forms of instruction to settings with a mixture of lectures, seminars and problem-based learning, it may become possible for them to use a range of approaches. This can lead to a plan for teachers to develop these styles through different teaching and learning activities, or it can lead to what might be seen as a type of 'pedagogic sheep dip', where teaching strategies aim explicitly to touch upon all styles at some point in a formal programme." If the predominant learning style can be identified for a group of students then the appropriate teaching style, teacher and learning environment could be tailored to suit them. In our literature review we found more focus on identifying the range of activities that take place in the classroom so that the space can be designed accordingly.

The Gradual Release of Responsibility (GRR) model was developed by in the 1980s and built on earlier developmental psychology theories (Pearson & Gallagher, 1983). The GRR model is a structured method of pedagogy which gradually shifts learning responsibility from the teacher to the student, creating autonomy and independence. Fisher & Frey (2008) built on the GRR model and proposed four key transition stages:

1. **Focus Lessons** – a teacher-centred lesson based on the expected learning outcomes clearly communicated to students.
2. **Guided Instruction** – the teacher facilitates small group working to improve student understanding and promote autonomy whilst offering support.
3. **Productive Group Work** – students work in collaborative groups and provides them with an opportunity to consolidate their understanding before they apply it independently.
4. **Independent Learning** – students apply what they have learned in class and outside of class.

Pedagogy is also changing in further and higher education. Some 70 years ago, Reid (1948) remarked "The lecture is not the only way of transmitting information; in many instances it is not even the best way." Graetz & Goliber (2002) also consider the changing nature of learning in universities: "research dating back a half century indicates that traditional lectures do little to inspire course-related thought or interest and are relatively ineffective for teaching course-related values, behavioural skills, and procedural knowledge, and it appears that lectures are destined for obsolescence." They highlight the shift in universities towards collaborative learning, defined as "a wide variety of educational activities in which human relationships are the key to welfare, achievement, and mastery" and teachers "help students learn by working together on substantive issues" (Brufee, 1999).

3.2 New classroom activities

Many educational commentators have categorised the types of activity that take place in the modern classroom. For example, to help with their research, Shield *et al* (2015) reduced classroom activity down to four key types: 1. plenary, 2. individual work. 3. group work and 4. watching/listening.

Activity	Description
Presentation 25-150 students	Students or teachers present to a largely passive group. Groups size may vary from one class cohort to a full form or year. Such activities facilitate efficient communication or information.
Large Interactive 25-75 students	Activities that move seamlessly from large to small groups and back, often organised in sub-groups of 4-6 that can be subdivided again into 2s or 3s. Facilitates peer-to-peer learning and team teaching.
Medium Interactive 10-25 students	Activities with a similar flow of movement to the above, but with a smaller group size and generally one teacher.
Creative Interactive 10-25 students	Interactive activities but with an emphasis on hands-on learning in addition to pens and keyboards, plus access to a range of resources that may include art materials, wet areas, laboratory or outdoors.
Small Interactive 2-5 students	The 'breakout' model of problem-based and peer-to-peer learning with small autonomous groups that can disperse and take responsibility for their learning.
Reflection 1 student	Singular activities that include reading, writing or hands-on research to meet learning objectives.

Table 1. Six teaching practices (Dovey & Fisher, 2014)

As part of their research, Dovey & Fisher (2014) developed a list of six key teaching practices based on constructivist (student-centred) pedagogies. Their typology, summarised in Table 1, is a continuum of group size from large group presentations to small group interactive activities to single student reflective activities.

In an earlier study, Eggenschwiler & Cslovejcssek (2008) noted that "Aside from frontal instruction, dominant in earlier times, a multitude of different teaching and learning forms are in practice today." They identified five teaching styles requiring different classroom layouts, see Figure 2:

1. Frontal sequences involving lectures and class discussion.
2. Circular seating plan for group discussion and play.
3. Group work for practicing and producing together.
4. Project work including gathering and presenting information.
5. Learning shops for independent learning.

Eggenschwiler & Cslovejcssek also point out that the use of flexible classrooms places additional demands on the participants (teachers and students), furnishings, layout and acoustics. This requires the acoustics to be considered, in detail, from the very outset of planning a new or renovated classroom.

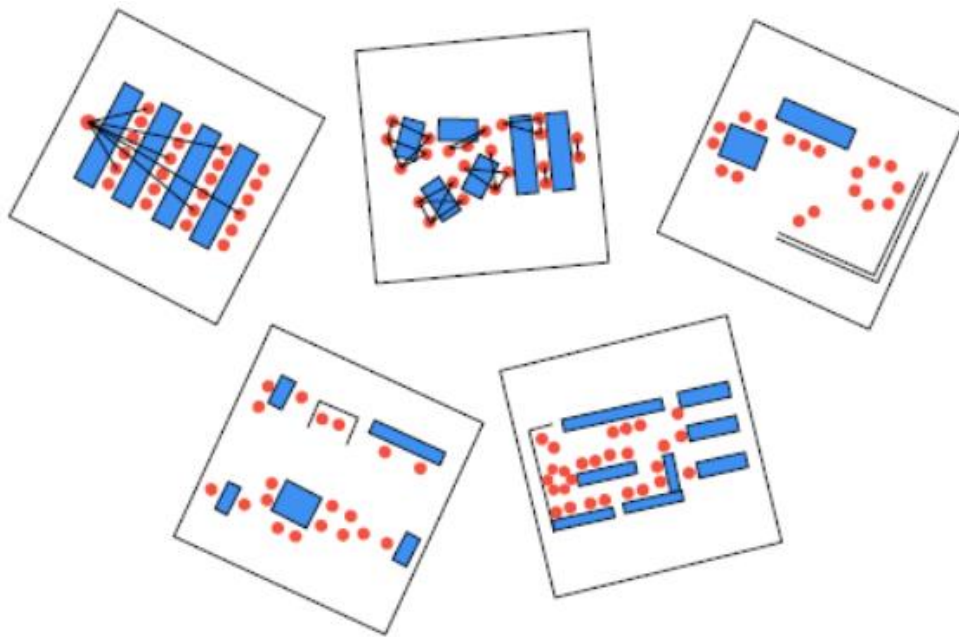


Figure 2. Five teaching styles and classroom layouts (Eggenschwiler & Cslovejcssek, 2008)

In their research on ILEs, Imms *et al* (2017) asked 6,000 school principals in Australia and New Zealand to choose the types of teaching approaches occurring within their schools from an illustration, see Figure 3. Their six typologies are a hybrid of teaching style and classroom layout, and similar to those of Eggenschwiler & Cslovejcssek with the addition of one-to-one instruction. These six typologies have been adopted in a number of recent research studies.

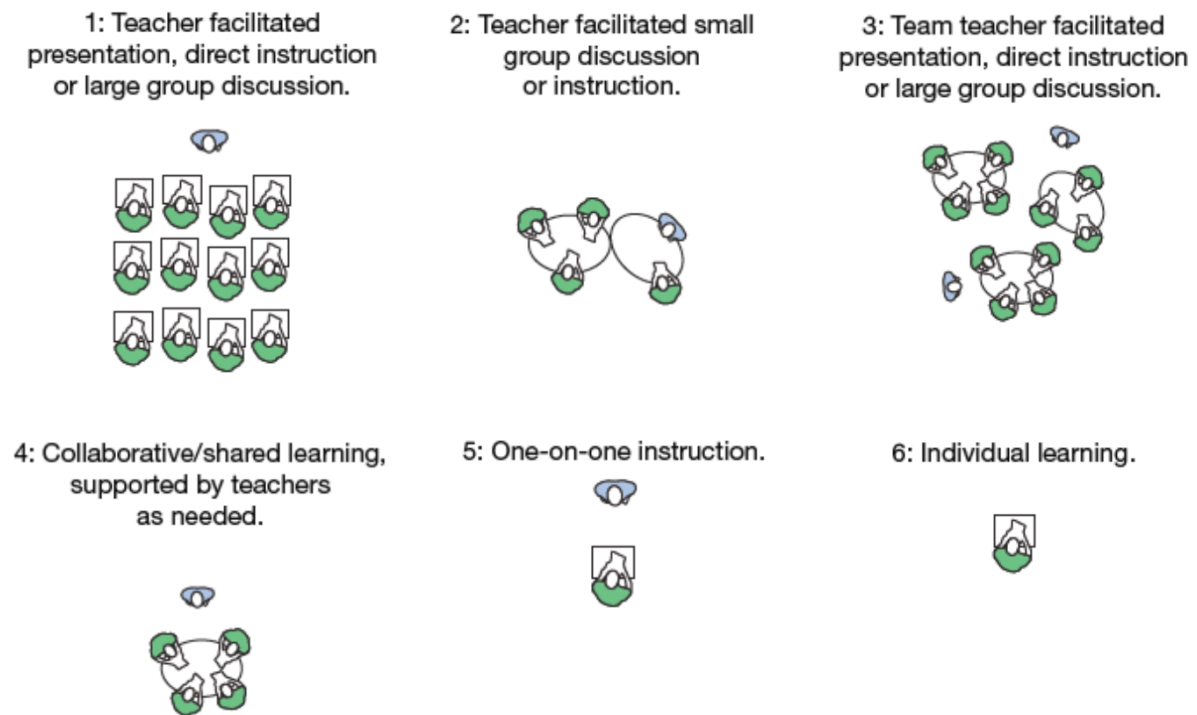


Figure 3. Six typologies of teaching practices (Imms *et al*, 2017)

The next section focuses on the rise of open plan classrooms and ILEs, and how they have been designed to accommodate the range of teaching practices and other factors.

4.0 Classroom design progression

4.1 The rise and fall of open plan classrooms

4.1.1 The first wave of open plan

Open plan classrooms gained popularity in the 1960s to 1970s following the post-war educational reform movements. As Shield, Greenland & Dockrell (2010) point out "Before this time, pedagogy largely consisted of didactic teaching, with the teacher speaking in a fixed position at the front of the class and the pupils listening from formal rows of desks. The years following the second world war witnessed a breakdown of this formality, as education began to focus on the individual needs of the pupils rather than the 'convenience' of teachers." As explained in Section 3, this new approach to education placed more emphasis on group work than didactic teaching, providing a more student-centred pedagogy.

There are many supporters of the evolving change in pedagogy. Nair (2009), an architect, commented "Who seriously believes that locking 25 students in a small room with one adult for several hours a day is the best way for them to be 'educated'? In the twenty-first century, education is about project-based learning, connections with peers around the world, service learning, independent research, design and creativity, and, more than anything else, critical thinking and challenges to old assumptions."

Greenland & Shield (2011) reported that by the mid-1970s, 10% of all primary schools in England and Wales were open plan, whereas in the USA over 50% of new build schools were either fully or semi-open plan. They continue that open plan classroom received criticism from educators and politicians, "they were found to be impractical and difficult to teach in, and during the last two decades of the 20th century, there was a return to the more traditional enclosed classroom." Furthermore, Shield, Greenland & Dockrell (2010) claim that "many previously open plan schools have had remedial work to convert them to conventional enclosed classroom designs, or to a 'semi-open' plan layout." They report that the primary reason for failure of open plan schools is usually noise and distraction.

Weinstein (1979) recognises the views of the advocates of the new approach to education but observes that "Their arguments, however, do not go unchallenged. In more than one community, parental response to the new facilities has been vehemently negative and antagonistic, and teachers and administrators have demanded that walls be erected as quickly as possible. Indeed, many facilities, once completely open, are now 'modified open space'; some are almost indistinguishable from traditional egg-crate schools." Baker (2012) comments that "Schools are influenced by political and social movements, new technologies and trends, the growing awareness of what makes us learn better and thus our notions of what makes a great school are constantly shifting and adapting to new ideas. Yet, we are still surrounded by the schools that matched the ideologies of over a century ago, when the world and our understanding of education was quite different." It is less clear whether a return to traditional open plan design also represented a return to traditional teaching methods, or more likely reflects a lack of adoption of the new pedagogy in the first place.

The reason for failure of the early open plan schools is not just due to a poor setting for teaching, particularly traditional didactic teaching. Shield, Greenland & Dockrell (2010) remind us that "An additional factor which influenced school design was economic. The emergence of child-centred teaching methods coincided with the introduction of post war economic restraints which affected the building of primary schools; designs which reduced the amount of non-teaching space while protecting the available teaching space were encouraged. Hence, the open plan school emerged as a combined result of responding to the new needs of the 'progressive' educationalists, and to the cost and area limits placed on new schools."

Weinstein (1979) points out that whilst the term 'open plan school' usually refers to the construction, it also goes hand in hand with the educational philosophy: "such schools are often

intended to permit flexibility in scheduling and spatial arrangements, encourage interaction among students and teachers, facilitate team teaching, and allow for learning options that the self-contained classroom is unable to support." Likewise, Deed & Lesko (2015) believe "openness is an amalgam of conceptions: physical (un-walling, undoing, breaking); social (choice, flexibility, autonomy); and cultural (democracy, freedom, community)." Therefore, openness can be expressed through school architecture or by "an approach combining flexible space, student choice, rich tasks, curriculum integration and a focus on individual rather than large-group teaching."

If the move to open plan school design was predominantly driven by cost saving, then it is likely that teachers were not trained or motivated in new approaches to education. Weinstein (1979) notes "For the teacher with a relatively traditional program in a conventional, four-walled classroom, arranging the physical environment is usually a simple process: the students' desks are arranged in rows ... In sharp contrast is the bewildering array of design possibilities that confronts the teacher in an open education classroom." Deed & Lesko (2015) believe that the modern open school architecture abstractly expresses open teaching: "It is the individual teacher who must break with convention in order to take and apply the meaning of openness ... While teachers might be aware that different teaching practice is afforded by a learning environment, they might continue to use pedagogical practices appropriate to more conventional space ... their adaptation could be constrained by institutional memory and routine." Weinstein (1979) cites Getzels (1974) who "argues convincingly that changes in classroom design are not merely the result of architectural and engineering advances, but reflect our changing vision of the learner." She continues, noting that "this vision is most consonant with the teaching practices theoretically characteristic of open plan designs." So, successful open plan design and teaching style are interrelated. A physical change alone will not instigate a change in pedagogy and the physical change is unlikely to succeed without first changing the teachers' approach to education.

When Guldbaek, Vinkel & Broens (2011) work on school developments they take into account four elements, the: society, child, future and school. Society relates to the kind of society and culture that the school will reflect. Regarding children, a set of values need to be established and adhered to. The future refers to looking ahead and accepting that it is going to be different and influenced by what is done today. The school relates to the consequences for the school system. They suggest that "In traditional schools we need to shift the focus by 180 degrees, from teachers being responsible for teaching and students being responsible for learning to the teacher being responsible for understanding children's individual learning needs and supporting them." They conclude by prosing that we develop schools which children are excited to go to, where they can learn and play.

Baker (2012) points out that open plan schools were not introduced blindly but were accompanied by some thorough research. For example, Baker reports that modifications, such as variable-height, sound-absorbent partitions between classrooms, significantly reduced classroom interruptions. The failure of the early open plan classrooms appears to be due to a mixture of: poor leadership & vision, sticking with traditional teaching, lack of training & motivation poor timetabling & coordination, driven by economics (reducing cost), poor acoustics, and designed too "open plan" or too dense! Weinstein (1979) recognised that much of the research on open-plan schools was conflicting, and as such, she cautioned her readers "it is still necessary to suspend judgment about the success or failure of the open space school to enhance the educational experience of children."

4.1.2 Recent uptake and success

Vinje, cited by Eriksen (2014), remarks that open plan schools gained popularity in Norway in the late 1960s and lasted for around 15 years, but in 2011 some 19 new school buildings in Oslo were based on open plan design and existing schools were being converted. He continues that the new wave of open-plan schools can be traced back to Norwegian enthusiasm for

Sweden's 'Skola 2000' project, which was eventually abandoned after negative experiences of increased noise and disturbance.

Regardless of the former problems with open plan, there is clearly a move in parts of the world towards new classroom designs. For example, "Despite former problems, current educational and architectural trends are leading to a resurgence of open plan design with schools being built to accommodate shared teaching space in clusters of open plan classbases, large volume atria or breakout circulation space." Greenland & Shield (2011).

Similarly, (Dovey & Fisher, 2014) remark that "Over the last century we have seen a slow transformation of the architecture of school classrooms in response to changing pedagogical theory and practice. A shift from teacher-centred to student-centred learning is accompanied by the move towards a more 'open' plan with new spatial types, interconnections and modes of adaptation ... The traditional classroom is a product of a teacher-centred pedagogy, framing a hierarchical relationship between teacher and students whilst closing out other activities and distractions."

As well as the recorded pitfalls of open plan, there are also success stories. Just after the first wave of open plan schools, Weinstein (1979) cited studies showing that open plan schools lead to increased interaction among teachers and increase their autonomy, satisfaction and ambition. She also reports "the majority of teachers also say they enjoy teaching in open-plan schools and would not return to a conventional building, despite the fact that they have complaints about excessive noise" and that there is evidence that the teaching style is more informal, and teachers spend less time conducting routine activities. From a student perspective "Open space schools generally appear to enhance students' feelings of autonomy, willingness to take risks, and persistence at a task" plus "Students also tend to meet with more teachers during the day to engage in a greater variety of activities and to move around more." In light of the recent 'sitting is the new smoking' warnings, such regular movement may be beneficial long-term for health.

Campbell (2017a) presented a case study of a successful early open plan school. De Werkplaats Kindergemeenschap (The Workplace children's community) in Bilthoven is one of the Netherlands' first primary schools without any classrooms. In a large open area of over 1,000 m², the 300 children move around to their next learning activities. A few years ago, De Werkplaats took the opportunity to rebuild and renovate the school abandoning the traditional idea of classrooms. So, each corner of the school is designed for a certain activity. School head teacher Jeroen Goes remarks "Our view is that the environment should adapt to the child rather than the other way around. The open space gives children much more freedom to do their tasks and decide where they do them and who with. This gives the children the independence they need to make their own choices and reflect on them. Children become more inspired as they move around." Teacher Hans Kloosterman is also a fan of the new school layout and explains "Working this way is less cramped than in the small classrooms. And the fact that everything is open means that I can see at a glance what all the children are doing. The pupils in the various classes sometimes switch around, which enhances the feeling of togetherness. The children I teach are no longer 'mine' but 'ours'. We help each other and there's a much better sense of community now." A lot of sound-absorbing materials were used to optimise the acoustics, in the structure itself, but also in the walls and acoustic ceilings such that teachers report they can speak to the children in a normal tone of voice without disturbing another teacher working just a few metres away.

O'Sullivan (2017) reports that open plan schools in Finland have not always proved successful due to distractingly high levels of noise. However, Finland has learned from the problems of the past to create contemporary open plan schools with softer, calmer space, so that one rarely has a block-like rectangular layout. According to Reino Tapaninen, chief architect at Finland's Department of Education: "We've given up the old type of school desk and chair and have a real

diversity now ... there are a lot of soft chairs, big cushions, rocking chairs, sofas as well as moveable walls and partitions behind which you can hide yourself for private discussions ... you will see lots of different kind of furniture, lots of colours and, I would say, a lot of happy people." Over the past few decades the country has been moving steadily towards a more informal culture where slightly higher levels of noise are tolerated. "It's possible that society itself wasn't ready during the 1950s and 60s for the open classroom experiments that took place" Tapaninen continues "Now, conditions and attitudes are different, and the idea that a school needs to be entirely quiet is disappearing to an extent." Finland's desire for more open plan classrooms is a direct reflection of its national curriculum, which rejects traditional academic silos and instead favours more student autonomy and cross-curricular connections, whilst eschewing standardised tests.

Wirtén (2018) reports on the new Hyllievång School in Malmö. The school design combines classrooms, open "street" spaces and small activity rooms; the layout comprises of 'team areas', with six classrooms sharing different sized rooms. Fredrik Andersson, one of the teachers, explains "We adults typically like to plan and decide in advance how each room should be used. Then the children come along and use the space completely differently."

It appears that new ways of learning in education is also being explored in the east. Currie (2018) shares early results of the new Secondary School Information and Media Centre in Ho Chi Minh City, Vietnam. He states that "the recently opened space is getting great reviews and feedback from students, teachers, staff and visitors."

4.1.3 Future classroom design considerations

After the first wave of open plan schools, Glass and Smith (1979) found that, some of the open plan classrooms have higher densities of students, probably for economic reasons. Their research concluded that a higher density results in lower student achievement. They recommend, when designing open plan classrooms, a social density of three to five groups of 6 to 12 students each. Furthermore, the spatial density should be such that both students and instructors have enough room to move easily from group to group, specifically, 1.2 to 2.1 m between groups. Barrett & Zhang (2009) cite Achilles (1992) who found that "children in smaller classes were found to outperform children from regular class sizes in all subjects, especially in reading and mathematics test scores with average improvements of up to 15%."

In their review of future *Design Implications for Primary Schools*, Barrett & Zhang (2009) note several key considerations in classroom design: 1. identify the proposed activities that are likely to take place and provide a well-defined area that offers resources that can be shared by students, regardless of whether an open plan or enclosed classroom, 2. size based on determining the average number of children involved with each activity and calculating the amount of space each child will need to function as they participate in activities such as reading, writing, working or simply listening in that activity and 3. the layout will need to be planned to accommodate activity modes including instruction, experimentation or group related activities.

Furthermore, Barrett & Zhang (2009) highlight the importance of choice, flexibility and adaptability. They note that "in order to easily accommodate diverse instructional modes, there is no doubt that maximizing flexibility is essential for contemporary and future-oriented schools" and "one of the most important aims of open plan is flexibility and adaptability so that schools can respond to changes in delivering teaching and learning." They recommend that "each large-group, small-group, and/or individual learning space should be an architecturally well-defined 'activity pocket' with all the furniture, equipment, storage, and resources necessary for that learning activity contained within."

Dovey & Fisher's (2014) review concluded that "while there were many reasons for this failure (including acoustics) it is clear that such open plans often confused flexibility with openness and were poorly matched to new learning practices. In the new century we are seeing a substantial

re-emergence of student-centred pedagogy in all educational sectors, geared also to communications technologies and information flows that are difficult to optimise in the traditional classroom. A new round of architectural innovation has emerged globally with the overt goal to enable better such pedagogies. Instead of simply open plans we are seeing assemblages of different spaces grouped in clusters with meeting rooms, learning commons and traditional classrooms in a myriad of new arrangements." The next section describes the evolution of the open plan classrooms into the new ILEs.

4.2 Innovative Learning Environments

4.2.1 A range of space types

Just like in offices, classrooms and school layouts can no longer be simply categorised dichotomously as enclosed or open plan. Modern schools have a wide range of classrooms designs that lie on a spectrum somewhere between traditional cellular classrooms and fully open plan spaces. Due to their diversity in design, evolution over time and response to changing pedagogy, such hybrid spaces are termed ILEs.

Some time ago, Bennet *et al* (1980) identified three main types of open plan classroom design: 1. fully open plan, 2. semi-open plan and 3. flexible open plan. This categorisation was adopted more recently by the IoA/ANC (2015) in their acoustic design guide for UK schools, derived from the original thesis by Greenland (2009), see Table 2. They comment that each category requires different organisation and management techniques, with some activities being more suitable than others. Whilst there is acknowledgement of a range of classroom spaces, the emphasis is still on open plan design.

Design type	Recommended use and management of space
Fully open plan – Provides a large degree of openness with divisions provided only by means of loose fixtures	Plenary session recommended for critical listening periods (instruction/discussion/presentation); group and individual work should be coordinated and managed by a single team, not organised independently; small enclosed rooms surrounding the open space are essential to withdraw to when needed.
Semi-open plan – Building generally open but teaching spaces are defined by walls with openings in them	Independent teaching involving simultaneous critical listening periods is possible given good acoustic design, seating layout and suitable activity plans. Small group rooms are recommended, particularly if space is used by those with special hearing and communications needs
Flexible open plan – Areas can be opened out or closed off by means of sliding or folding partitions	Compatible for independent teaching sessions involving general learning activities. Sufficient sound insulation would not be achieved for specialist activity involving high noise levels (such as music, drama and design technology), therefore careful timetabling and management of these activities is required.

Table 2. Three categories of open plan classrooms

Imms *et al* (2017) observe "ILEs exist in a confusing array of designs, from huge open spaces to highly flexible arrangements of classrooms that can be reconfigured to create learning spaces such as student retreat spaces, 'maker' spaces and much more." Similarly, Heppell, Heppell & Heppell (2015) note that the new spaces in schools "have been characterised by greater scale, a multifaceted layout with zones and activities marked out by furniture and colour, with little three sided spaces - nooks or booths - offering privacy without secrecy, and an intentional absence of traditional details like expensive corridors, rows of identical chairs, a teacher zone, or closed doors."

Dovey & Fisher (2014) analysed a sample of 59 notable and award-winning middle schools drawn from three international organisations. They used the plans to develop a typology of six spatial components: 1. classrooms – traditional closed learning space, 2. commons – a larger learning space that cannot be fully enclosed, 3. streetspace – a large pen learning space exposed to through traffic, 4. meeting area – a small learning area, 5. fixed function – a learning space with specialist use, and 6. outdoor learning – considered an integral part of the learning cluster. They propose that these components help simplify a complex range of places and allows space plans to be analysed showing the degree to which each of the spatial components appears and their interconnectivity with adjacent spaces.

Using their six components, Dovey & Fisher (2014) then proposed that the layouts of most schools can be categorised within a framework of five cluster types along a loose continuum from the traditional to the fully open plan. Their five types are: A. traditional classroom clusters, B. traditional classrooms plus streetspace, C. convertible classrooms, D. convertible streetspace and E. dedicated commons. The five types were nicely illustrated by Cleveland (Cleveland, Soccio & Love, 2016; Imms, Cleveland and Fisher, 2016) and form a spectrum of learning space designs, see Figure 4.



Figure 4. Five cluster types of learning spaces (Dovey & Fisher, 2014)

Dovey & Fisher (2014) intended to “reveal rather than to eliminate ambiguities and there are many variations that lie between and within the types diagrammed.” Plan types C and D labelled ‘convertible’ are those with a relatively high level of reversibility through the use of removable (folding, sliding) walls. They represent an architecture that is more likely to satisfy both traditional and student-centred learning at different times i.e. they represent the more recent ILEs.

In a recent study, Imms *et al* (2017) adopted a slight variation of Dovey and Fisher's five clusters of learning spaces and overlaid it with their own typologies of teaching practices, see Figure 3. Their slightly amended typology is: A. traditional closed classrooms entered by a corridor, B. traditional classrooms with breakout space, C. traditional classrooms with flexible walls and breakout space, D. open plan with the ability for separate classrooms and E. open plan with some adjoining spaces. When they compared the assessment of learning spaces with teaching practices, made by 6,000 school principals, they discovered that 70% of schools had traditional classroom types (Type A & B) but only 36% of the time was spent in teacher facilitated presentations (Type 1), see Figure 5. It is sometimes argued that open plan and ILEs are not so good for traditional 'chalk and talk' style teaching, due to noise and distraction, but it should be recognised that such teaching practices are no longer dominant in classrooms and, therefore, equally traditional classrooms are not best suited for the other increasingly common teaching activities.

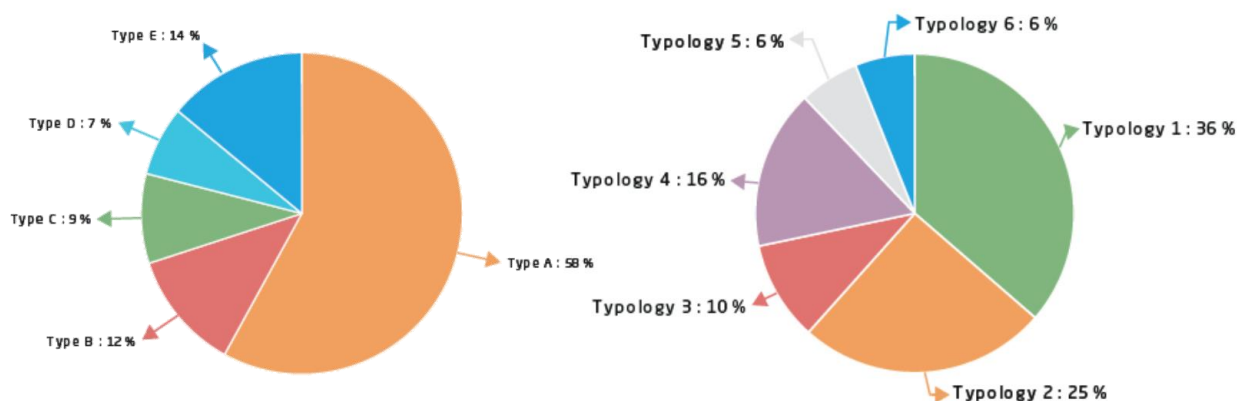


Figure 5. Comparison of typologies of learning space designs with teaching practices

Dovey & Fisher (2014) note that as a school becomes more open (Types C, D and E) it also becomes more exposed and possibly noisy, which may constrain the activities which it was initially designed to accommodate. The openness therefore produces a demand for segmentation or semi-enclosure and so many of the Type E spaces incorporate a variety of smaller separate 'retreat' areas. They conclude that "the most open of plans are often not the most adaptable because they constrain choice" but "the danger is that open plans are cheaper to construct than segmented ones and, for budgetary rather than pedagogical reasons, are more likely to be supported." The semi-enclosed and more flexible cluster types (C and D) appear to be the optimal solution in terms of construction, cost, use and success.

4.2.2 Successful and less successful ILEs

Imms *et al* (2017) remind us that whilst ILEs are celebrated by some for the new teaching practices that they facilitate, we must verify "whether the anticipated pedagogical value of these 'non-traditional' spaces is based on idealised visions of teaching and learning rather than sound evidence." Vinje (2014), cited by Eriksen (2014), is highly critical of the open plan schools being built in Norway and believes that the schools are not good for learning and are built on the basis of financial incentives and accommodating growing student numbers within the same space. Vinje comments "This is being done under the pretext of greater flexibility and more possibilities for adapted teaching, but the reality is often more noise, less concentration, and the practice of ability grouping that is pushing the limits of what is permissible under current regulations."

Cleveland, Soccio & Love (2016) conducted a qualitative evaluation of 12 learning environments with a mixture of the five cluster types shown earlier in Figure 4. All the learning environments that they evaluated were supportive of a range of teaching practices. However, small group work was identified as challenging in the more traditional classrooms (Type A and B).

Furthermore, the traditional classrooms were found to be less supportive of teacher supervision than the other three types of learning environments. In contrast, whole class work was identified as challenging in the more open 'dedicated commons' (Type E).

Despite their positive review of ILEs, Heppell, Heppell & Heppell (2015) comment that the new spaces have received mixed reviews "In many schools these have been spectacularly successful, with better engagement, better learning, better results and more enjoyment all round. They are bigger spaces, but they should not be the barn-like noisy open plan spaces of the 70s in any sense. Despite that success, in most cases staff still had to discover how it could all work for them, and for their students. Most did so successfully, but in a few cases the staff simply collectively wrung their hands and asked how they could carry on exactly as before now that their teachers' desks, or the walls, had gone? And they tried to use furniture, plants, screens, anything to (badly) recreate the 'closed boxes' of the 20th century." Training staff and changing mindsets is therefore of paramount importance for the success of ILEs.

In their survey of 6,000 school principals in Australia and New Zealand, Imms *et al* (2017) assessed teacher's mind frames. A teacher's mind frame is considered the mediating variable that directs how they think and act when engaged in all aspects of teaching. The study found that those "in schools with a higher prevalence of traditional classrooms reported a lower assessment along the teacher mind frame continuum, with the reverse in more flexible learning spaces." Imms *et al* also found that "students in traditional classrooms exhibited less deep learning characteristics, with the opposite in more flexible learning environments."

Plotting the mean scores on the teacher mind frames and student deep learning scales for all schools in each of the five learning space types, illustrates how flexible classrooms (their Type D and E) support these performance metrics better than other types, see the chart on the left of Figure 6. Imms *et al* then compared schools the schools with traditional classrooms (Type A). In this subset, they discovered that schools (shown in red) where the most teacher-centric teaching approach predominates (Type 1 in Figure 3) have much lower teacher mind frames and student deep learning. In contrast, for those traditional schools (shown in blue) where other teaching approaches predominate (Types 2 to 6 in Figure 3), the means of teacher mind frames and student deep learning are much higher. In conclusion, both the type of space and type of activity affect teacher performance (mind frame) and student learning.

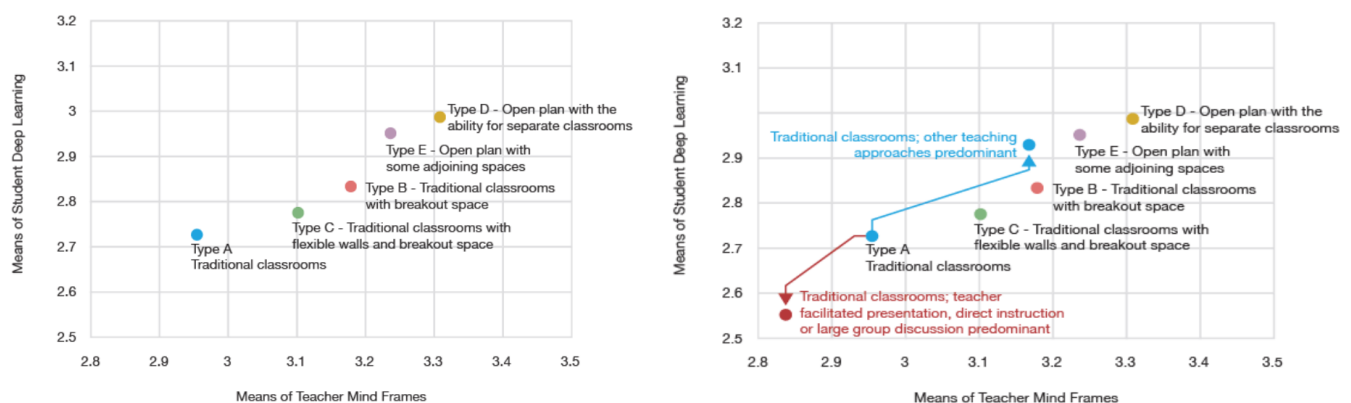


Figure 6. Learning space clusters by teacher mind frames and student deep learning

Vinje (2014) conducted surveys of 1,700 Norwegian teachers and found that 81% favoured the traditional classroom. He is quite critical of open plan schools and argues that "Through open learning spaces, architecture is becoming a lever that opens the door for a new type of pedagogy that has no basis in scientific research. It also conflicts with what teachers and parents believe provides optimal learning environments for children and adolescents." Furthermore, Vinje found that the open plan solutions had no pedagogical plan to support them

such that the traditional method of class grouping and teaching was retained. He claims that traditional teaching is not conducive to large open spaces, surrounded by small rooms, thus many teachers end up squeezing more students into the smaller rooms leaving the larger spaces unused. The issue here appears to be that staff were not motivated, or instructed how, to change their teaching style.

4.2.3 ILEs in further education

Another form of ILE is collaboration space, more commonly seen in further and higher education institutions. Graetz (2006) notes "The classroom is no longer a place where information is delivered to passive students. A growing number of students get that information elsewhere and do not expect to hear it repeated verbatim in class. Instead, the classroom is becoming an interactive, collaborative environment where knowledge is created actively by students." Nevertheless "Surveys indicate that the lecture is still the most common instructional method used by college educators in the United States." So, there is some uptake of collaborative spaces in colleges, but there appears to be some reluctance to uptake too.

Graetz & Goliber (2002) highlight the problems of using traditional college lecture theatres for collaborative learning: "You divide the class into five small groups and ask each group to solve a problem and present a solution. Anyone who has attempted such a feat can attest to the inadequacy of most college classrooms for supporting group work and the importance of the physical environment in determining the success of collaborative learning." They identify several other reasons why lecturers may not be adopting collaborative learning: "Their continued use of lectures probably stems from situational factors, specifically, the absence of support for alternative methods, the absence of extrinsic incentives to change, and the requirement to use classroom facilities inadequate for supporting collaboration." They also identify the layout (rows of desks), the space and density (lack of space required for group work) and noise as key barriers to uptake by college lecturers.

Braat-Eggen *et al* (2017) suggest there are two broad categories of learning spaces in higher education: formal and informal. Formal learning spaces are classrooms and lecture halls, whereas informal learning spaces are all other environments where students can work individually or in groups e.g. libraries, study areas, lobbies, atria, corridors, lounges, coffee shops, canteens, restaurants and outdoor spaces – mostly open plan spaces. The research of Braat-Eggen *et al* (2017) showed that 38% of their surveyed students observed are disturbed by background noise. The main disturbance is speech when performing complex cognitive tasks and significant, but weak correlations, were found between the room acoustic parameters, noise disturbance and people walking by. They revealed that students in open plan informal spaces work on group assignments, brainstorming and in discussion, thus producing speech-based noise. However, the space is also simultaneously used for concentration and individual work, which creates an acoustic dilemma. More than half (57%) of the students indicated they use earbuds or headphones to minimise distraction. Such open informal spaces are clearly unsuitable for such contrasting activities and require a wider range of spaces, or better coordination of activities, as in the more successful ILEs.

Scannell *et al* (2016) objectively measured acoustical characteristics and architectural features plus surveyed 850 students in 23 informal learning spaces in a Canadian university. They found that the sound levels tended to exceed maximum values recommended by standards. Some design features such as more vegetation, the presence of soft furnishings, and lower seating density predicted some perceived aspects of suitability. In these spaces, the students want to be able to talk to and hear colleagues in their small working groups, whereas noise (unwanted sound) may arise from background sources that are not part of the learning activity and so are distracting. In general, the acoustical aspects of the spaces were considered unsuitable for their learning activities. Scannell *et al* recommend limiting density, incorporating vegetation, including couches or other soft materials and enhancing speech intelligibility and privacy.

5.0 Classroom acoustics

5.1 Development of acoustic standards

In her detailed historical review of American schools, Baker (2012) identifies the timeline for introducing acoustic standards in schools. She refers to a 19th century reference to school design (Barnard, 1842, cited by Weisser, 2006) which reported that schools are “almost universally, badly located, exposed to the noise, dust and danger of the highway, unattractive, if not positively repulsive in their external and internal experience.” Nevertheless, many books were written on the design and construction of schools at the turn of the century e.g. Briggs (1899). However, Baker also notes that architects did not devote time to designing classrooms for acoustic performance until the late 1940s. The later consideration of acoustics may be because new models of learning were being introduced which required better acoustic control. Baker refers to Hamon (1948) who noted that “Sound control has become an important problem in schools, because of more informal school procedures and a greater use of non-sound-absorbent building materials.”

Baker quotes Luce (1949) who explained that “good hearing conditions in any room requires the satisfaction of four basic requirements: 1. sufficiently low level of background noise, 2. adequate separation of successive sounds (reverberation control), 3. proper distribution of sound within the space, 4. sufficient loudness of sounds.” Unfortunately, Luce also revealed that these acoustic principles were not implemented by the designers of schools constructed in that time. Baker (2012) notes that acoustical standards and research gained more popularity during the 1960s “especially as the industry sought feedback on the effects of open plan schools.”

The acoustic mantle was picked up again when “research conducted in the 1980s and 1990s greatly contributed to industry understanding of the necessity of good acoustical conditions in classrooms. These papers, which covered the importance of low background noise level, speech intelligibility and the avoidance of sites with periodic acoustic disruptions helped to identify not only that acoustics mattered, but also the appropriate thresholds for acoustical standards” (Baker, 2012). Since then many countries have introduced national standards for acoustics in schools and more recently more detailed and/or stringent best practice guidance has been introduced, for example through *BREEAM*, *LEED*, *WELL* and the IoA/ANC’s *Acoustics of Schools: A Design Guide* (2015). However, national standards use different acoustic criteria, as explained in the next section.

5.2 National standards for traditional classrooms

5.2.1 Design criteria

Barrett & Zhang (2009) explain that “the subject of room acoustics is concerned with the control of sound within an enclosed space. The general aim is to provide good quality conditions for the production and the reception of desirable sounds ... Comfortable and clear auditory perception, along with freedom from noise not only improves communication but also promotes working and learning efficiency.” They continue that “the essential requirements for good acoustics in learning spaces can be summarised as follows: an acceptable noise level, adequate levels of sound, even distribution to all listeners in the room, a suitable rate of sound delay for the type of room.”

In the UK, school acoustics is governed by Requirement E4 (in Part E of Schedule 1 of the *Building Regulations*, 2010) which refer to *Building Bulletin 93 (BB93)*. Interestingly, Requirement 4 only covers schools and not further or higher education. *BB93* also refers to the *Independent Schools Standards 2013* and *School Premises (England) Regulations 2012* “In a school with a good acoustic environment, people will experience good sound quality – enabling people to hear clearly, understand and concentrate on whatever activity they are involved in.” Regarding internal conditions, *BB93* specifies the indoor ambient noise levels ($L_{Aeq,30min}$), airborne sound insulation ($D_{nT,w}$), impact sound pressure level ($L'_{nT,w}$), mid-frequency

reverberation times (RT_{mf}) and the Speech Transmission Index (STI). Different levels are set for newly built schools and refurbished ones, and more stringent criteria are set for open plan classrooms, see Table 3.

Other European standards and guides use similar criteria. For example, Eggenschwiler & Cslovejsek (2008) refer to the *TC-RBA WG3* report of the European Acoustics Association which recommends for open plan classrooms an RT 0.3-0.4 s, acoustic attenuation between two teaching groups of <15-20 dB and an STI >0.6 within teaching groups and <0.2 s between teaching groups. These seem in-line with some of the national standards listed in Table 3. Møller Petersen & Rasmussen (2012) refer to *Guideline 218* published by the SBi (Danish Building Research Institute; Hoffmeyer, 2008). The report contains recommendations and guidelines on effective sound reduction (by 15-20 dB) as well as managing the STI , see Table 3. It also recommends large amounts of absorption resulting in very short reverberation times. Some national standards include the Speech Transmission Index (STI) whereas others do not.

The New Zealand Ministry of Education (2016) highlight that listening is critical to the learning process and, while there may factors affecting student listening ability, the following acoustic factors can be managed through good design: ambient noise, activity noise (from other learning activities in nearby spaces), reverberation and low signal-to-noise ratio, sometimes referred to as speech-to-noise, or signal-to-noise, ratio (SNR) i.e. the ratio of the teacher's voice to the ambient noise. Shield *et al* (2015) estimate that 40% and 50% of teaching time is spent in plenary sessions with the teacher speaking to the whole class. Imms *et al* (2017) estimate that only 36% of the time was spent in teacher facilitated presentations. Therefore, it is essential that the acoustic design of the classroom enhances STI throughout the classroom and the SNR .

Guidance from The National Union of Teaching (NUT, 2013) emphasises the importance of SNR . The sound level of the teacher's voice minus the background noise level in the room equals the SNR – the larger the SNR , the greater the speech intelligibility, whereas if the SNR is negative the teacher will be hard to understand. The NUT suggests that "in classrooms having a signal-to-noise ratio of less than +10 dB, speech intelligibility is significantly degraded for children with average hearing. Ideally, for good speech intelligibility, the level of the voice needs to be at least 10 to 15 dB above the background noise level." They also propose RT s in the range of 0.4-0.8 s but comment that reverberation times in many classrooms fall outside these limits.

The American ANSI S12.60 standard specifies maximum background noise level and RT along with specifications for Sound Transmission Class (STC) ratings for wall assemblies and Impact Insulation Class (IIC) ratings for floor-to-floor noise transmission.

In summary, in terms of acoustics ambient noise levels need to be maintained at a reasonable level (L_{Aeq} 35-40 dBA), reverberation times minimised (RT <0.5 s), speech intelligibility improved in the classroom (STI >0.6), but reduced between classrooms (<0.2), and speech-to-noise ratio increased (SNR +15 dB).

Before moving to the next section, it needs to be pointed out that noise is commonly defined as 'unwanted sound'. Humans convert air pressure waves to sound, through perception, and then through cognition determine if those sounds are either noise or acceptable depending on the meaning and context etc. (Oseland and Hodsman, 2017). So, in the classroom, the sound level is only considered noise if found distracting by the teacher or students for the task in hand. Introducing music for example, through speakers, will increase the ambient sound level but it may not be distracting or annoying (a noise) for all and, research shows, could even help some personality types improve their performance. Similarly, higher sound levels are likely to be more acceptable for group work or less focussed tasks. It is a pedantic point, but nevertheless whilst most standards and research refer to noise levels, they actually mean sound level (and L_{Aeq} is defined as a sound level, not noise, measurement).

Country	Standard/Guidance	Type	ANL L _{Aeq} (dBA)	RT (s)	STI within	STI between	SNR (dBA)	Notes
Australia	AS/NZS2107:2000	Enclosed	<35	<0.4-0.5			+15	
Australia		Open						No information
Canada		Enclosed		0.4-0.5				
Canada		Open						No information
Denmark	SBI Guidelines 218	Enclosed			≥0.6	≤0.2		
Denmark	SBI Guidelines 218	Open	30	<0.3-0.4	≥0.6	≤0.2		
Finland	SFS 5907	Enclosed	28 ⁱ , 33 ⁱⁱ					ⁱ Class A/B, ⁱⁱ Class C
Finland		Open						No information
Iceland		Enclosed		≤0.4	≥0.6	≤0.2		
Iceland		Open						No information
New Zealand		Enclosed						
New Zealand	Designing Quality Learning Spaces	Open	35-45	0.5-0.8 ⁱ				ⁱ flexible learning spaces
Norway		Enclosed		≤0.4 ⁱ				ⁱ higher education
Norway		Open						No information
Slovakia	STN 73 0527:1975	Enclosed		0.6-0.8				
Slovakia		Open						No information
Sweden		Enclosed		≤0.4 ⁱ				ⁱ higher education
Sweden	SS 25268:2007	Open	30	0.4				
UK	Building Bulletin 93	Enclosed	35 ⁱ , 40 ⁱⁱ	≤0.6 ⁱⁱⁱ , ≤0.8 ^{iv} ≤0.8 ^v , ≤1.0 ^{vi}				ANL = L _{Aeq,30mins} , ⁱ new build, ⁱⁱ refurbished RT = T _{mf} , ⁱⁱⁱ new primary, ^{iv} refurbished primary ^v new secondary, ^{vi} refurbished secondary
UK	Building Bulletin 93	Open	40 ⁱ , 45 ⁱⁱ	≤0.5	≥0.6	≤0.3		ⁱ new build, ⁱⁱ refurbished
USA	ANSI S12.60-2002	Enclosed	35 ⁱ	0.6 ⁱⁱ , 0.7 ⁱⁱⁱ			+15	ⁱ volume of space <566 m ³ ⁱⁱ volume of space <283 m ³ , ⁱⁱⁱ 283-566m ³
USA	ANSI S12.60-2002	Open	40 ⁱ					ⁱ volume of space >566 m ³

Table 3. National standard for traditional and open plan classrooms

5.2.2 Field measurements

Shield, in her introduction to the *Essex Study* (Canning & James, 2012) comments that "Problems caused by noise and poor acoustic design in educational settings have been recognised for over 100 years. If noise levels are too high or rooms are too reverberant pupils find it difficult to hear and understand their teachers, while teachers find it difficult to speak and often suffer from voice disorders as a result of continually raising their voice. Despite the introduction of various guidelines over the years aimed at ensuring good speaking and listening conditions in schools, many schools continue to be built which are acoustically 'unfit for purpose' with high noise levels and reverberant conditions creating difficulties for both pupils and teachers."

The NUT (2013) draws a similar conclusion: "Teaching and learning are acoustically demanding activities. It is recognised, however, that a great number of classrooms in England and Wales have poor acoustics." Even after the introduction of *BB93* "some new schools are failing to comply with minimum statutory requirements on acoustics."

Mydlarz *et al* (2013) surveyed 203 classrooms in 12 UK schools. They found that the ambient noise levels (L_{Aeq}) in 67% of the surveyed classrooms had noise levels above the *BB93* recommendation. They also discovered that student density had high significant negative correlations with noise level. These correlations are understandable as more students in a smaller classroom space would inevitably lead to increases in noise level (and also CO_2 , another potential issue). Mydlarz *et al* also investigated the difference between open plan and traditional cellular classrooms but, surprisingly, they found that "it would seem that these room types have similar L_{Aeq} values."

Shield *et al* (2015) examined enclosed classrooms in 13 UK schools and open plan ones in four schools. The average open plan ambient noise levels (L_{Aeq}) were slightly higher than the traditional classrooms, by 1.8 dBA, but close to standards. They believe the slightly higher noise levels are due to traffic surrounding the inner city open plan schools and conclude that "unoccupied noise levels and reverberation times in open plan spaces generally conform to current required standards." They also found that the STI was similar in the traditional (0.71) and open plan classrooms (0.74). So, it appears some classrooms, regardless of whether traditional or open plan, perform acoustically better than others. Non-acoustic factors include the management of student behaviour, the types of activity being carried out within and around the classroom, and the coordination of those activities.

Zannin and Marcon (2007) reported that every objectively measured acoustic characteristic (background noise, reverberation time, sound insulation) of the classrooms studied fell short of Brazil's national standards. Shield *et al* (2015) also report that surveys of primary schools show background noise levels in unoccupied classrooms approximately averaging 40-48 dBA in UK, 33-54 dBA in USA and 33-44 dBA L_{Aeq} in Italy. So, it appears Italian schools are better at meeting standards. They also report that in university classrooms noise levels are lower and in-line with standards. The classroom activities and teaching style clearly affect noise levels.

5.3 Additional requirements for open plan

5.3.1 Noise level and reverberation time

Campbell (2017_b) notes that "From an acoustic perspective it is quite straightforward how to secure a good acoustic environment in traditional classrooms, depending on the volume, geometry and construction of the materials ... However, moving from traditional cellular classroom creates more challenges around the sound environment when doors and walls are removed." Likewise, the New Zealand MoE (2016) report focuses on acoustics in ILEs: "just as in traditional classrooms, for these flexible spaces to support learning it is important that they are acoustically engineered to address potential background noise issues."

From an acoustics perspective, it therefore appears that with care it is possible to design successful flexible classrooms, but perhaps less so for fully open plan environments. The USA standard on classroom acoustics, *ANSI 12.60*, actively discourages the use of open plan classrooms: "Adequate noise isolation between adjacent learning groups cannot be assured unless each learning group is fully enclosed by ceiling-height sound barriers. Because of the inherent low noise isolation, partially enclosed or unenclosed learning spaces are not recommended when good speech communication is desired." The standard, however, assumes that classrooms are either enclosed or not, and does not appear to recognise the new varieties of flexible or semi-open plan classrooms, or Type D and E ILEs. It does, however, recognise that acoustics requirements are activity based.

The New Zealand MoE (2016) reports states that "The evolving focus on self-directed learning reduces the traditional emphasis on acoustic connections between the teacher's voice and the whole-class group. It establishes the need for acoustic privacy for students engaged in self-directed learning or in small group tasks, and acoustic management of larger spaces to reduce background noise, particularly during collaborative learning sessions." Furthermore "With careful acoustic design didactic teaching can also be carried out side-by-side in flexible learning spaces." As guidance, the report offers the following four key acoustic parameters are:

1. **Reverberation time** – An RT of 0.5-0.8 seconds for flexible learning spaces and 0.4-0.5 for breakout and meeting spaces.
2. **Sound insulation performance** – A Sound Transmission Class (STC) value of 50 between walls of separate flexible learning spaces and breakout spaces. However, for 'coordinated flexible learning spaces' the STC values do not apply, but adequate sound insulation and absorbent materials are required.
3. **Impact sound insulation** – Achieve a minimum Impact Insulation Class (IIC) performance of 55 between floors.
4. **Ambient noise level** – An ANL of 35-45 dBA (L_{Aeq}) for flexible learning, breakout and meeting spaces.

The MoE guide distinguishes between separate flexible learning spaces, managed independently, and coordinated ones, connected to form a learning hub, see Figure 7. Furthermore "Where separate learning hubs are connected via openings, void spaces, open stairwells, or are part of a larger space, the sound-ratings do not apply. In these cases, sound separation should be achieved through a combination of distance, screening and sound absorption. Some coordination between learning hubs may be required." The New Zealand design criteria are shown alongside other National Standards for 'open plan' classrooms in Table 3. Some standards have further requirements for non-traditional classrooms.

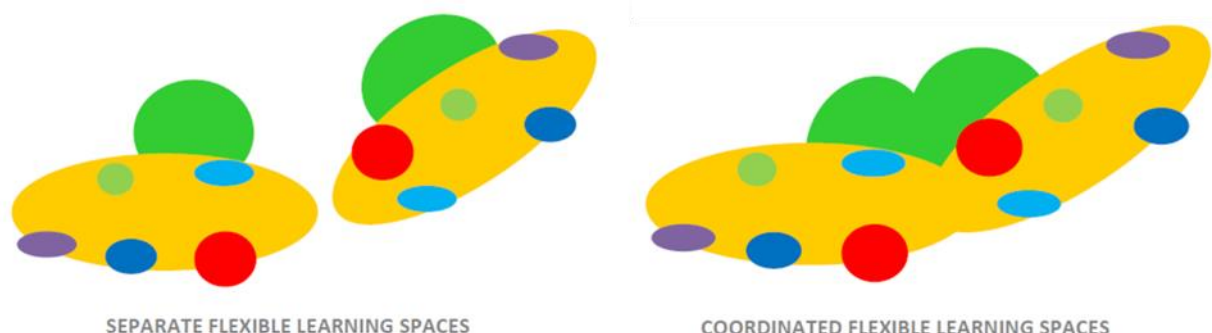


Figure 7. Separate and coordinated flexible learning spaces

Petersen (2002) recommends a maximum reverberation time of 0.3-0.4 s for open plan classrooms, which is consistent with the findings of Greenland, Shield & Dockrell (2009) who recommend <0.4 s for furnished, unoccupied classrooms. The IoA/ANC (2015) recommend that "In the absence of full partitioning to control sound transmission, it is essential to control reverberation times and reverberant sound levels as far as possible, to cope with the reduced signal-to-noise ratio due to higher intrusive noise. For this reason shorter reverberation times are required in open plan classrooms compared with enclosed classrooms."

Canning & James (2012) conducted a six-month experimental study of Swayne Park School, referred to as the 'Essex Study'. They used four similar classrooms in the Mathematics department and acoustically modified three of the classrooms, on three separate occasions, and used the fourth classroom as a control. Visual clues to the changes were kept to a minimum creating a blind study in which the staff and pupils did not know when changes were made to the classrooms. The experimental conditions were: 1. 'Untreated' – slightly outside the *Building Bulletin 93 (BB9)* minimum standard, 2. 'BB93' – meeting the requirement in *BB93*, 3. 'BB93 HI' – the *BB93* requirement for classrooms specifically for use by pupils with hearing impairment and 4. 'BATOD' – meeting the standard recommended by the British Association of Teachers of the Deaf.

Canning & James (2012) found that the RT was significantly lower in the 'BB93 HI' and 'BATOD' conditions, achieved by introducing plasterboard which provided significant absorption at low frequencies. They also found that the reduction in RT from the 'Untreated' to 'BB93' conditions, from 1.2 to 0.8 s, resulted in a decrease in ambient noise levels of 9 dB. Furthermore, the difference in RT between the 'BB93' and 'BB93 HI'/'BATOD' conditions, from 0.8 to 0.4 s, resulted in a further 9 dB decrease. The researchers quite rightly comment that "an 18 dB decrease is very significant indeed." Absorption therefore appears to affect both RT and the ambient noise level.

5.3.2 Speech Transmission Index (STI) in open plan

In the UK, *Building Bulletin 93 (BB9)* highlights that open plan classrooms do not satisfy the normal means of meeting *Building Regulations*: "open plan spaces require additional specification as they are significantly more complex acoustic spaces. The main issue is that intrusive noise arising from activities in adjacent learning areas and circulation spaces significantly increases the background noise level, which in turn decreases speech intelligibility and can cause distraction." As such, "In order to comply with the *School Premises Regulations*, the *Independent School Standards* and the *Equality Act*, it is necessary to consider the Speech Transmission Index (STI) in open plan spaces (both new build and refurbishments), and it is strongly recommended that STI criteria for open plan accommodation are incorporated as a contractual requirement within the employer's requirements/design brief."

BB93 is also initially disparaging of open plan classrooms: "Occupants working and talking within the space tend to raise their vocal effort as the background noise level increases, resulting in a spiralling increase in noise levels. This can be reduced, but not eliminated, by the provision of large amounts of acoustic absorption. Open plan teaching and learning spaces should not be regarded as a simple alternative to traditional classrooms and may be unsuitable for some children." However, *BB93* also recognises the importance of activity when setting acoustic criteria: "in some instances, open plan designs may not be intended for critical listening activities, or multiple and simultaneous independent instruction. For example, critical listening activity may only occur as a single, plenary session (i.e. having negligible intrusive noise from adjacent areas), followed by break-out activity sessions. These breakout sessions may only involve less critical personal listening activities (e.g. one-to-one or small group instruction, paired or small group work) or individual study. In this case it is necessary to demonstrate STI compliance for the plenary session only, provided that the reverberation time target is also achieved."

In their recent report which builds on *BB93*, the IoA/ANC (2015) verify that open plan spaces must address speech intelligibility because intrusive noise arising from activities in adjacent learning areas significantly increases the background noise level, which in turn decreases speech intelligibility and causes distraction. As a consequence, "Occupants working and talking within the space tend to raise their vocal effort as the background noise level increases, resulting in a spiralling increase in noise levels, *unless sound absorbent finishes are provided.*" They recommend an STI of ≥ 0.6 s for instruction or critical listening activity within a group and an STI ≤ 0.3 s for critical listening activities between groups. However, it should be noted that sound absorption can help dramatically improve speech intelligibility.

5.3.3 Signal to Noise Ratio (SNR) in open plan

Shield, Greenland & Dockrell (2010) recommend that "For open plan classrooms with dynamic learning activities and varying intrusive noise levels, it is more appropriate to use a design criterion such as STI which combines both speech-to-noise ratio and reverberation in a single parameter." They summarise that "The literature generally recommends providing at least 15 dB speech-to-noise ratio throughout the classroom (with reverberation time controlled to 0.5 s) to ensure that all participating listeners are able to receive the signal without degradation." Shield, Greenland & Dockrell cite Houtgast (1981) and Bradley (1986) who showed that in classrooms with occupied reverberation times of less than 1.2 s, student speech intelligibility scores improved as the SNR increased to +15 dBA.

In their own research, Shield *et al* (2105) found the ambient noise levels in open plan and enclosed classrooms were similar, but the averaged approximated SNR for plenary activity was 4 dBA less (poorer) in open plan classrooms. On first appearance, rooms having similar noise levels but a difference in SNR seems contradictory. However, Shield *et al* conclude that "The particular difficulties caused by distraction from intrusive noise in open plan classrooms are likely to be due to the 'irrelevant speech effect' reported in open plan offices rather than to high levels of classroom noise."

5.4 Acoustic design of future schools

Twenty-first century national standards acknowledge the need for good acoustics in schools and recommend a number of metrics and criteria to provide acceptable noise levels in schools. Nevertheless, many schools, regardless of whether traditional enclosed or modern open plan, fail to meet the standards. More stringent criteria are placed on open plan schools because of the potential of interference and distraction from adjacent classes and conflicting activities.

The standards, and reports of poor open plan schools, mostly reflect the unsuccessful large open plan spaces of the 1960s-70s rather than the new successful ILEs founded on a change in pedagogy, teacher attitude, learning style, coordination of classroom activities, and management of student behaviour, all accompanied by a range of design features aimed at minimising distraction. It appears that acoustics is a challenge in all schools and more open environments can magnify the problem if not designed and managed well. However, it also appears that the more involved and collaborative approach to designing the new ILEs results in acoustics being more likely to be considered at an early, rather than remedial, stage of the design process.

6.0 Impact of noise in classrooms

6.1 Effect on students

Whilst many reviewers report that noise has a negative effect on student performance, Shield *et al* (2015) conclude that the evidence from schools actually indicates that the effect of noise on student behaviour and attainment is complex, depending not only on classroom conditions and individual factors concerning the child but also on the task being undertaken and the corresponding cognitive demands.

Indeed, in her detailed review, Weinstein (1979) refers to Slater's (1968) study of seventh-graders' performance on a standardised reading test under three noise conditions, ranging from 45 to 90 dBA. She concludes that "the data analysis revealed no noise effects, either detrimental or facilitating, on speed or accuracy of performance." She then reports on her own study which examined the impact of noise in an open plan school on reading comprehension. She found no differences in the reading performance of fourth-graders under quiet and normal background noise levels. However, Weinstein (1979) concludes that "Although effects have not been found in these short-term studies of internal school noise, there is evidence that long-term exposure to extreme noise may have a detrimental influence on performance." For example, Mealings *et al* (2014) found that high noise levels adversely affect speech perception, cognition, concentration, and the psychoeducational and psychosocial achievement of students.

Zannin and colleagues have carried out several studies of schools in Brazil. Zannin and Marcon (2007) interviewed 62 teachers and 462 students in Brazil and both groups reported that noise in the classroom was a major source of disturbance and came mostly from other classrooms. Presumably, teachers and students in adjoining classrooms spoke too loudly. In a prior study, Kruger and Zannin (2004) showed that classrooms were not a productive and comfortable place to acquire knowledge, because of poor acoustics. Zannin and Zwirter (2009) carried out a study comparing schools built in 1977–2005. Despite reverberation time, sound insulation and ambient noise levels meeting standards, they found that many classrooms are simply not comfortable places to acquire knowledge or to be mentally focused at all time, due to noise interference. They conclude that even when following best practice, the results are sub-optimal for a learning environment.

In their review, Barrett & Zhang (2009) refer to Schneider (2002) who commented that in general the research demonstrates that good acoustics are fundamental to good academic performance. They also cite Evans & Lepore (1993) who studied 1,358 students aged 12–14 years, in their own classrooms but under different noise conditions, and found that a statistically significant decline in recall performance was associated with the noise conditions. However, in a later study Barret, Davies & Zhang (2015) compared the national curriculum points, of 3,766 students in 27 schools with physical factors, and found only a weak correlation with noise (assessed through sound level measurements and expert evaluation). Their multiple regression analysis revealed seven key design parameters that accounted for 16% of the variability in pupils' learning progress, notably: light, temperature, air quality, ownership, flexibility, complexity and colour.

Sparks (2015) reports that sound can increase stress and interfere with memory and learning. She refers to a 2013 study in which 8 and 9 year-old students exposed to higher ambient noise levels in school performed significantly worse on standardized tests in mathematics and French language: "A difference of 10 decibels of regular background noise was associated with 5.5-point-lower scores on average in both subjects." She believes that "low-volume but chronic ambient noise raises cortisol, a chemical marker of stress, in both children and adults, but younger children are especially sensitive to it." In another cited 2014 study, Swedish students were asked to learn texts in either a quiet classroom or one with background speech. Text was more difficult to remember in a classroom with background speech. Sparks (2015) also quotes UK research on the working memory of students aged 8–10 years exposed to 65 to 85 dB of

white noise. They found that students assessed as having good attention skills were affected worse by the noise. However, they also found that students with poor attention skills benefited from the additional noise. The latter finding may be related to arousal theory and the view that those with a lower level of arousal require stimulation (Oseland & Hodsman, 2017).

Lewinski (2015) focuses on the effects of noise on younger children, citing Chiang & Lai (2008), Mills (1975) and DiSarno *et al* (2002) and claims that noise influences not only learning outcomes but also their health. Lewinski concludes that, in the case of young children, they have not yet developed enough executive skill in activities involving communication channels, like speech comprehension, use of language, and written and oral skills, "Therefore, interference profoundly interrupts the process of acquiring those essential capacities in children, and noise is far from the only possible kind of interference. Noise undermines reading, writing and comprehension skills, as well as overall academic performance, as noise makes it hard to focus on the task being performed."

6.2 Effect on teachers

The 'Essex Study' conducted by Canning & James (2012) was referred to earlier in Section 5.3.1 – they compared the noise measurements and teacher responses in classrooms designed to different acoustics standards. They found that the rooms built to the more stringent standards, i.e. 'BB93 HI' and 'BATOD', clearly have the best perceived quality (a lower score) according to the teachers, Figure 8.

The majority of studies which have examined the impact of noise on teachers, invariably end up showing an effect on teacher voice disorders, or dysphonia. The NUT (2013) in the UK claim that poor acoustic conditions in the classroom increase teachers' vocal strain as most teachers find it difficult to make themselves heard above high noise levels. Furthermore, recent surveys in the UK and elsewhere have shown that the incidence of voice strain/loss amongst teachers is amongst the highest across all occupations. Mealings *et al* (2014) concur reporting that only 5% of the general population experience vocal fatigue whereas it is experienced by 80% of teachers, putting them at high risk of vocal abuse and pathological voice conditions. They also suggest that noise raises blood pressure, increases stress levels, causes headaches, and results in fatigue so that teachers in classrooms with poor acoustics are more likely to take sick leave. Similarly, Chen *et al* (2010) note that "teachers are the most likely to develop voice problems of any professional group" and that up to "89% of teachers have been reportedly experienced a variety of vocal symptoms such as vocal fatigue, dysphonia, increased phonation effort, dry throat, tightness, sore throat, etc." This is mainly because "teachers often spend long periods of time talking loudly in noisy environments and in stressful situations."

Anderson (2004) also found that teachers have to increase their speaking loudness level to maintain speech intelligibility and teaching efficiency in a classroom because the background noise is almost as loud as teacher's voice. In her doctoral thesis on teacher voice problems, Åhlander (2011) cites Vilkmann (2000) who summarises that investigations of complaints among teachers, show that the majority have experienced vocal problems with 10% suffering from severe problems and 5% experiencing problems so severe that their working ability is questionable. Likewise, Pekkarinen, Himberg & Pentti (1992) reported that 40% of the teachers compared to 23% of nurses found the background noise disturbing, and that the noise from inside the classroom was considered more disturbing than that coming from outside.

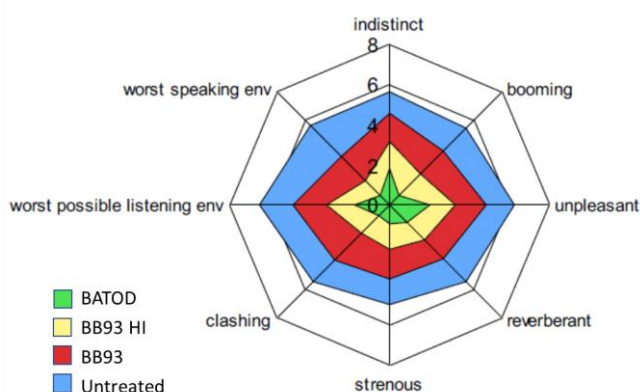


Figure 8. Teacher's perceived classroom quality

Åhlander (2011) notes that several researchers attribute the cause of vocal stress to the Lombard effect (Lane & Tranel, 1971) in which the speaker automatically raises their voice to compete with background sounds. She also notes that "Teachers commonly work in a stressful environment with high vocal and psychological demands and a large number of students" thus stress is another contributing factor adding to voice load. In her own study of teachers in 22 Swedish schools, Åhlander found that 13% of her sample reported voice problems. Whilst there was some relationship between the voice and classroom acoustics, most "comments were seldom about the physical environment but mostly about trying to get the students to talk in more hushed voices, or to resist straining their own voice by using written instructions, handclapping to draw attention, or simply to talk less." Furthermore, a number of teachers with voice problems changed to small-group teaching to decrease their vocal load.

Chen *et al* (2010) conducted their own study of 117 Taiwanese teachers and compared those with and without voice disorders, identified through a self-assessment. The voice disorder group used a loud voice in classrooms and "had significantly greater effects in changing overall job opinions, reduction of overall communicative ability, decreasing phone calls, reduction of overall social ability, influence on overall emotional state, and the frequency of being upset" compared to those without voice disorders.

In the more recent New Zealand MoE (2016) the Oticon Foundation's study of traditional primary school classrooms is cited. The study revealed that: 1. some 71% of teachers felt that internal classroom noise was a problem, 2. more than 33% of teachers indicated they had to speak at a level that strained their voices and 3. around 50% of teachers said they had to considerably raise their voices during group work.

Oberdörster & Tiesler (2006) studied the impact of sound pressure level ($L_{Aeq,5min}$) on teacher heart rate (HR), a proxy for stress. They compared 33 teachers taking different classes at the Baumberge Schule in Havixbeck in Germany. Figures 9 illustrates how the SPL is improved (decreased) post-refurbishment in two classes. Furthermore, the HR is loosely correlated with SPL, so the acoustic refurbishment also reduced teacher stress. In a later study of teachers in 175 classes, Tiesler, Machner & Brokmann (2015) found that poor acoustics conditions increase the sound level placing more strain on the teacher's voice and thus increasing stress.

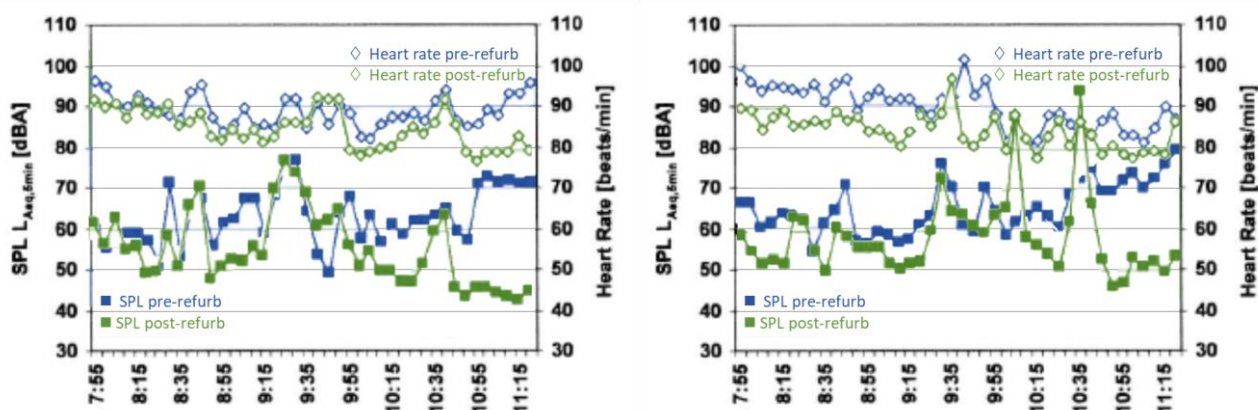


Figure 9. SPL and HR pre and post refurbishment in two classes

The main focus of this report is the relationship between teacher personality and classroom noise. Very few studies of noise in classrooms refer to personality, but Åhlander (2011) cites Roy, Bless, & Heisey (2000) who found that the majority of people with functional dysphonia tend to be introverts. In contrast, Pekkarinen *et al* (1992) did not find any significant correlation between the Extroversion and voice problems.

7.0 Impact of open plan classrooms

7.1 Acoustic field measurements

The rise of the open plan classroom in the 1960s-70s and reintroduction of improved variations of open plan and ILEs has resulted in a number of field studies of the acoustic properties of such spaces. Shield, Greenland & Dockrell (2010) provide a detailed review of historic studies carried out over the 40 years prior to their review. Four studies made a direct comparison between noise levels in open plan and enclosed classrooms but only one (Finitzo-Hieber, 1988) found significantly higher average noise levels in open plan classrooms (by 3 dB). However, Shield, Greenland & Dockrell comment that the latter study assessed a fully open plan area with 100 students which is not typical of today's open plan designs. Despite similar sound levels, they report that "perceptions of higher noise levels, distraction and disturbance by noise in open plan classrooms are consistently reported" which is more likely due to the intrusive noise from neighbouring classes rather than the noise generated within the classroom.

Greenland & Shield (2011) studied 42 open plan classbases (classes taking place within a larger open plan area) in 12 primary schools across southern England. Their schools included the full range of open plan unit sizes and layouts, but all were of semi-open or flexible open plan design. The most commonly occurring classroom activity was work at tables (58%) followed by whole class teaching (23%). They found that the mean intrusive noise level increased with increased activity in the adjacent classbases. They also found a significant increase in mean noise level when the number of classbases increased above three, whereas the STI was significantly better with fewer classbases (the average STI was also better for classbases with sound absorbent ceilings). As a consequence, they recommend limiting the number of classbases to three in one open plan area.

Pavčková, Rychtáriková & Tomašovič (2009) also note that "The problems of classroom acoustics become even more complicated when a room is used by several teachers working with groups of students independently of each other." They examined the speech intelligibility in two different classrooms where two teachers and their student groups were present at the same time. They then modelled the two settings exploring the effect of different types and levels of absorption on the STI in group work. Good ceiling absorption (the whole ceiling), screens and a good volume of space produced the best results. Smaller classrooms do not allow for sound sources to be placed far enough apart, hence they recommend at least 6 to 7 m between working groups in the same space.

In an earlier study, Barnett, Nichols & Gould (1982) compared an enclosed classroom of 30 children with an open plan classroom consisting of two groups of 30 children, but with a similar student density. No significant difference was found between noise levels in the open plan and enclosed classroom. Similarly, Wohlwill & van Vliet (1985) examined the effects of high density classrooms on students. They concluded that high density classrooms, with too many children or too little space, results in interference, reductions in privacy and loss of control, and can lead to excessive student stimulation, increased arousal and stress.

Mealings *et al* (2014) Compared the acoustics of an enclosed classroom of 25 students with an open plan Kindergarten classroom containing 91 children in three groups in Sydney. Their results revealed much higher intrusive noise levels (noise heard from other classes) in the open plan classroom and both the SNR and STI dropped dramatically below standards. Mealings *et al* "strongly suggest that open plan classrooms of this size or larger are not appropriate for speech communication because of their high intrusive noise levels." They also found that the reverberation time in the open plan classroom was also outside the recommended level. So, it appears that the size of the number of students in the open plan class and the volume of space are critical.

Mydlarz *et al* (2013) found that during lessons, the ambient noise level is significantly correlated with student numbers, with an increase of 0.33 dB (L_{Aeq}) per student. Similarly, Shield *et al* (2015) examined noise levels in 274 classes in 185 (enclosed and open plan) teaching spaces in 13 UK schools. They found significant correlations between the number of students and noise levels.

The total number of students and classroom density (students per m^2) therefore appears to be a key design variable for creating good acoustics, and other learning factors. It is therefore feasible that any observed detrimental effects of open plan may be more associated with an increase in student numbers and density rather than the design *per se*. In the office world, there is good and poor open plan design – the poor is usually high density with fewer alternative work-settings and facilities (Oseland, 2016).

Pääkkönen *et al* (2016) evaluated the acoustic performance of classrooms in the Oulu Normal School, a Finnish school with new learning spaces. The survey showed that the airborne sound insulation and background noise level did not meet the Finnish standards. However, impact sound insulation, STI and RT were all within the (Class C) recommendations. The researchers revealed better results for the spaces with carpet and acoustics panels across the whole ceiling (e.g. room R134 in Figure 10). The researchers also propose that the attenuation of sound over 5 m and the cooperation by users of the space are the most crucial factors.

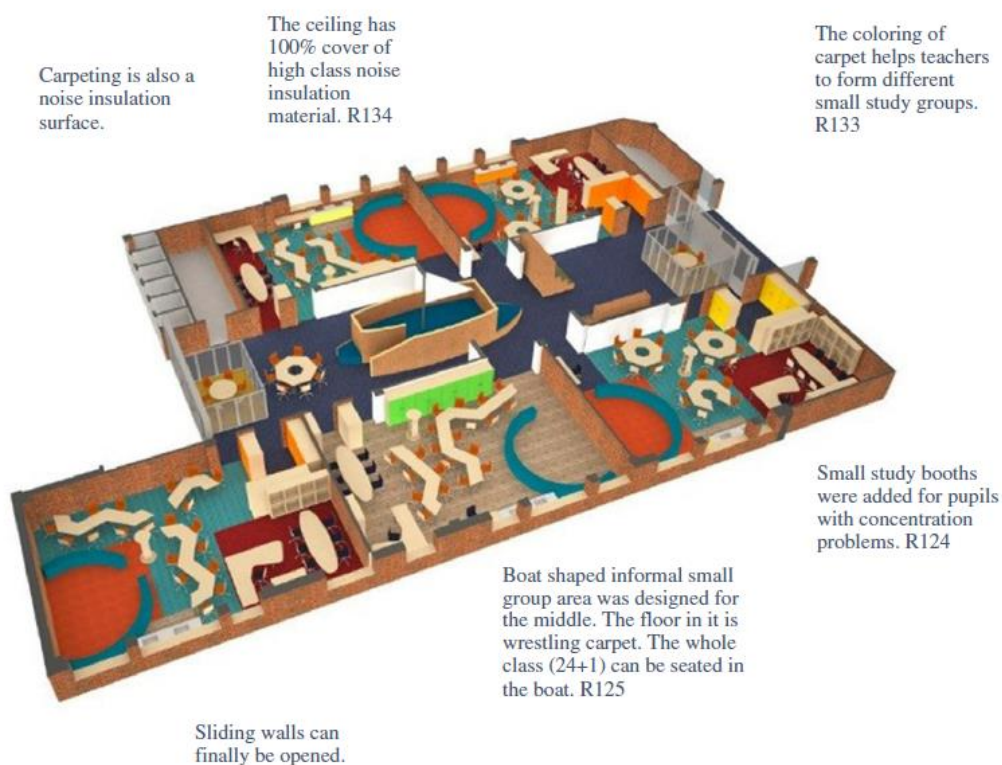


Figure 10. Axonometric plan of Oulu Normal School, a Finnish ILE (Pääkkönen *et al*, 2016)

In contrast, Møller Petersen & Rasmussen (2012) describe the design, measurements and subjective evaluation of two Danish schools undergoing acoustic treatment: Hellerup School one of the newer open plan schools completed 2002, and Absalon School, Holbæk, a new semi-open plan school completed 2005. In 2010 the Hellerup School underwent acoustic improvements including more absorption on surfaces and through free-moving panels, and by creating 'hexagones' – hexagonal acoustic pods (Figure 11). The new semi-open plan design improved the RT and STI measurements. As in Hellerup, absorption was added to the surfaces and 30 moveable absorbing screens introduced to the open areas at the Absalon School. As a

consequence, the RT and sound level was reduced in the teaching areas, and also the staff perceived less noise. Møller Petersen & Rasmussen conclude that, according to the users, the general conditions at both schools are satisfactory due to optimised acoustical conditions and the teaching methods adapted to the special open environment.

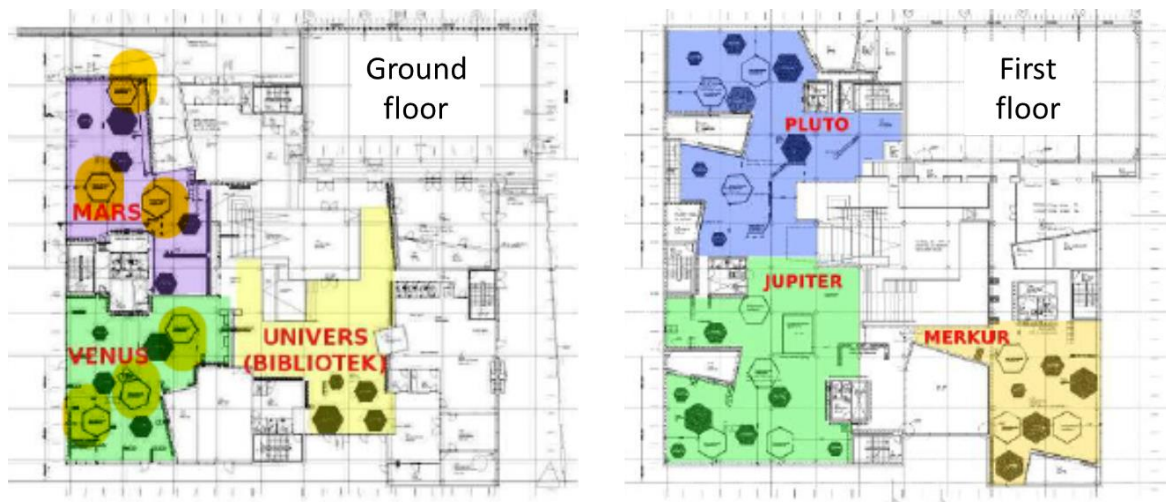


Figure 11. Plans of Hellerup School showing 'hexagones'

Mahat & Campbell (2017) evaluated the Berufliche Schulen Witzhausen in Germany, which has a large plenary area with smaller rooms coming off it. They introduced glass screening, storage walls, plasterboard barriers in the ceiling void, and side-on and staggered entries to the classbases. The school design resulted in an RT of 0.48 s and STI >0.7, which are both good results. The sound map (Figure 12) illustrates how the design inhibited sound transmission across the space despite the flexible open plan layout.

Mahat & Campbell also examined De Werkplaats in the Netherlands. The school added a new open plan learning landscape to their traditional classroom layout. They added wall absorbers to reduce class to class disturbance. Based on their two case studies, Mahat & Campbell offer recommendations based on both physical (acoustic treatments) and leadership/behavioural solutions. They also propose exploring the impact of teachers' personality profiles on working in open plan classrooms.

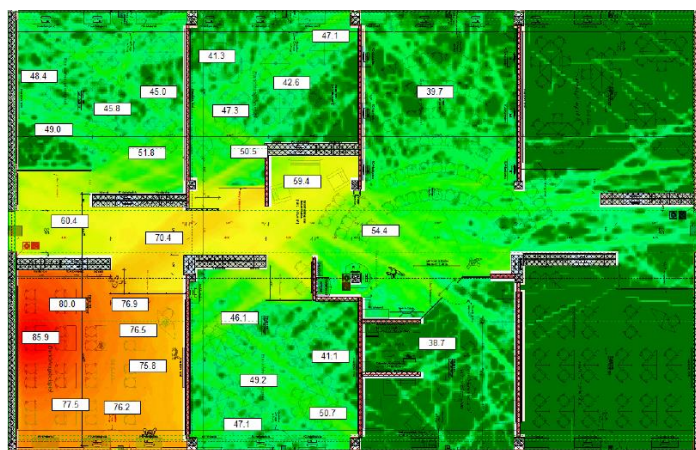


Figure 12. Reduced noise using staggered entrances

Shield *et al* (2015) monitored the noise levels (L_{Aeq}) produced by different classrooms activities. They found the following mean sound levels for each core activity: plenary (63.3 dB), individual work (62.3 dB), group work (67.3 dB) and watching/listening (65.0 dB). Considering that a 10 dB difference is perceived twice as loud, the 5 dB difference in individual and group work will be noticeable and result in interference, if such different activities are carried out in the same space. Shield *et al* also compared the mean noise levels during different subjects: maths (63.6 dB), English (63.3 dB), science (65.6 dB), modern foreign languages (64.5 dB) and humanities (63.1 dB). Science lessons probably have the highest average noise levels as they have the highest occurrence of group work.

Nunes (2009) commented that the main source of noise in traditional classroom is the teacher at the front, the children are not actually allowed to make noise, so it is not surprising that open plan classrooms are noisier! He quite rightly continues by saying that group work, facilitated by flexible spaces, will invariably create more noise. However, as previously mentioned, whether a sound is noise is dependent on a person's interpretation of the sound. The increased sound level observed in group work is therefore not technically an increase in noise level. It could be argued that comparing sound levels in modern open plan classrooms (which are designed to foster more student-centred group work) with sound levels in traditional classrooms (which are designed to facilitate teacher-centred learning) is immaterial.

7.2 Effect on teacher performance

When considering the effect of different classrooms designs on teachers (and students), rather than simply comparing sound measurements, there appears to be conflicting results. In a review of the first wave of open plan schools in the 1960s-70s, George (1975; cited by Weinstein, 1979) concluded that "neither the open space schools or the conventional school have demonstrated a clear superiority." Weinstein (1979) remarked that "research reports often omit any mention of the type of open space schools studied, failing to distinguish between truly open areas and modified spaces where movable walls are present. They do not attempt to define and describe the type of instructional program and frequently make no reference to the issue of teacher or student self-selection mentioned above. Problems like these make their results ambiguous." She continued "In as much as open space schools vary tremendously in design, educational philosophy, and instructional practices, any generalisations based on such limited, perhaps idiosyncratic, data must be viewed cautiously. At the present time, it is still necessary to suspend judgment about the success or failure of the open space school to enhance the educational experience of school children."

Deed & Lesko (2015) assessed the Bendigo Education Plan (BEP), a regeneration of junior secondary schools in Victoria, Australia, based on contemporary classroom design principles. The schools have large open spaces accommodating 100–150 students in neighbourhoods, with up to four neighbourhoods per building. Each neighbourhood is staffed by a small team of teachers who were observed by Deed & Lesko. They report that the teachers' "initial reaction was to control the spaces by instigating behavioural protocols, controlling access by locking some doors, organising furniture into classroom arrangements in each corner of the large building, and emphasising the traditional teacher responsibilities for controlling, directing, and shaping behaviour of their students ... Teacher perceptions of what the spaces could offer for different teaching and learning were evolving through experimentation and re-imaging their teaching practice."

Deed & Lesko (2015) discovered that initially there was a level of uncertainty as the new space did not match the teachers' traditional teaching styles. However, they eventually began to recognise the possibilities for introducing different teaching practices. Furthermore, "Open spaces, such as those reported in the case study, were seen as a positive contrast to being 'locked' into classrooms or being 'tied' to one set of students. Yet strong memories persisted among teachers of routine and security associated with conventionally walled classrooms." Deed & Lesko observed how the new teaching spaces expressed openness, accommodating a range of teaching practices, including conventional or experimental pedagogy. The spaces can provide either low or high levels of student autonomy and interaction – a set of individual desks for a teacher-directed (low autonomy) task or a set of tables for tasks requiring high levels of constructive interaction.

In a follow up to their 2014 study of kindergartens in Sydney, Mealings *et al* (2015_a) report that "Teachers of larger, noisier classrooms (especially those that were not acoustically treated) were more distracted by noise and found speech communication significantly more difficult than the teachers of smaller, quieter classrooms ... This suggests that smaller enclosed classrooms

are more appropriate learning spaces for teachers of young children.” Furthermore, Mealings (2015) remarked that “Teachers we visited reported being more distracted by noise, found speech communication significantly more difficult, and thought children had more difficulty hearing them, compared to the teachers of the enclosed classrooms. These teachers also needed to elevate their voices and experienced vocal strain and voice problems more often than the teachers in the enclosed classrooms.” She continues “Our findings suggest that open-plan classrooms that are unable to control the noise from adjacent classes are not appropriate learning environments. Acoustically treated enclosed classrooms are much better listening environments. If open-plan classrooms are still strongly desired, then they need to be purpose-built as flexible learning spaces with proper acoustic treatment and, most importantly, operable walls that can be closed when a class is engaged in critical listening activities.”

Whittaker (2015) is also critical of the new open plan schools, in particular Clifton Hunter High School in the UK. He discovered that school administrators tailored class timetables to help cope with teaching problems caused by the open-plan classroom layout, and further work was going on to develop teaching philosophies and practices that are more conducive to an open-plan environment. Both sensible solutions that perhaps should have been in place before occupying the new school. School inspectors reported that “Teachers often provide low-level, unchallenging, mechanical tasks that fail to engage and motivate students. Excessive noise levels are commonplace. Behaviour deteriorates when students become bored and disengaged, noise escalates and in the open-plan classrooms this can have negative consequences, not only for themselves but also for learners in adjacent lessons.” So, the emphasis is on adjusting the teaching style to match the classroom design, but a better solution is that the design matched the teaching style – a case of ‘form follows function’ rather than vice versa.

For his doctorate thesis, Wood (2017) conducted ethnographic research and qualitative interviews with teachers, at a new academy school in the north of England. The school ethos and its design, featuring innovative and flexible learning spaces, were intended to transform education. Wood argues that “the flexibility of ‘flexible learning spaces’ is both a rhetorical move and an ontological claim that is untenable – an example of spatial fetishism – and as such it can have ethical and political effects.” The gist of his thesis is that labelling a space flexible because of its spatial properties alone does not make it flexible; other factors include timetabling, type of activity and characteristics of its users. He concludes “Expecting people to be able to teach flexibly or learn flexibly because they are in a ‘flexible learning space’ might therefore overestimate the powers of space and underrepresent people’s efforts.”

7.2 Effect on student performance

There appears to be fewer rigorous studies that have compared the student performance in traditional versus new learning environments, and the ones published show conflicting results. For example, Bell *et al* (1974) examined two groups of first-graders, one group in open plan and the other in a conventional school. Preschool tests revealed no differences between the two groups, but mid-term tests showed the students in the conventional school to be significantly ahead of those in the open plan on all reading tests. Similarly, Townsend (1972) found significantly poorer grades for students in open space. Likewise, Wright (1975) compared the achievement test scores, of 50 pairs of fifth-graders in traditional and open plan schools and found that the traditional school students scored significantly higher.

Weinstein's (1979) carefully designed experiment assessed the effect of naturally occurring background noise on students' reading performance within a fully open plan school, whilst controlling for factors such as fatigue, individual ability, class teacher, and time of day. The study found no significant effect on reading error rate between ‘quiet’ and ‘noisy’ periods of intrusive noise from adjacent classbases, but a slight tendency to work more slowly in noisy periods. However, Weinstein emphasised that the results were not necessarily applicable to

schools where background noise levels were higher, and that noise was still likely to affect annoyance and speech communication, and to reduce the number of available teaching options.

However, after the first wave of open plan schools, Killough (1972) found that the mean achievement grades were significantly better after students were located in an open plan school for two years or more. Similarly, Barnett *et al* (1982) compared the performance on an auditory selective attention test of two groups of children, taught in open plan or enclosed classrooms. The classrooms had similar average noise levels during lessons and similar densities of pupils. They found that the children in the open plan school performed significantly better than the other children. Barnett *et al* suggest that children in open plan classes may habituate to intrusive noise over time, and so find it less distracting to their attention than children in enclosed classrooms.

Mealings *et al* (2015a) built on their 2014 study cited earlier. They conducted a study of four kindergartens, in Sydney, with different classroom designs: 1. 'enclosed' with 25 children, 2. 'double' with two 44 children in two groups, 3. 'triple' with 91 children grouped linearly into three classes, and 4. 'K-6' with the entire school, 205 children, in the one area with no barriers between them (Figure 13). Approximately 22 children in each of the four classroom types participated in an online four-picture choice speech perception test (for accuracy and response time) while adjacent classes engaged in quiet versus noisy activities.

Measurements of the noise levels revealed acceptable listening conditions in the enclosed and double classrooms when the other classes were engaged in quiet activities. In contrast, the noise levels in the triple classroom were problematic, particularly when the other classes were engaged in noisy activities. Unexpectedly, the noise levels in the K-6, large open plan space, did not reach the levels found in the triple classroom despite having over twice the number of children. Of even more interest is that "the children in this [K-6] classroom also had significantly better speech perception scores overall compared to the children in the other three classrooms, if noise levels were to be held constant across all the classrooms." Mealings *et al* (2015b) offer several explanation for the better performance of the K-6 classroom: 1. it was newly purpose-built as a 21st century open plan learning space, 2. it had more absorption from pin-boards and furnishings reducing the RT, and 3. it had the greatest spatial separation between classes such that the speech coming from other classes was likely to be less intelligible.

Mealings *et al* (2015a) realise that the triple classroom and K-6 open plan classrooms are not representative of the new ILEs. They conclude that their "results suggest that if open plan classrooms are desired, they should be acoustically built as flexible learning spaces. That is, they should have operable walls that can stay open for group work and other activities that benefit from an open plan space, but can be closed for critical listening activities."

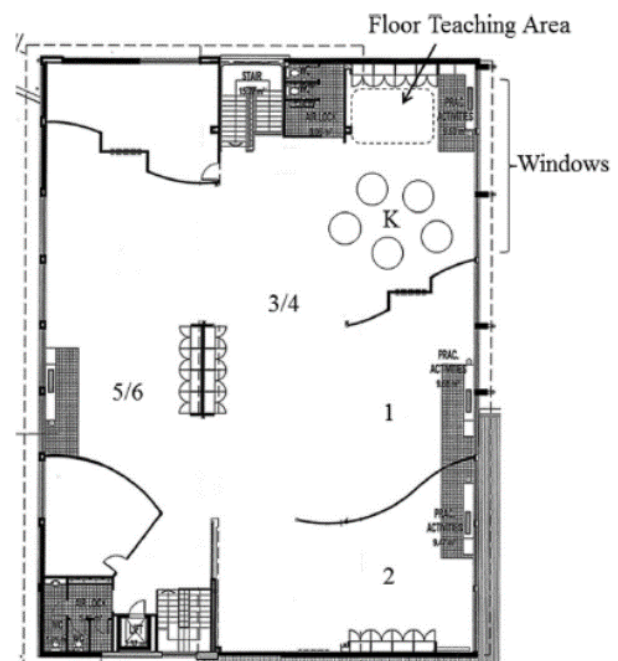


Figure 13. K-6 open plan classroom

Despite positive comments in studies reported earlier, in a later paper Mealings (2015) commented that "Our recent study of four different-sized Sydney [kindergarten] schools found that most children were annoyed by the noise, and 50-70% of children surveyed said they could not hear their teacher very well, or at all, when the other classes were doing noisy group work activities." Mealings also found that the distance of the child from their teacher was inversely proportional to speech perception (perceived correct words), see Figure 14. So, in large open plan classrooms, students need to be close the teacher for certain tasks such as traditional didactic teaching.

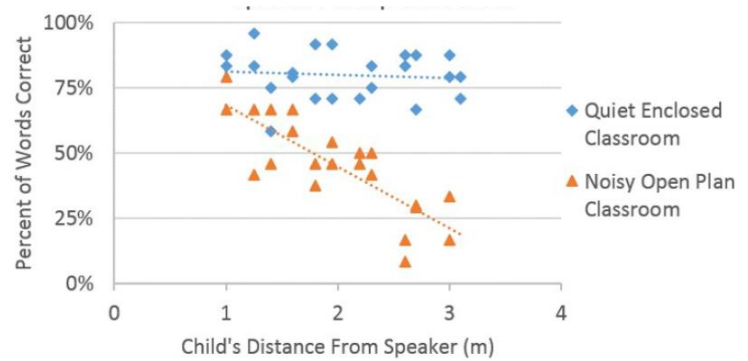


Figure 14. Effect of distance from teacher on speech perception

8.0 Open plan classroom solutions

8.1 Multiple solutions

Innovative learning environments, the modern adaptation of open plan classrooms, are gaining popularity on some countries as they facilitate a change in pedagogy. However, some of these new spaces are less successful, and can result in noise and distraction, due to their design and use. Several authors have therefore offered practical solutions which we have broadly categorised as: 1. management, 2. layout, 3. furniture and 4. absorption solutions.

The IoA/ANC (2015) provide a risk chart which covers many of the practical solutions, see Table 4. They advise that "The risk chart shown may be used early in the design process to provide an initial evaluation of whether an open space design is likely to be compatible with the educational vision and the level of detail needed for the acoustic assessment."

Management plan	Risk category		
	High	Moderate	Low
1. Number of teaching groups sharing space	4+ groups	2-3 groups	1 group
2. Point of control	4+ independently operating teachers/facilitators	2-3 facilitators, with some planning and interaction	1 single team planning cooperatively
3. Area per student	<3 m ²	3-4 m ²	>4 m ²
4. Time spent in area	Usual or permanent place of learning	Frequent, but not 100% of lessons	Occasional/breakout activities
5. Curriculum grouping	Different age/stage/subjects	Mixed, but closely linked groupings	Similar age/stage/subjects
6. Activity types	Frequent critical listening (instruction or discussion in large groups)	Critical listening is less frequent: Mainly individual/small group work/1 on 1 instruction	Critical listening occurs as plenary session only. Individual/small group work/1 on 1 instruction is co-ordinated. OR Resource/social area
7. Organisation of activities	Simultaneous use, independently planned	Simultaneous use, but activities planned co-operatively	Sequential use
8. Communication distance	>4 m	3-4 m	<3 m
9. Extraneous circulation	Access to other areas of the building required through open plan unit during teaching time	Restricted or minimised during teaching time	None within open plan unit
10. Vulnerable listeners	Need to use open plan space frequently	Very occasional use	Mix of enclosed and open to provide extra support/alternative accommodation

Table 4. Level of risk associated with modern classroom design (IoA/ANC, 2015)

8.2 Management & behaviour solutions

Even after the first wave of open plan classrooms, Weinstein (1979) realised “the relationship between physical design and educational program has been relatively neglected by educational researchers, although there is a growing practical literature on the need for congruence between architecture and program.” More recently, Gislason (2007) and others have identified that noise and distractions in open plan spaces can be mediated by organisational support through timetabling. Greenland & Shield (2011) recommend that “teachers should plan activities between classbases, so that work involving movement is coordinated and does not take place when other classbases are involved in critical listening activities such as whole class teaching.” The New Zealand MoE (2016) concurs: “Flexible learning spaces work best when educators collaborate and coordinate learning activities within the space. This can be by effective scheduling of learning activities to avoid clashes between quiet and noisy activities. This co-teaching practise is considered a ‘coordinated’ flexible learning space”, as illustrated earlier in Figure 7.

The IoA/ANC (2015) advise that “Open plan teaching and learning spaces call for the commitment of end users to coordinate and manage activities in adjacent teaching and learning spaces and circulation areas, in order to control intrusive noise levels. Users of the space cannot reasonably expect to use open plan areas in the same way as cellular types of accommodation, whilst maintaining the same degree of privacy.” This is in-line with earlier advice, but they go to say that “Research has shown that in many large open plan ‘flexible’ areas certain activities are severely restricted, or have to be dropped, because of noise interference. The management team will need to make decisions around curriculum delivery and timetabling at the outset of the educational vision to avoid this pitfall, which appears to be harsher advice.

In their practical guide to ILEs, Heppell, Heppell & Heppell (2015) advise that “The activities do not need to be sequential - although you might need to start, and/or end, in a plenary with everyone together. A final plenary to review the session together is always a nice punctuation point to signal closure.” They caution teachers that an investment in time is required: “For the first term you will plan together more than ever, so you will need to put aside additional planning time. You need to agree the schemes of work, get used to each other, produce individual lesson themes, and plan these lessons together.” Furthermore, “At the outset it seems daunting to change, but gains include less work for the teachers, with more engagement for the learners and better outcomes. You will need to dedicate a little more planning time at the outset until you get into the routines. You will get that time back quite quickly.”

Heppell, Heppell & Heppell (2015) also note that several teachers will operate in the same space: “Typically, there will be more than one of you teaching in and around the spaces at any one time. In this case, it is enjoyable and effective to teach together. To do so, each teacher must have an explicit role at all times” and “Different teachers can be the ‘lead’ for different areas, but you all need to have had input into the lesson ... with a team of teachers you can’t ‘wing it’ on the day.”

In his opinion piece on Finnish Schools, O’Sullivan (2017) observes that “There is a lot of variety in learning situations, and the schools, teachers can decide at the beginning of the month or week, or even at the beginning of the school day, how they want to work.” Furthermore, the investment in the new Finnish schools “isn’t just a case of high specifications for buildings, it means using more funds on training teachers in methods that suit such layouts, paying them well, and empowering them to pilot the day-to-day use of these skills.”

Following their ethnographic study of three catholic schools in Sydney, Saltmarsh, *Chapman & Campbell (2015)* “argue that the ways in which teachers conceptualise and operationalize notions of ‘structure’ is pivotal to the responsiveness of pedagogic approaches within open plan spaces.” By structure they mean “the ways that teachers’ ... understand pedagogy as an activity that ideally is, or ought to be, ordered, organized and conducted in particular ways.”

So, in ILEs potentially conflicting activities need to be coordinated between teachers and timetabled. However, prior to that the pedagogic philosophy needs to be agreed by the relevant Ministry of Education and then cascaded down to the head teachers and their staff. Change management and training will most likely be required to change opinions, attitudes and the motivations of those teachers more accustomed to traditional didactic teaching. It appears that in many of the less successful open plan classrooms, there was only a change in space rather than in a change in teaching style. Training in new teaching practice will need to happen in teacher training colleges for new teachers as well as offering on-the-job training for employed teachers.

Campbell (2017_b) advises that to match the teaching and learning activities to the appropriate spaces requires consideration, and an understanding, of the leadership, pedagogic approach and culture of the school. The model shown in Figure 15 is an enhancement of the Gradual Release of Responsibility model, discussed in Section 3. The model provides an indication of the teaching approach, level of student autonomy and associated activities cross-referenced with the appropriate five space types of Fisher & Dovey (2014). The model highlights that ILEs (Types C and D) and fully open plan spaces (Type E) are only suited to new teaching styles which place more emphasis on student autonomy, including a coordinated mix of collaborative and independent working.

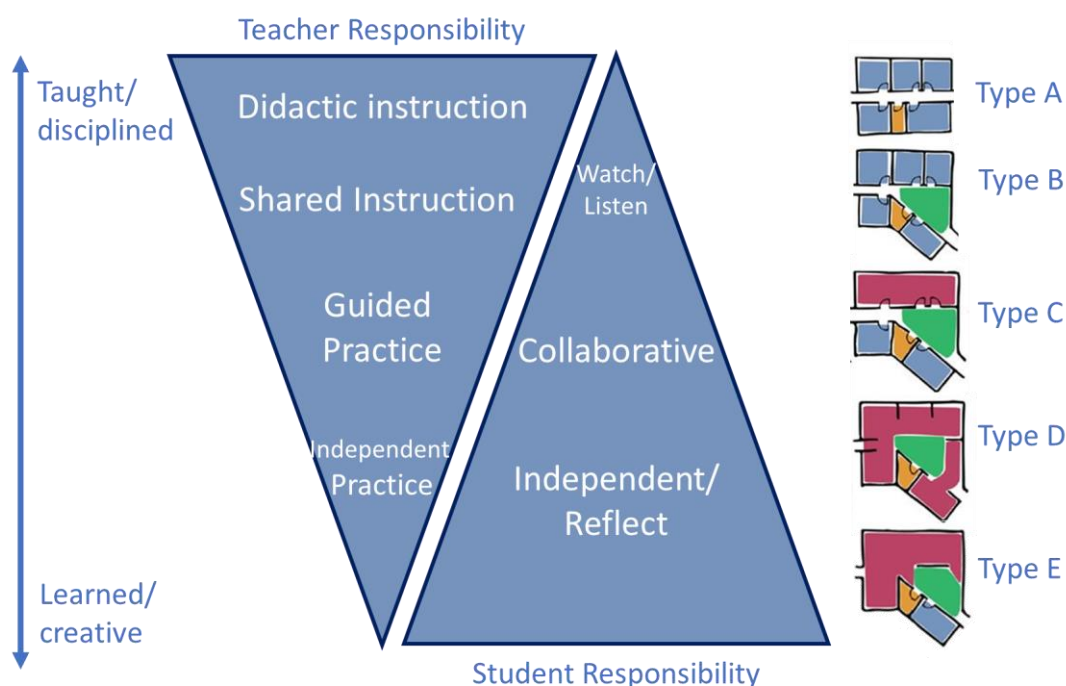


Figure 15. The modified 'Gradual Release of Responsibility' model

In their study the Hellerup School, one of the first newer open plan schools in Denmark, Møller Petersen & Rasmussen (2012) suggest that the reason for the success of this school is not due to optimised acoustics alone, but the combination of pedagogy, architecture and acoustics and the good will from sponsors, teachers, students and parents. The quote the headmaster speaking on his new school: "It represents a paradigm shift in Danish pedagogical thinking. It illustrates how theories on learning and pedagogy can be applied actively to the architecture and furnishing of a school."

Likewise, Wirtén (2018) cites Bodil Bøjer, a Danish researcher studying ILEs, who believes that having a specific design is not the primary factor for success; the most important success

factor is involving the management and teachers in the design. Furthermore, "Bodil points out that it is crucial for teachers to be involved right from the design phase, and for school management and consultants to be sensitive and listen to teachers' needs and views."

Graetz (2006) proposes 'clickers' as a simple practical solution to allow teachers to gain student attention, gather their feedback and stimulate discussion. Using flashing lights have also been considered as a means of gaining attention or controlling noise levels (Nunes, 2009).

A more extreme measures of controlling noise is on insisting on silence in classrooms. Recently the headteacher of the Albany School, in east London, banned students from talking while walking between lessons (Telegraph, 2018; O'Brien, 2018). The headteacher claims that lessons now start on time and students have a calmer mindset in class, and she also believes that "silence creates a very mutually respectful relationship between students and staff." However, such draconian methods are not popular with students or their parents, and conflict with the more modern student-centred pedagogy.

O'Sullivan (2017) also believes that the success of the Finnish ILEs is related to smaller flexible spaces and "low student-to-teacher ratios (13.2 students to every teacher in 2013) that make it easier for classes to break up into smaller groups without entirely foregoing supervision." Class size is therefore key, as is the volume of the teaching space and student density as discussed in the next section.

8.3 Layout solutions

Solutions based on the classroom layout include the shape, arrangement, flexibility and size of the room, whereas solutions related to size include density, or distance between students and spaces. For example, Campbell's (2017_b) study of the Witzenhausen School, mentioned previously, illustrated how sound transmission could be reduced between classbases by staggering/overlapping entrances to semi-open plan areas, and introducing cupboards and wall absorption, without the need for doors and walls. The spaces achieved an impressive RT of 0.48 s and STI of >0.7 and Campbell concludes "The effectiveness of the overlapping doorway sound traps make the learning spaces more acoustically closed than first appears while supporting the school to be more educationally open and transparent with their teaching and learning activities."

Heppell, Heppell and Heppell (2015) suggest "Schools have learned that zoning a space, and selecting the right furniture, fixtures & equipment for the right activities ... helps both students and teachers be reflective about the different modes of learning that might be on offer ... If you have 20, 50 or even 90 students in the space you certainly don't need 20, 50 or 90 chairs and desks. But you will need more activity places than children or else it becomes a little like musical chairs as the last ones to settle try to find an increasingly elusive place to settle in."

The IoA/ANC (2015) recommend that "for open plan arrangements that require multiple groups to be instructed independently (or other simultaneous critical listening activity), semi-open plan designs (where teaching areas are separated by walls, with openings onto a shared area) are generally more effective at controlling intrusive noise and are preferable acoustically." So, semi-open plan with staggered entrances are more favoured than fully open plan spaces, and more in line with the ILE concept (and space Types C and D).

In terms of layout, Barrett & Zhang (2009) recommend Dyck's (1994) 'Fat L' layout as it "offers teachers options in how they might organize their classrooms to facilitate the development of their students in various learning Activities." The 'Fat L' layout provides three distinct zones facilitating large group seated teaching, project activities and quiet group working, see Figure 16.

Barrett & Zhang (2009) also propose flexibility in the modern classroom: "It has to accommodate the formation and functioning of small learning groups while providing a sense of separation, because groups working together will experience distractions and non-productive interaction. It has to be flexible enough to allow the continual reorganisation of the whole class into various sizes and number of small learning groups. This means the space must be as free as possible of permanent obstructions. It has to be manageable by a single teacher who has command of the entire space. This means the space must be compact and open."

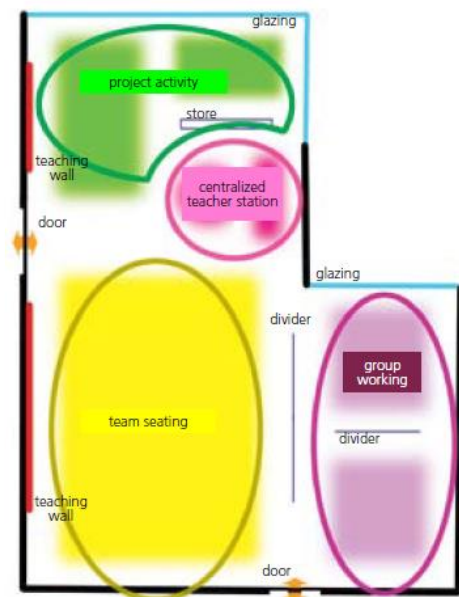


Figure 16. 'Fat L' layout

The need for flexible spaces is also recognised in universities. Graetz & Goliber (2002) comment that "Successful universities will ... stop building large lecture halls and plan instead for small groups of students gathered around tables and engaged in discussion. They will anticipate movement, not just of students and instructors, but of tables, chairs, white boards, data projection, and laptops."

The New Zealand MoE (2016) recommend that "to achieve good acoustics and maintain flexibility of the space, designers are to:

- look for every available opportunity to use highly absorbent materials on floors, ceilings, and walls,
- typically provide for 3-4m² floor area per learner to allow better acoustic separation,
- provide a range of adaptable learning spaces, including spaces that can be acoustically separated when required (such as breakout spaces)."

Furthermore, "The designs of new learning spaces are to carefully balance flexibility and adaptability of use with the acoustic performance required for a range of learning activities. The design should aim to provide:

- a range of spaces to allow teachers and students to choose where they learn,
- degrees of acoustic separation, which will help to reduce distraction from other activities."

They also propose using movable screens, sliding doors and sliding or hinged partitions to divide larger spaces into smaller separate zones, or create breakout spaces. The flexible partitions "create spatial differentiation in the space; provide nooks and alcoves for small group and individual work. They also provide acoustic 'zoning' in the space" and assist passive surveillance. Lastly, the New Zealand MoE recommend an adequate spatial volume with as high ceiling as practicable to allow sound dispersion and also provide more surfaces for absorbent materials to be applied.

Regarding room height, Shield *et al* (2015) found that RT increases with increased room volume and height, leading to a poor STI. They recommend that to provide an RT <0.8 s, the room height should not exceed 2.4 m.

In a case study of the acoustic design of Plazas 1 and 2 at Olborough School in Kent (Figure 17), Nunes (2009) proposes a number of layout solutions. To "Create a building which provides a positive, forward thinking environment, rather than the standard Victorian teaching often found in schools" he recommends creating an open space, free from cellular classrooms (and by removing all screens and partitions), capable of holding 60 to 90 pupils and allowing the users to see each other and work together. Furthermore, he suggests creating a large flexible space where teachers and pupils can move around, using a range of seating layouts, and provide a high level of comfort and flexibility in an atmosphere which appeals to a wide range of students. Nunes' specific solutions include:

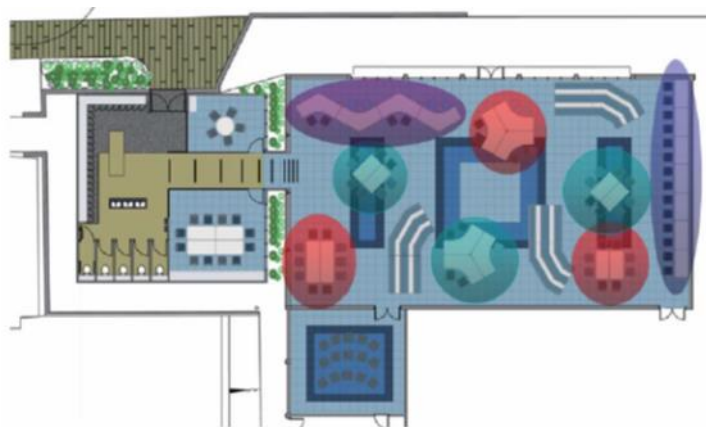


Figure 17. Separated small-group working

- **Layouts** – the layout of the furniture in the space will affect the distance between student groups and help reduce the negative effect of large groups contained within a small area.
- **Distance** – sound is reduced over distance so place teaching spaces further apart to increase separation and reduce speech interference.
- **Screens** – breaking the line of sight between two points can be an effective way of providing a small but effective acoustic break between two spaces.
- **Partitions** – when high levels of separation are required, partitions are seen to be the only solution

Shield, Greenland & Dockrell (2010) cite Greenland (2009) who found that a distance of at least 6.5 m between classbase openings would minimize noise transmission to achieve adequate speech privacy. They also propose that a buffer space, such as an enclosed room, may be used to maximize spaces between openings and hence enhance speech privacy. Furthermore, arranging the classbases in a linear rather than square or cluster arrangement has been shown to achieve maximum attenuation.

Shield, Greenland & Dockrell (2010) propose that "significantly more floor area is required for open plan classrooms than for enclosed classrooms, with 4-5 m² per child recommended in the literature. However, surveys of open plan classrooms built in the 1970s showed that the average floor area per child in UK schools reduced over the years to 3.0 m² while current UK guidance recommends 2.1 m² basic teaching area per primary school child. It is interesting to note that 9 m² floor area per child is provided in Hellerup School in Denmark."

The school layout can also help with the separation of particularly noisy activity and spaces. Barrett & Zhang (2009) recommend that music rooms, playrooms and mechanical service rooms are located away from the base classroom and heavyweight walls or floating floors are used to enclose any noise. They also suggest using storerooms and corridors as a buffer zone to separate and isolate the noisier spaces.

Barrett & Zhang (2009) also propose using wider circulation routes and breakout for small group learning. "The ability to instruct a few children or individuals on similar topics, at different paces and in different ways, allows for the customisation of each student's personal profile ... Interior windows and openings can further allow for effective breakout spaces in the nooks and crannies off circulation routes that were previously perceived as unusable spaces."

Based on their study of 42 open plan classrooms, Greenland & Shield (2011) found that "it is possible to achieve 'good' speech intelligibility conditions ($STI \geq 0.6$) throughout the classbase when the size of the open plan unit is limited to three classbases and reverberation time is limited to 0.4 s (achieved by use of a highly efficient sound absorbent ceiling)."

In summary, to design a successful ILE consider the: volume and size of space, student density, number of classbases, semi-partitioned and staggered classbase entrances, range of smaller spaces/areas available, and flexibility through movable partitions and furniture (discussed in more detail in the next section).

8.4 Furniture solutions

The IoA/ANC (2015) note that a major improvement in the acoustic privacy between spaces in open plan areas can be realised by installing full height moveable walls, fitted with seals, but then caution that such partitions are often under-used because of the time and effort required to open and close them. However, they do propose that movable screens and furniture can be used to define zones, provide nooks and quiet corners, and provide acoustic separation if the screens are absorbent.

Shield, Greenland & Dockrell (2010) also recommend the use of barriers with a mass of at least 10 kg/m^2 (for absorption) and a height of 1.6 to 2.0 m to cut off the line of sight between the source and receiver. However, it was also noted that use of partitioning might actually encourage noise, with individuals confusing visual and acoustic privacy and behaving as though they were in totally enclosed areas. IoA/ANC (2015) propose that the screens should be at least 1.7 m high, to block the line of sight, and ideally should reach to within 0.5 m of the ceiling. However, they realise that screens higher than 2 m, whilst acoustically better, are more difficult to move.

Whilst separation is good for reducing noise interference between group working, the same space may require that students are close to the teachers for better speech intelligibility during plenary instruction and didactic lessons. Greenland & Shield (2011) comment that "Where activities are not coordinated during critical listening periods, the furniture layout should allow students to gather within 3 m of the speaker."

Nunes (2009) illustrates how it is possible to reduce the distance between the teacher and pupils by 1.25m if a horseshoe seating arrangement is used, see Figure 18. He also explains that an amphitheatre is a recognised method of increasing sound levels across an audience. Furthermore, replacing classroom tables with small flip writing tablets it is possible to further reduce the distance between the teacher and students.

Based upon the design principles of the amphitheatre, Nunes developed the free-standing 'banana seat' (similar to the seating in Figure 19). This seating reduces the distance between the teacher and students to less than 2.6 m. Due to the size and absorbent materials of the 'banana seat' it can also be used to break up open plan areas into smaller zones.

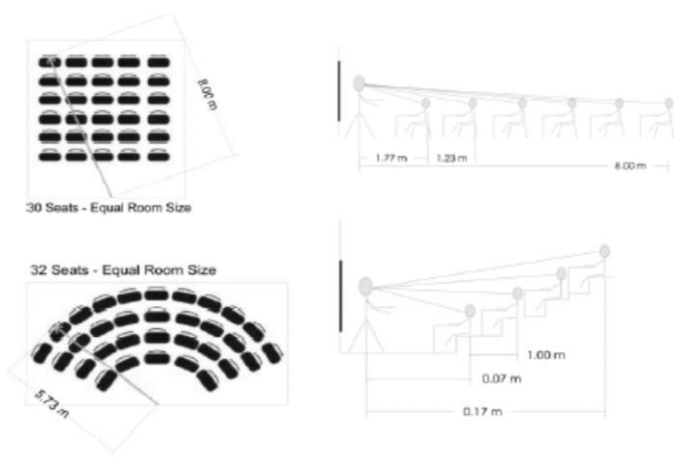


Figure 18. Amphitheatre seating

Heppell, Heppell & Heppell (2015) propose several furniture solutions for open plan schools:

- **Tiered seating** – tiered seats for speaking briefly to a large cohort; if shallow and high then all students are close to their teachers and they are good for a large group of children to come together.
- **Family learning tables** – large tables offering circa 12 seats; used for parallel quiet work, rather than for teacher-centred presentations.
- **Reading zone** – a quiet, comfortable, reading corner is an important zone as at home just about all children read whilst comfortably seated rather than on an upright straight-backed chair; reading corners are often shoes-off with comfy sofas, bean bags, soft furnishings, good lighting (250 to 450 lux).
- **Collaboration/conversation tables** – small group activity is best suited to a small 'coffee table' with two of three seats; limiting the number of seats and adding acoustic absorption helps structure the parameters of the activity.
- **Three-sided spaces** – spaces either constructed into the walls as 'nooks' or free standing to support quiet collaboration in small numbers, whilst teachers can see what is happening.
- **Attention square** – an area marked out on the floor for announcements, usually with good line of sight to all the nooks and alcoves.



Figure 19. Tiered seating

Whilst not strictly a furniture solution, it is worth noting that MACH Acoustics (Nunes, 2009) have been working on a software tool enabling real time monitoring of noise levels within a teaching space. This system is aimed at changing the colour of lights on a desk (or wall) to indicate to the students when they are getting too noisy.

The IoA and ANC (2015) comment that it is "unlikely that classroom furnishings will provide significant amounts of absorption, but they can be beneficial in scattering sound and deflecting it onto other absorbent surfaces." The next section focusses on adding absorption.

8.5 Absorption solutions

The IoA/ANC (2015) caution that, in practice, fully open plan spaces will necessitate a highly sound absorbent ceiling or suspended horizontal acoustically absorbent raft. They recommended that the absorption area should be equivalent to Class A coverage of 100% of ceiling area (meeting *BS EN ISO 11654: 199710*). The New Zealand MoE (2016) recommend that the ceiling treatment is as thick as practicable, ideally 50 mm or more with a noise reduction coefficient of 0.85.

As previously mentioned, Møller Petersen & Rasmussen (2012) improved the acoustics in the Hellerup School and Absalon School. This was achieved by retrofitting the reflective surfaces (ceiling and walls) with 'absorbers', providing moveable free-standing absorbent screens, and in the case of Hellerup, introducing internal screening between groups using 'Hexagones' (absorbent pods without roofs). Petersen (2002) recommends a ceiling absorption of at least 90%, with a maximum ceiling height of 3.5 m. Shield *et al* (2015) recommend that the amount of glazing (reflective surfaces) should be below 16%.

The NUT (2013) also recommend (fabric-faced glass fibre) wall panels along with carpet and ceiling tiles, particularly for older classrooms with high ceilings: "A suspended ceiling with a noise reduction coefficient (NRC) in the order of 0.60 generally provides most classrooms with

the required reverberation time.” They also suggest voice amplification systems to raise the teacher’s voice and improve the signal-to-noise ratio. However, they caution that “such systems also have their limitations. An overly-reverberant classroom, for example, will cause the sound from the loudspeakers to build up and remain unintelligible. Whether or not a sound reinforcement system is used in the classroom, it is vital to employ acoustical treatments that reduce reverberation time.”

Shield *et al* (2015) found that an absorbent ceiling has more of an impact on RT than carpet, reducing the RT by 0.3-0.4 s, but recommend both a carpet and an absorbent ceiling should be provided. O’Sullivan (2017) notes that in Finnish schools “textile flooring has become more popular – the materials are much better than they used to be, and now far easier to clean,” and also “We now have what we call ‘shoe-less schools,’ where pupils either change into softer shoes or simply wear socks when they come indoors.” Shield, Greenland & Dockrell (2010) note that whilst carpeted flooring is recommended in most studies it mostly reduces impact noise from footfalls, and furniture movement, rather than airborne sounds.

The IoA/ANC (2015) also recommend an absorbent acoustic wall treatment, such as pin-boards, on all available wall surfaces, and equivalent to at least 20% of the ceiling area). Likewise, the New Zealand MoE (2016) also propose that designers use thick acoustic panels as a wall treatment or add acoustic pin-boards.

In Wirtén’s (2018) report on the new Hyllievång School in Malmö, he observes that there is clear attention to acoustics – a long wall is used as a big sound-absorbing noticeboard, and wall-to-wall carpeting dampens the sound further while providing a feeling of calm and concentration. Stefan Östman, the school architect, explains “An acoustic ceiling is not enough – wall absorbers are also needed. And the ceilings must have appropriate sound damping with the correct distance between the ceiling and joists.”

Many studies have shown that absorption is critical in reducing reverberation in classrooms and therefore enhancing speech intelligibility through improved STI and SNR. The requirement for good absorption is even more relevant in the more open plan classrooms. Absorption can be applied to the ceilings (tiles or rafts), walls (pin-boards and panels), floor (carpet) and applied to movable partitions and furniture.

9.0 Conclusion and next steps

Despite the introduction of standards, noise distraction in all classrooms appears to be an issue – affecting teacher and student performance. There are mixed results on whether noise is any worse in modern Innovative Learning Environments (ILEs) compared to traditional enclosed classrooms, or the large open plan classrooms of the 1970s. The impact of noise can be exacerbated in ILEs if the teachers do not embrace, or are not trained in, new constructivist pedagogy and if the classbase activities are not coordinated. However, adding absorption, using furniture (such as tiered seating) and considering the layout of the space (such as staggered opening to zones) can all help reduce noise distraction.

This literature review set out to test whether:

1. Any identified issues with noise in open plan classrooms can be partially mitigated through design improvements and acoustics solutions.

There certainly appears to evidence to support this hypothesis, especially in modern Innovative Learning Environments.

2. A teacher's personality profile, in particular extroversion, will enable them to better cope with noise in the (open plan) classroom.

Currently there is very little evidence to support this hypothesis and more research is required.

3. Organisational factors such as teacher training, coordination of the space, timetable administration, changes in pedagogy, and managing student behaviour will help resolve any identified issues with open plan classrooms

This also appears to be the case for all learning environments including ILEs.

Our next step is to further test hypothesis 2 initially through on-line surveys and field measurements, and later using intervention studies. Hypothesis 3 will be tested through more qualitative research including ethnographic observation, interviews and workshops.

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