THE IMPACT OF **SCHOOL FACILITIES ON STUDENT LEARNING AND ENGAGEMENT**

Net ZED
Case Study Lab

UNIVERSITY OF OREGON

The Impact of School Facilities on Student Learning and Engagement

Prepared for

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About the White Paper

This document outlines, catalogs, and summarizes a framework of literature that highlights the impact of school of facilities and classroom environments on student engagement and learning. The NetZED Laboratory at the University of Oregon commenced this project following a Request for Proposals from the California School Facilities Research Initiative (CSFRI) which sought to identify elements of the built environment of K–12 schools that result in higher levels of student engagement and learning. CSFRI's goal was to summarize existing literature regarding the effects that physical organizational environments and furnishings within classrooms, makerspaces, laboratories, and interior ancillary facilities, as well as space at the exterior of the building that contribute to student engagement and learning. The overall intent of this white paper is to draw upon published evidence and original research to support the design planning and process for facility planners/managers, architects, educator, and community members who will seek funding to renovate and build new schools in California.

With learning and engagement at the center, we developed a diagram of relationships of the school's physical environment that includes three categories: indoor environment, spatial environment, and the people/community in relation to the school and classrooms. The review initially captured more than 750 peer-reviewed papers, reports, dissertations, books and literature reviews using framework, key word searches, and relevancy criteria, and stored through shared referencing software (Mendeley). Approximately 500 publications were selected to become an annotated bibliography and form the basis for this white paper. The review included studies from around the world, though most studies are applicable to conditions in the U.S.

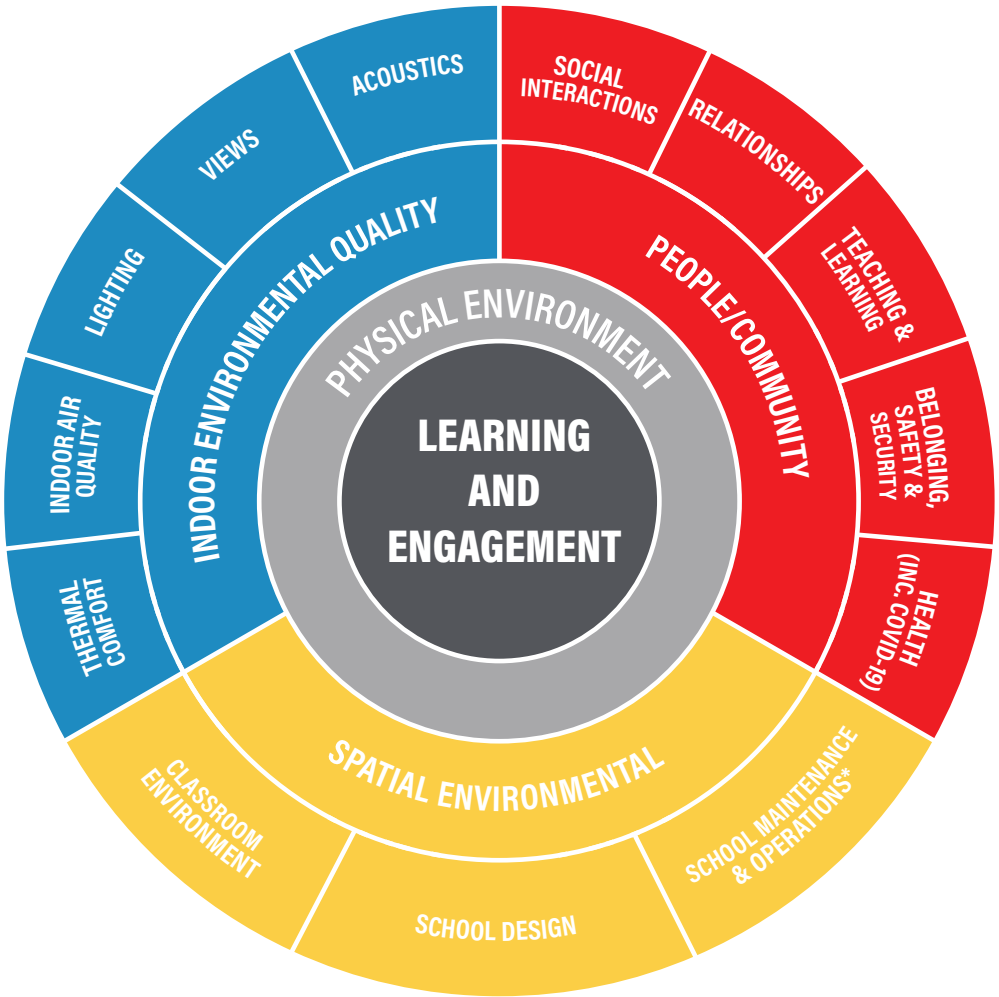
This paper is organized by the three categories shown in the Framework Diagram (opposite) and examines the sub-categories as they impact learning engagement and performance:

1. **Indoor Environmental Quality (IEQ)** refers to all the factors that influence the occupants' sensory experience of a place and includes thermal comfort, indoor air quality (IAQ), lighting (daylighting and electric lighting), views, and acoustics.

2. **Spatial Environment** includes school design characteristics of the buildings and grounds, school operations and maintenance that influence the functioning and operations of building systems and surroundings, as well as the spatial design of classrooms and within classrooms such as furnishings and arrangements.

3. **People and Community** includes social interactions, relationships, teaching/learning, belonging, safety and security, health and recent innovations and impacts of the design planning around the pandemic.

Across all categories, the built environment plays many key roles in shaping the student learning experience in schools, in addition to student health, wellbeing, comfort, security, and productivity (current and future). The white paper provides an executive summary at the beginning of each of the three categories, along with key findings and in-line annotations to the references at the end of the white paper. The reader may then delve more deeply into the content for that category and sub-category topics. We anticipate that this white paper will be used as a launching document to inform project teams who are working towards developing and building school facilities.



The indoor environmental quality (IEQ) category refers to factors of the school environment that influence the sensory experience of a place. This category includes subcategories: thermal comfort, indoor air quality (IAQ), lighting (daylighting and electric lighting), views, and acoustics. This category often matches physical measurements of classrooms with qualitative surveys of perceptions, attitudes, and behaviors.

Guidelines, Standards often referenced: ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy, ASHRAE Standard 62 Ventilation for Acceptable Indoor Air Quality, American National Standards Institute (ANSI) / Acoustical Society of America (ASA) for various classroom acoustics guidelines and standards (e.g. American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools; Part 2: Relocatable Classroom Factors; Part 4: Acoustic Standards for Physical Education Teaching Environments), Illuminating Engineering Society of North America (IESNA)

Executive Summary

Indoor Environmental Quality (IEQ)

KEY FINDINGS:

1. There is consistent evidence that children prefer cooler temperatures than adults. [1–9]
2. There is no consensus on which temperatures allow for better student performance. [2, 3, 10–18]
3. Thermal distraction, discomfort, and physiological responses may decrease student performance.
4. Issues of adaptability, ventilation types, and temperature variations for performance need further study. [2, 13, 15, 19]
5. Increased ventilation rates increase student performance. Conversely, low ventilation rates hinder concentration and test performance. standards. [11–14, 20–30]
6. Researchers have studied pollutants and microbes in schools concerning health, but few studies have linked them directly with student performance. [25, 31, 32]
7. The relationship between IAQ, health, absenteeism, and performance needs further study. [25, 31, 33]
8. Access to daylight and windows positively impacts student performance scores. [34–39]
9. Higher lighting Color Correlated Temperature (CCT) appears to play a role in students' visual acuity and performance, but the wide variety of studies doesn't allow to reach a universal conclusion. [40–46]
10. Lighting produces non-visual effects associated with mood and behavior. [34, 38, 47]
11. Views of nature decrease stress and increase student performance. [48–52]
12. A good view out of windows is significantly associated with better student learning. [35, 53, 54]
13. Indoor plants have a positive impact on student attention and perceptions of the classroom and class. [55–59]
14. Children are a high-risk group for chronic noise exposure. [60–68]
15. Poor acoustics affect students' learning and communication. [62, 66, 69–74]
16. High reverberation times and background noise decrease student performance. [63, 71, 75–82]

Thermal Comfort

Indoor Environmental Quality (IEQ)

Thermal comfort and children

Multiple studies have investigated the thermal comfort of children using a wide variety of approaches. Studies have found that students prefer cooler temperatures than adults.[1–8, 19] These studies are critical since the current thermal comfort standards were developed using adult subjects[1,7] and more studies are needed to validate thermal comfort of children. For example, a study in Hawaiian classrooms found an 80% of acceptability in students in naturally-ventilated and air-conditioned classrooms, regardless of being inside or outside the comfort zone.[83] Similarly, a study in Japanese classrooms found that students in air-conditioned classrooms were inside the comfort zone, but had slightly cool sensations, while naturally ventilated classrooms were 5.4 °F (3 °C) warmer, but students still indicated comfort votes in the middle 3 categories of the ASHRAE scale, nearing neutrality.[84]

In addition, thermal comfort literature recognizes that children from different developmental stages have different metabolic rates. Therefore, the way metabolic rate fits into the current models needs to be adjusted.[1, 2] Some researchers have even argued for the need of thermal comfort guidelines for different ages and developmental stages.[8] Nonetheless, currently no widely accepted model includes such variations.

In schools, students are often not in control of the classroom thermal conditions. Typically, the teacher has control or authority over the thermostat or whether the windows/doors are open or closed, making students passive recipients of the environment.[2] It is assumed that If children are in a constant state of thermal discomfort, this may reduce their performance at school.

Thermal comfort studies must define the type of ventilation in the classrooms and data compared to the relevant standards, in most cases, ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy. For example, a study in higher education with 50 undergraduate students found no differences in performance between students in naturally ventilated (NV) and mechanically ventilated (MV) classrooms. This study found that when the students could adapt and modify their surroundings in well-designed NV classrooms with operable windows and other means to increase air movement, the student performance was similar to performance in MV classrooms.[85]

Thermal comfort and performance in schools

Researchers believe that thermal comfort impacts student performance when exposed to either too high or too low temperatures. However, there is currently no consensus in the literature about the conditions under which this happens. Therefore, researchers have proposed two approaches: 1) an

inverted U-model, where a temperature of 72°F (22 °C) is the highest temperature at which a student can appropriately perform, and 2) the extended U-model, which proposes a broader range of temperatures that allow for adaptive behaviors in a naturally ventilated space or within proximity of an operable window.[2, 10] A review of adaptive thermal comfort since 1998 states that there is more evidence for the extended U-model than previously studied.[2]

Wargocki & Wyon (2007) found that reducing the air temperature in classrooms from 77°F to 68°F (25°C to 20°C) improved the performance of children schoolwork in numerical, language, concentration, and logical thinking tasks in terms of speed at the $p < 0.05$ level.[12] Another study found a similar result, as it found that students' math scores increased per each 1.8°F (1°C) decrease in temperature within the 68–77°F (20–25°C) range.[29] In a review of 7 field experiments, Wargocki & Wyon (2013), found that increasing temperatures above the 68–72°F (20–22°C) range caused a decrease in performance of up to 30%.[13] Similarly, a study with college-age females found significant differences in performance under three different temperatures 68, 73, 77°F (20, 23, 25°C). Participants performed significantly faster at 77°F (25°C) and 73°F (23°C), relative to 68°F (20°C).[11]

On the contrary, another study found that higher temperatures 77°F to 80.6°F (25°C or 27°C) affected children's performance in different kinds of tasks.[15] A cross-sectional study of Finnish schools found that students who had never experienced high indoor temperatures had 4% more correct answers than those who experienced them daily.[16] A secondary analysis of SEDA test scores compared to historical weather data for school districts in the US found that an additional day above 80°F (26.7°C) reduced achievement by 0.04 of a standard deviation. The impact on math scores was three times as large as the impact on ELA. Hot temperatures affected vulnerable, low-income communities more than higher-income districts. The effect of hot school days was more prominent for younger students (3rd to 5th grade) than for older students (6th to 8th grade).[86]

Nonetheless, other studies have contradicted these findings. A study using undergraduate students found very little evidence of the effects of thermal changes on cognition, with performance changes as low as 2%, when comparing temperature steps ranging from 93.2 °F to 71.6 °F (34 °C to 22°C). They found that the preferred temperature was 78.8 °F (26 °C), while only 62.5% of students found 71.6 °F (22°C) thermally acceptable.[17] Despite being developed with undergraduates, this study contests the idea of a 71.6 °F (22°C) threshold.

Researchers have also documented comfort at cooler temperatures. For example, a study with 6th to 8th graders in Chile found that students were comfortable in the classroom, despite being exposed to temperatures well below the comfort zone between 45.5 °F and 51.8 °F (7.5 to 11°C).[87] Another Chilean study found that children were comfortable in temperatures ranging from 58.5 °F to 60.8 °F (14.7 °C to 15.6 °C) during the winter and 72.5 °F to 73.6 °F (22.5 °C to 23.1 °C) in the spring. In an experimental study, Jiang et al. found that 12-year-old students felt neutral at 59°F (15°C) and performed optimally at 57.2 °F (14 °C). Nonetheless, their performance varied significantly depending on the type of task, and the best performance occurred when students were feeling cold or slightly cold.[3] Another experiment performed during the winter in rural China found that students wearing winter clothing performed better under temperatures ranging from 55.4 °F to 59 °F (13°C to 15°C).[18]

Researchers have proposed that distraction, discomfort, and thermal discomfort physiological effects may cause an impact on performance, which has a more significant impact in children than in adults.[13] Nonetheless, it has not yet been possible to determine if subjective acceptance of thermal discomfort would be sufficient to remove the direct effects of physiological responses to performance.[15] For example, a study found other associations between math test results and headaches or difficulty concentrating; however, the authors stated that these associations need further investigation.[16]

Highlights

1. There is consistent evidence that children prefer cooler temperatures than adults.[1–9]
2. There is no consensus on which temperatures allow for better student performance.[2, 3, 10–18]
3. Thermal distraction, discomfort, and physiological responses may decrease student performance.
4. Issues of adaptability, ventilation types, and temperature variations for performance need further study.[2, 13, 15, 19]

Indoor Air

Indoor Environmental Quality (IEQ)

IAQ, student health and performance

Researchers have recognized the need for high-quality research looking at health risks related to IAQ in schools.[88] IAQ depends on the activity performed in a room and the furnishings and materials as they may prevent cleaning the space adequately.[89] One of the most common reasons for studying IAQ in educational buildings is the effects that indoor air can produce on children's health. Children are one of the most vulnerable populations when exposed to hazardous pollutants, respiratory symptoms, and asthma.[88, 90] Researchers have proposed that mechanisms through which indoor air quality affects cognitive performance in the general population are attention or distraction, motivation, arousal, neurobehavioral symptoms, and acute health symptoms, sleep quality, and absenteeism.[15]

IEQ parameters are essential and potentially related to student health and performance.[91] However, few studies have assessed various health outcomes with IEQ factors in schools. Most studies have looked at respiratory health, but other types of health outcomes such as nasal patency, lung function, or rhinometry have been mostly overlooked.[88] Studies that looked at nasal patency (nasal openness) and nasal inflammation have improved health with increased ventilation.[26] Researchers have found that the most common self-reported symptoms related to IEQ are fatigue, stuffy nose, tiredness, skin symptoms, dry/sore throat, and headaches.[92, 93] Research has also reported positive perceptions of air quality (fresher air) associated with increased ventilation rates.[14] Nonetheless, the evidence of improved performance is more compelling than that of improved health.[26]

Absenteeism is one of the most common measures to relate student health and performance with poor IAQ. Research assumes that poor IAQ increases absenteeism, which in turn decreases student performance.[94] For example, a study found that students who did not miss school due to respiratory infections had 1.1% more correct answers on math.[16] Nonetheless, other research didn't find any significant relations between IEQ parameters and absenteeism.[91]

Research has also looked into IAQ and student health and performance through the lens of asthma and absenteeism caused by asthma. A study found that children with asthma missed two more days of school on average.[95] In another study, children with asthma reported higher school absenteeism ($p<0.05$), while children with diagnosed asthma had higher absenteeism than those with undiagnosed asthma ($p<0.05$).[96] Similarly, a study found that nighttime asthma awakenings may affect absenteeism and performance and parent absence to work. Children with more night awakenings had higher odds of having absences at school.[97] A study investigating the relationships between absenteeism, presence of asthma, and asthma severity level with standardized test level performance, found a

significant inverse relationship between absenteeism and test level performance p<0.001. However, it found no differences in test level achievement between those with and without asthma (p = 0.12). Those with persistent asthma were more likely to score below nearly proficient than those with mild or intermittent asthma.[98] Therefore, it remains unclear whether asthma-induced absenteeism can be directly related to student performance.

Ventilation rates, CO_2 concentrations, and student performance

Literature reviews and studies investigating data from ventilation rates and CO_2 concentrations from previous studies have found that ventilation rates are inadequate in many classrooms. They usually do not meet the minimum ventilation rates specified in the standards,[13, 25–27] which leads to health symptoms. Studies have found compelling evidence of an association of increased student performance with increased ventilation rates.[12, 14, 26, 29, 30, 91, 99, 100] A literature review on this issue pointed out that this increase could go up to 15%.[26] A study found that increasing ventilation rates in primary classrooms from 1 L/s to 8L/s increased students' attention and vigilance on computerized tests.[99] Similarly, multiple studies have found that lower ventilation and increased CO_2 concentrations negatively impact student performance in concentration and memory, affecting teaching and learning.[11, 13, 21, 22, 99]

Studies have found specific associations between ventilation rates and satisfactory performance in mathematics.[29, 30, 91] For example, one study calculated an increase of 0.5% in mean math scores per each L/s per person increase in ventilation rates.[29] Along the same lines, a study found associations between low math scores and ventilation rates below the standards.[100] Finally, some studies have found a significant effect of ventilation on increased student work rate or speed[12, 14] but found no significant differences in errors committed on academic tests[14] or in some specific tasks.[12]

There is evidence indicating that student absence significantly decreases with increased ventilation rates.[24] Research has correlated absenteeism with CO_2 concentrations over 1000 ppm. A study looking at traditional and portable classrooms found that dCO_2 (indoor minus outdoor carbon dioxide concentration) was significantly associated with the annual average daily attendance.[27] Another study found a significant decrease in illness absence for each additional 1 L/s in the school districts.[24] A study also found associations between ventilation rates and visits to nurses for respiratory symptoms and between culturable bacteria and nurse visits due to gastrointestinal symptoms.[91] The existing evidence indicates that student absence decreases with increased ventilation rates, but the available data are limited, and further research is necessary.[26]

Pollutants and microbes in schools

Indoor pollutant ranges vary in different parts of the world, depending on climate, type of ventilation, outdoor pollution, occupancy activities, and building practices.[88] A review on IAQ and health in school buildings found that the literature had reported low concentrations of volatile organic compounds (VOC) such as formaldehyde (HCHO). These are known to lead to increased allergic sensitivity, chronic irritation, and cancer. In addition, the literature also reported microbiological contaminants like allergens, fungi, and bacteria. Finally, the review found that studies commonly reported asthma and sick building syndrome in school buildings.[25]

Studies have investigated the relationships between microbial pollutants and children's health, but only a few have made the additional link with student performance. For example, a study of man-made and natural pollutants on children's performance from early childhood stages found that students scored 1 to 2 percent lower on math and reading on days with high pollen levels or fine airborne particulate matter.

In addition, asthmatic students performed about 10% lower on days with high ozone levels. Thus, the study concluded that poor air quality in the early stages of life could affect school readiness.[31]

Relative humidity levels are an issue of contention and are closely related to microbial contaminants. Extremely low or high levels of relative humidity (RH) produce optimal conditions for pollutants to thrive.[101–103] A study found correlations between the concentrations of relative humidity in classrooms and bacterial load in different moments of the day.[104] Increased levels of RH can facilitate the emergence of mold and dampness.[105] A metanalysis looking at the relationship of the respiratory health of school occupants with visible dampness and mold found that cough and wheeze generated moderate increases in health risk.[106]

Similarly, a study found that high RH, high student density, and cat allergens at schools were associated with the occurrence of infections.[107] Regarding low relative humidity, a study exploring teachers' health and classroom humidity found no statistically significant increases in respiratory symptoms in teachers exposed to low relative humidity during a prolonged period.[108] Other studies have assessed the potential of humidification to reduce the concentration of viruses such as influenza A in schools.[109, 110] Studies have related different levels of RH to microbial pollutants but haven't directly associated them with student performance.

Highlights

1. Increased ventilation rates increase student performance. Conversely, low ventilation rates hinder concentration and test performance.[11–14, 20–30]
2. Researchers have studied pollutants and microbes in schools concerning health, but few studies have linked them directly with student performance.[25, 31, 32]
3. The relationship between IAQ, health, absenteeism, and performance needs further study.[25, 31, 33]

Lighting

Indoor Environmental Quality (IEQ)

Daylighting and student performance

Studies have associated daylight with enhanced student performance, primarily through test scores.[34–37] For example, a study that examined records from three school districts in the United States, in over 2000 classrooms during an academic year, found that students in classrooms with the most daylighting advanced 20% faster on math tests and 26% faster on reading tests.[35] Similarly, a study with undergraduate students found a significant positive correlation between daylight and student GPA over a year.[36] Another study developed a secondary analysis on lighting data found positive relationships between performance scores and types of window shading, latitude, percentage of window facing south and glazing, with the largest impact due to window-to-floor area ratio.[37] Conversely, research has related variables associated with window glare, sun penetration, and lack of visual control with negative student performance.[53]

Research has associated daylighting with non-visual health effects. For example, studies have found associations of daylighting with improved eye function, vitamin D, and circadian rhythms and reducing cancer, stress, and microbes.[34, 47] In addition, studies have found that daylighting improves security, mood, sleep, and comfort and is associated with reducing stress, depression, violent behavior, and seasonal affective disorder.[34, 47]

Studies have also associated the non-visual effects of daylighting with student performance.[38, 39] A literature review found evidence of a direct relationship between early morning daylight, alertness, vitality, and cognitive performance. Short bright light morning exposure appears to be necessary to maintain circadian entrainment; therefore, light interventions in schools could enhance alertness and performance.[39] A doctoral dissertation found that natural light was essential for non-visual effects in primary school children. Students exposed to more natural light felt less sleepy and had better sleep quality and mood overall.[38]

A qualitative case study paper investigating four daylighting interventions in schools in the US found positive perceptions from school principals regarding these interventions. Among the benefits they mentioned are increased attendance and well-being, increased interest from parents wanting their children to attend school, and economic savings through energy efficiency.[111] However, there are still some knowledge gaps regarding the benefits of daylight, such as the positive effect of contextual clues provided by a view and the higher onset of visual discomfort glare. Therefore, scholars have suggested that further research should concentrate on the impact of daylight on some aspects of human performance, health, and behaviors that may translate into economic benefits.[112]

Electric lighting and student performance

Research has studied the effects of Color Correlated Temperature (CCT), luminance, and illuminance on children's performance and concentration using various methods and measures. A study using combinations of CCT and illuminances found that lighting positively influenced children's concentration. Their results suggested that older students might be less affected by lighting than younger ones, but other factors may explain these differences. This research concluded that further research was necessary to assess the effects of lighting setting, exposure, and relations to different tasks.[40] An intervention study found that students in a classroom with blue-enriched white lighting showed faster processing speed and better concentration than those with standard lighting. They found four significant interaction effects, and only the verbal memory interaction effect failed to reach significance.[41] A study with primary students found that focus lighting led to a higher increase in oral reading fluency performance (36%) than control lighting (17%). The study didn't find any effects of lighting for motivation or concentration, which they thought might be explained by the young age of the respondents.[42] A study comparing fluorescent lamps of 4100 K and 3000 K CCT in two second grade classrooms found a relation between the higher CCT and more student on-task behaviors ($p = 0.38$).[43] Finally, a review on the effect of lighting on task performance suggested that task performance improved at higher illuminances, contrast ratios in the range of 7:11, and higher CCT, but made no universal conclusions. The review concluded that future studies should also include the effects of vertical illuminance, daylight provision, and outside views on task performance.[44]

Some studies have compared the influence of lighting technologies on students. For example, a study compared the effect of fluorescent and LED lighting on student performance using three different CCT and found that the percentage of correct answers in arithmetic problems increased in the LED group and was highest in the 6500 K lighting.[46] A different study measured students' mood, light perception, saliva cortisol concentration, and the light environment and electricity consumption of the classroom. They found only marginal differences between the lighting systems, a slight preference for the LED classrooms, and minimal energy savings due to flaws in the overall system.[113] Finally, a study with a small sample of pre-K students found that children were significantly more engaged under the LED lamps than under fluorescent lamps.[114] Thus, it appears that LED lighting might have a more positive influence than fluorescent lighting, but more research is necessary.

Some studies have associated natural light or a combination of natural and artificial light with increased student performance using self-reported perceptions of students and teachers.[115–118] A questionnaire to school teachers addressing how lighting influences students' performance found mixed perceptions of lighting for task behavior and focus.[119] Another study found that lighting significantly influenced student achievement based on students' self-reported perceptions.[117] Finally, a post-occupancy evaluation of primary schools in Australia found that while students preferred daylighting for learning, the staff deemed artificial lighting more appropriate.[118] Therefore, there seem to be differences between the perceived influences of lighting on student performance from different points of view.

Visual and non-visual effects of lighting

Research has found that CCT plays a role in student visual acuity and visual comfort. A study found that a higher CCT lamp produced significantly better visual acuity ($p < 0.001$) when comparing a 3600K lamp with a 5000K lamp with identical luminance conditions. Under a lower luminance condition, children had significantly less visual acuity for the 5500 K. There was no significant difference between the 3600 K lamps at the higher luminance in contrast to the 5500 K lamps at the lower luminance.[120] A study with undergraduates found that students could

perceive a 5 K/s rate change in lighting, but this didn't interfere with their concentration. The threshold at which participants perceived the change was 5000 K. Concentration and arousal were highest in controlled or color-tuned lighting scenarios, but subjective assessments didn't reflect these effects.[121] A study investigating the impact of different illuminance levels and their corresponding color temperatures on undergraduates' brightness sensation, lighting perception, and cognitive performance found that 4000 K was deemed the optimal lighting for educational settings. An increase in CCT led to a rise in brightness sensation, but changes in CCT didn't linearly increase light comfort. Levels of perceptual properties, acceptance, and satisfaction were not affected by changes in CCT from 3000 K to 5700 K.[122]

Classroom design plays a crucial role in student visual comfort. A study of 90 UK classrooms found that 80% of the classrooms used 100 Hz fluorescent lighting. This lighting can cause headaches and impair visual performance from the imperceptible 100 Hz flicker. Also, 84% of the classrooms exceeded illuminance levels beyond which visual comfort decreased, and lighting levels could not be controlled. Most projector bulbs produced an uncomfortable glare in the projected screen.[123] On the other hand, poor lighting might cause adverse effects, such as temporary visual, psychological, and permanent problems of the visual system.[115]

Researchers have investigated the non-visual effects of light from a variety of approaches and perspectives. An experimental study found significant effects of lighting CCT with subjective appropriateness and significant impacts of lighting in recess and academic activities.[46] A study found that teachers from all school grades associated images of classrooms with higher CCT as encouraging positive affect, alertness, and energy. Similarly, lower CCT was associated with promoting calm mood.[119]

A study from 1984 found no consistently significant results regarding cause-effect relations between "simulated outdoor light or prescribed colors or light/color combinations in the school environment and student ability or achievement levels, attitudes towards school subjects, misbehaviors warranting disciplinary action, absences due to illness, refractive eye problems or blood pressure." However, the study did find a short-term effect of stimulating color increasing blood pressure between am and pm times.[124] A study using the same premises exposed children to a prescribed classroom setting that used grey and blue colors and full-spectrum lighting. The study found a 9% decrease in blood pressure and a decrease in off-task behavior of 24% in pre-post conditions.[125] Finally, a study from 1995 documented that students under fluorescent lights developed fewer dental cavities and had better attendance, achievement, and development than those under high-pressure sodium vapor lamps.[78]

Research has associated poor lighting with inadequate hormone levels, negatively affecting children's behaviors.[115] For example, a study looking at lighting and depression in adolescents found a causal relationship between low grades and depression. Still, it didn't have enough evidence to deduce a relationship between academic performance and vertical illuminance.[126]

Highlights

1. Access to daylight and windows positively impacts student performance scores.[34–39]
2. Higher lighting Color Correlated Temperature (CCT) appears to play a role in students' visual acuity and performance, but the wide variety of studies doesn't allow to reach a universal conclusion.[40–46]
3. Lighting produces non-visual effects associated with mood and behavior.[34, 38, 47]

Views

Indoor Environmental Quality (IEQ)

Windows, nature, and student performance

Windows and views play a definite role in student learning and performance. A study comparing the performance of 8000 3rd to 6th-grade students in 450 classrooms in Fresno, CA, found that classrooms with a better view out of windows were positively and significantly associated with better student learning in standardized math and reading tests over an academic year.[53] In a similar study, students with the largest windows progressed 15% faster in math and 23% faster in reading. In classrooms with operable windows, students' academic progress was 7 to 18% faster than those with fixed windows. The findings were consistent across different types of schools.[35]

Studies have found that the presence of windows affects thermal sensations. An experimental study found that undergraduates felt cooler and more thermally comfortable in a room with windows. Memory and the ability to concentrate were higher in the space with a window.[54] They found no significant differences in short-term memory, planning, and creativity performance between the two conditions.[54]

Classrooms with views of greenery can improve concentration and student grades.[48] For example, a study comparing classrooms overlooking a concrete wall vs. classrooms with views of nature found significant differences for the final scores in the same undergraduate class. Similarly, classrooms with views of nature rendered significantly more overall positive perceptions of the course.[127]

Previous research has related views of nature with reduced stress.[48, 51, 128] A study found that fourth-grade students reported less stress and more focus in classrooms with windows with natural views.[51] An experimental study found that students with a view to lush vegetation had significantly increased their recovery from stressful situations and their attention compared to students in classrooms with no windows or windows without a good view.[128] A study investigating views from undergraduate dorms and their effect on student attention found that the students with natural views could direct attention better than those with fewer natural views from their windows. Those with less natural or built views scored significantly lower than those with natural views on the Symbol Digit Modalities Test.[52] A study comparing the effects of plants and the color green on verbal creativity found that it increased regardless of the scenario.

The influence of indoor plants on students has been studied in various settings, rendering positive results. A quasi-experimental study in an elementary school in Taiwan found that classrooms with indoor plants reported fewer misbehavior records and fewer sick leave hours, which may be related to visual and psychological mechanisms caused by indoor plants.[55] Another study found that students had a more positive perception

of the environmental quality of classrooms with indoor nature. Research has found that students rate their teacher and class higher and report greater attention in classrooms with indoor nature than in classrooms that don't have it.[56, 129] A study found that elementary students in classrooms with green walls performed better on selective attention tests and had better classroom perceptions.[57] An analysis of a small sample size of preschoolers suggested a positive relationship between house plants and children's ability to direct attention but couldn't find statistically significant results due to sample size.[130] In general, research has found that indoor nature exposure is beneficial for health.[59]

Other studies have studied the influence of windows and views of greenery using different elements. For instance, a study found that virtual windows showed positive associations with student task completion and student performance when compared against windowless classrooms.[131] Also, a study with undergraduates found no difference in visual creativity in students exposed to plants, the color green, and natural views. Nonetheless, all conditions increased students' visual creativity.[132]

Highlights

1. Views of nature decrease stress and increase student performance.[48–52]
2. A good view out of windows is significantly associated with better student learning.[35, 53, 54]
3. Indoor plants have a positive impact on student attention and perceptions of the classroom and class.[55–59]

Acoustics

Indoor Environmental Quality (IEQ)

Acoustics and children

There is a need to provide adequate acoustic conditions in classrooms and lecture halls, as children spend most of their time in school in these spaces.[71, 133] Children are one the highest risk groups of vulnerability due to chronic noise exposure[60, 61], as it can lead to hearing loss.[62] Infants and toddlers are particularly vulnerable as they are in early developmental stages.[61] A study found that children chronically exposed to noise had worse recognition memory.[62] Poor acoustic conditions appear to have a more significant influence on children than adults.[63, 64] A study found no significant effects of noise levels of ambient noise on executive functioning.[65] However, research has found that poor acoustics decreases concentration.[66, 67]

Noise can also affect the physiological and psychological health of children. For example, a study found that classroom conditions with an average daily Leq between 59 to 87 decibels were significantly related to more prevalent symptoms of fatigue, headaches, and reduced diurnal cortisol variability, which are indirectly or directly associated with stress reactions in children.[68]

Teachers' health is also affected by poor acoustics.[134, 135] For example, in schools, there's a significant risk for occupational voice disorders.[136] In addition, researchers found that teachers' exposure to daily high levels of sound pressure can cause temporary changes in the outer Organ of Corti [in the inner ear] that can become permanent over time.[134]

Acoustics and performance

Researchers have proposed that there are two types of auditory distractions. The first type is distractions that interrupt processes, and the second is distractions that interfere between learning processes. The former harm memory capability, while the latter do not.[69] Degrading listening conditions can take away the attention from a primary task.[70] A study found that students perceived the acoustic and visual quality of classrooms as having the most considerable impact on their performance in school overall IEQ parameters.[66]

Acoustical issues create learning and communication problems in schools.[71, 73, 134, 136] Children perform significantly worse in noisy environments regarding comprehension and auditory working[70] and recognition memory.[62] Acute noise exposure has a negative effect on speech perception and listening comprehension.[63, 66] Research has found that noise-induced disruption affects non-auditory tasks.[63] Performance in tests involving details, understanding, vocabulary, and reasoning can be more affected by noise ($p<.05$).[70]

Children are significantly affected in classrooms without correct acoustics and reverberation times (RT).[63, 71, 75, 76] Reverberation affects children's speech perception, short-term memory of spoken word[71] and lowers performance in verbal tasks.[63, 71] It can also affect social relationships between students and teachers and increase the burden of noise in the classroom.[71] For example, in a study with primary school children, long reverberation times seemed to reduce students' perceptions of fun and feeling happy about themselves.[75]

Background noise (BN) can also affect student performance and learning[76, 77, 136–138], especially regarding demanding verbal processing demands.[79] However, individual external events have larger impacts on performance scores.[138] For example, a study found that increasing background noise and reverberation caused a decrease in performance on comprehension tasks, but there was a minimal difference in measures of sentence recognition.[137]

Indoor background noise can be caused by building systems like plumbing, heating, electrical applications, and ventilation.[136] Studies have found that children exposed to quiet conditions learned words more accurately than those in white noise conditions.[80] Similarly, researchers found that students learning in quieter environments got higher scores in reading skill tests.[81] Also, a study found that learning in a plain

speech in quiet conditions produced similar results to learning in clear speech with white noise. However, the plain speech condition had fewer accurate words than clear speech, no matter what situation.[80] A case study found that higher BN levels in unoccupied rooms decreased scores for student reading and language subject areas.[82]

Noise coming from typical educational activities can also disrupt listening and communication.[136] Even if students are well-behaved, they still cause the most dominant amount of noise.[139] A study exposing children to background noise in a foreign language found that children's ability to store and process verbal information was affected.[140] Even with low levels of babble background noise, there is an interference with listening comprehension.[141] Similarly, joint babble and activity noise have a more negative effect on performance.[142–144] In addition, researchers found that multi-talker babble noise harms the auditory working memory of children.[143] Studies have found that irrelevant speech affects multiple types of tests[145], and it has different kinds of effects depending on the task (speed, literacy, verbal).[144]

Research has significantly correlated speech clarity with reading test scores.[146] Children need a more prominent speech signal-to-noise (SNR) than adults.[135] For example, a study found that intelligibility scores increased as reverberation times decreased when holding a constant signal-to-noise ratio. A case study found that the intelligibility scores of young children increased when the added sound consisted of early reflections of speech sounds.[147] A study stated that sound quality affects a children's cognitive performance, not the absolute level.[140] Nonetheless, other studies have found that increased levels of noise can hinder student performance.[148] For example, a study found that when compared to 50 dB L(Aeq), adolescents' performance on reading and vocabulary-learning tasks significantly decreased at 70 dB L(Aeq) and only had a detrimental effect in older students at 64 dB L(Aeq).[148]

Children's performance in schools is also affected by external noise such as traffic noise and aircraft noise. In an experimental study, road traffic noise negatively affected students' reading speed and basic mathematic skills. Nonetheless, reading comprehension and mathematical reasoning were not affected.[145] A study found that younger students performed better on a math test in traffic and quiet conditions than classroom noise conditions. In older students, these differences disappeared as the age of the student increased.[77] Research has found that the combination of traffic noise with babble noise significantly decreases speech perception.[149] A questionnaire study found that students were most annoyed with noise during tests and reading times, followed by noise from other students in the classroom and traffic noise.[79]

High exposure to aircraft noise significantly lowers reading scores.[60, 63] A study found that children chronically exposed to aircraft noise had learning deficits in reading even while taking the tests in quiet conditions. Research has found that children in schools exposed to aircraft noise have more difficulty completing a complex test or task.[150] In addition, those exposed chronically have impaired speech perception.[151] The learning issues caused by chronic aircraft exposure cause stress and worsen cognitive performance for young school children.[60] A study found that aircraft noise combined with train or road traffic greatly increased recognition and recall.[152]

The effects of noise vary by age. In some studies, younger students have been more affected by noise.[153] Younger children have more trouble blocking out the noise than older children.[76, 142, 153] A study found that 2nd graders in the lower sound transmission index (STI) range understood fewer words than the students in other grades.[154] Nonetheless, children who have a good selective attention rate can be protected against noise and its effects when completing tasks in quiet and moderate rooms.[153] In other studies, researchers have found that older studies are more affected.[73, 138, 148, 155] Research has found that older students hear better in all conditions when they see their teacher and are more affected by speech-like

interference.[156] Younger children performed better than older children with background babble from other children on the playground outside. Younger children are sometimes faced in different ways, making hearing and listening harder if they can't face or see their teacher.[156]

Learning spaces and acoustics

Open-plan classrooms usually have more problems regarding acoustic performance than regular classrooms.[157] In these classrooms, when higher noise levels occur, there is a decrease in speech perception, accuracy, and speed.[158] A study found that an open plan design reduced test scores of kindergarten students by decreasing their speech perception on critical listening tasks.[158] In an online questionnaire, students in open-plan classrooms or attending schools with external noise reported less positive perceptions about school and school acoustics.[148, 159]

Informal learning spaces in schools should also have an excellent acoustic performance. A case study investigating the role of acoustics on post-secondary students' perceived suitability and well-being in informal learning spaces found that they preferred rooms with softer materials. However, they also found that density created acoustic problems and that sound in unoccupied spaces was detrimental.[133]

Research in other spaces in schools has found that these spaces have a variety of acoustic performances. A study found that the dining hall and corridors between classrooms had the worst conditions for listening and understanding peers and teachers.[79] Nonetheless, a case study found that the corridor area's acoustic performance was usable for educational purposes with a soft carpet.[160] A study in a gymnasium found that physical education classes suffered from poor acoustics.[157]

Non-native speakers, children with hearing disabilities, or language or attention disorders are more affected by poor classroom acoustics than native speakers.[63, 148, 159, 161] A study found that non-native children have a disadvantage while listening with typical noise and reverberation, as their word recognition decreases more.[162] Children who are hard of hearing are more affected by poor acoustic conditions in classrooms.[163] In children with autism, increased noise can affect behavior. An observational study found that several observed behaviors occurred more like hitting, loud vocalizations, blinking, verbally complaining, repetitive motor movements, and repetitive speech.[164]

Acoustic interventions and technology

Studies have found that most classrooms don't have sufficient acoustic conditions[76, 157, 165] and don't comply with national acoustic standards and guidelines.[136, 160] Researchers have pointed out poor acoustics as the most critical condition for deaf and hard of hearing students and non-hearing impaired students with ambient noise levels at 4-37 dB above the current "optimal" understanding.[166] A study found that optimum reverberation times in classrooms are from 0.4 seconds to 0.5 seconds, much shorter than the standard.[64] Acoustic interventions positively impact classroom conditions[73, 76, 167, 168], where students report teachers' voices to be clearer and more audible after the interventions.[73, 168]

Some solutions to enhance classroom acoustics include sound field amplification systems, noise control, signal control without amplification, and individual amplification systems.[165, 169] Other solutions include having "soft" spaces and elements that can absorb sound along with wall-mounted cork boards and curtains over the windows[61] or other diffusive and absorptive surfaces.[146] Façade acoustic insulation can also decrease sound pressure levels in newer buildings.[170] Researchers have found that sound-field (SF) amplification systems create more effective acoustic conditions in classrooms[169, 171], and particularly for children with developmental disabilities.[171] However, intervention studies have found that SF systems to improve classrooms with poor acoustics can increase student performance on

speed processing and listening comprehension but have no lasting effects on numeracy, reading, or spelling.[172] In addition, teachers have reported that these systems improve children's listening and attention.[172]

Highlights

1. Children are a high-risk group for chronic noise exposure.[60–68]
2. Poor acoustics affect students' learning and communication.[62, 66, 69–74]
3. High reverberation times and background noise decrease student performance.[63, 71, 75–82]

Executive Summary

Spatial Environment

KEY FINDINGS:

1. Schools' outdoor green space has a significant positive impact on health, learning and academic achievement.[51, 173–181]
2. Schools should be flexible and accommodate for a variety of learning situations and activities: social/private, noisy/quiet.[182–189]
3. Less dense classrooms are related with increased student ownership and better student-teacher connection.[190–195]
4. Ventilation investments are a necessary and long-lasting measure to prevent COVID-19 and support student performance and general health.[24, 26, 196–208]
5. Building disrepair has been associated with student performance and absenteeism.[209–218]
6. Green schools haven't been directly associated with increased student performance, but their enhanced IEQ, relation to nature and energy efficiency are beneficial for students.[213, 219–221]
7. Flexible learning spaces allow students to be less sedentary, enable improved student performance, but may present pedagogical challenges.[222–230]
8. Classrooms that incorporate technology, such as Active Learning Classrooms may increase student engagement and performance.[191, 215, 229, 231–233]
9. Ergonomic furniture positively impacts student health.[234–240]

The spatial environment category includes school design characteristics both inside buildings and outside of the classrooms on the school grounds. This category includes subcategories: school design characteristics, school operations and maintenance that influence the functioning and operations of building systems and surroundings, and the classroom environment (e.g. furnishings, technology, flexible organization).

Guidelines, Standards often referenced: U.S. Department of Education, Office of Educational Research and Improvement: Space Guidelines for Planning Educational Facilities, National Institute of Building Sciences: Whole Building Design Guide for Educational Facilities, books and planning guidelines offered by state agencies. For example, funding models in many states are based on a per student square footage allowance, which may or may not align with allowances.

School Design Characteristics

Spatial Environment

School and classroom size

Research has addressed the density of students in a classroom with children's experience and performance in schools. School size, classroom size, and study spaces' location and environmental qualities directly impact academic achievement in elementary schools.[190, 191] Research has linked smaller school and classroom sizes (# of students/ teacher) and student density (# students/sqft) with positive impacts on student performance. Conversely, large classes and crowded classrooms can impair the academic experience.[192, 193] For example, a literature review reported two studies that found significant differences in academic achievement in classes larger than 13 to 17 students on average.[192] Similarly, a study found a minimal effect of reduced classroom size in California Kindergarten classrooms on second-grade reading and math test performance but found no effect on language and spelling tests.[194] A study conducted interviews and focus groups with students and teachers in six schools and found that social and spatial density was a concern for both teachers and students. They found that smaller school populations and class sizes were preferable, but larger classroom dimensions leading to lower density were better.[193]

A study in Dutch universities found that the size of the institutions negatively correlated with student success. This study also found that the quality of different services and aspects of schools, including facilities, cleanliness, classrooms and classroom environmental conditions, explained 3.5 % of the variance in study success. Other variables such as spatial representation, informal spaces catering facilities and indoor climate (air and temperature) were not statistically significant.[212]

Smaller communities give students a greater sense of ownership[190, 192] and generate conditions beneficial for creating relationships and opportunities relevant to student learning.[192, 241] A literature review suggested that capping school size at 500-600 students aided in the generation of ownership.[190] Similarly, research has reported that smaller classrooms provide more opportunities for participation and teacher-student interaction and individual assistance.[192] Finally, researchers have suggested that schools that have "well-defined activity pockets" and provide spaces that offer social/private opportunities, loud/quiet spaces, etc., can be beneficial for learning.[190]

Outdoor learning spaces, nature & school grounds

Students can be positively influenced by being in nature. A review found that nature-based learning increased interest in uninterested students, improved grades, reduced dropout rates, disruptive episodes, and helped to close income-related gaps. In group settings, nature allowed for less fidgeting for students with attention disorders, allowing for less distraction and a better

learning environment. Researchers have found that low-performing students improve and increase their leadership in nature-based environments.[173] Other studies have found that green spaces, such as grass areas and tree cover, had a significant impact and were positive predictors of student performance.[175, 242] A study measured the relationships between tree cover, diversity, and species on school property and their effect on student performance. It found that tree cover positively correlated with children's academic performance using multiple regression and affected diversity and species using correspondence analysis. The effects of species composition they found were more evident in math tests than in reading and writing tests.[175]

A qualitative case study found that successful indoor/outdoor interfaces and plenty of play space in gardens and forests provided students with a great sense of joy, freedom, social cohesiveness, and aesthetic pleasure in relation to the built school environment.[176] Similarly, a comparative case study found three attributes that produced the greatest benefit for student health and well-being in campus open spaces: healing gardens where greenery and plants produce restorative effects; flexible spaces that accommodate functional needs of different activities; and green buildings that incorporate open space as a catalyst for integrated eco-system.[177] Another study found that the time students spent in nature or taking care of plants helped them feel comfortable, learn satisfactorily, release stress and fatigue and pay more attention during lessons. Nonetheless, they could not find any associations between attention and concentration tests and the naturalness of classroom views.[51] Similar results have been reported regarding vegetation and nature near children's residential environment as mediators to endure the impact of life stress. A study found that the psychological effects of stressful life events varied depending on the amount of access to nearby nature that children had. Children with high access to nature appeared to be more protected from the impact of stressful life events, showing less psychological distress and higher global scores of self-worth.[243]

Research has found that outdoor classrooms have valuable qualities for student learning.[180, 181] These qualities include providing maximized choices, having many distinct spaces, especially child-sized ones, including embedded play affordances within pathways and borders, encouraging spatial evolution, and supporting ongoing stakeholder engagement.[181] In addition, outdoor learning areas can aid young children in developing sensory and motor skills, cognitive development, and general health/muscle development. All the former developmental issues can impact a child's learning ability once they are school-age and learning in an indoor classroom setting.[180] For example, a study compared the academic achievement of third graders in an indoor and an outdoor classroom and found that children's scores and engagement increased in outdoor settings. The most significant gains in student attainment happened with the students with the lowest grades in the indoor condition. The researchers argue that the physical environmental quality of the space and greater enjoyment and participation likely improved attainment.[178] Another study compared classes taught in traditional indoor classrooms versus classes taught in outdoor classrooms during half of one academic term and found that students behaved significantly better and were more engaged in the outdoor classroom. Nonetheless, there were no significant differences in student grades between the two conditions.[179] It is important to note that outdoor learning also brings some challenges. For example, it requires changing traditional teaching styles to fully profit from the opportunities provided by open-air classrooms.[244] Similarly, the location and size of the space and the safety of children may be an issue.[245]

Spending time outdoors at school has multiple health benefits for children. For example, a study found a statistically significant increase in kindergartners' motor fitness, coordination, and balance when they were provided with a natural landscape to play.[246] Similarly, a literature review found robust evidence

that students who spent more time outdoors were significantly less likely to become myopic.[247] Finally, research has found that green spaces for play support children with Attention Deficit Disorder (ADD).[248]

Spatial layout and design

Research has shown that students and teachers believe that students' self-reported engagement levels in the classroom are affected by the built environment and its design.[182] For example, studies have found that movement and circulation, along with other environmental variables, impacted student outcomes.[183] A study correlated 39 design patterns of schools adapted from Alexander's "A Pattern Language" with standardized test scores. The study found that four patterns, including technology for teachers, pathway, the overall impression of the learning environment, and positive outdoor spaces, were significant predictors of achievement.[184] A similar study investigated elementary schools' design patterns of movement and circulation, large group meeting places, daylighting and views, and instructional neighborhoods. The study found a positive correlation between student test scores and qualities or patterns of the schools deemed to be desirable or positive. Nonetheless, in some cases, the relationship was more pronounced than in others. Overall, the study found that these design patterns explained between 2% and 7% of additional variance in achievement.[185] Another study identified five environmental characteristics that independently predicted greater perceived creativity: the complexity of visual detail, views of nature, use of natural materials, fewer cool colors used, less use of manufactured or composite surface materials, and found that students work was deemed more creative in spaces where these conditions were better.[186]

Research has found benefits in open learning spaces. A study found that teachers perceived these spaces to be more flexible, allowed for more visibility and scrutiny, which meant less privacy, but also elevated performance. In addition, teachers perceived that these spaces de-emphasized hierarchy and leaned towards collaborative practice, teamwork, and interactions, where the classroom unit dissolved and the neighborhood or school became more of a community.[187] Similarly, a study found that "See and be seen" activities, like waiting or looking around, were more common in the spaces with more openness in schools. Spaces with a range of spatial openness provided maximum flexibility for several activities, including group study, eating, etc.[195] Nonetheless, open learning spaces also present challenges for their operation, as covered in the acoustics section.

Some studies have found similar patterns in other types of learning spaces. For example, a study found that 3rd, 4th, and 5th-grade students preferred the learning commons over a traditional library. The learning commons had an enclosed space for books but had a more open distribution and included other spaces such as group study areas, social areas, areas for eating, quiet study space, computer spaces, etc.[188] Similarly, other studies in universities have found evidence that spaces for practical learning should have good sightlines, be easy to navigate, and avoid excess clutter.[189]

Highlights

1. Schools' outdoor green space has a significant positive impact on health, learning and academic achievement.[51, 173–181]
2. Schools should be flexible and accommodate for a variety of learning situations and activities: social/private, noisy/quiet.[182–189]
3. Less dense classrooms are related with increased student ownership and better student-teacher connection.[190–195]

School Maintenance & Operations

Spatial Environment

Building and classroom condition and cleanliness

Research shows direct association of building conditions with student performance. The quality of the facilities mediates perceptions of the facility by different actors (teachers, students, parents, school leaders), affecting school climate, which ends up producing an impact on student achievement.[209–212] Student success depends on a built environment which then creates social interactions in adequate spaces inside large institutions.[212] For example, a study found that 70% of the variance in academic achievement was linked to the building condition and mediated by attendance and school climate. They also found that many students perceived their social climate as a positive experience affected by the physical space.[210] In another study, perceptions of the quality of the facilities were strongly correlated to the assessment of resource support. Similar to the previous study, the quality of the facilities was significantly related to the school climate index, and perceptions of the quality of the facilities were significantly related to student achievement and mathematics. School climate and quality of the facilities together explained 39% of the variance in student achievement. Another study found that cleanliness and neatness were independent factors of building quality.[211]

Other studies have associated building disrepair with student performance and absenteeism. A dissertation found that schools needing major repairs in their roofs, building envelope and site-related features were associated with higher chronic absenteeism. Similarly, it found that schools with more disrepair had a high proportion of minority and disadvantaged students.[213] Similarly, a study found that absenteeism was associated with visible mold, poor ventilation, vermin, humidity, poor ventilation, multiple individual building condition problems, and building system or structural condition problems. In this study, schools from lower socioeconomic districts and younger students had higher associations to building quality problems.[214] In addition, a set of studies found that school building quality affected student achievement. These studies attributed approximately 5% of the student achievement variance to school building quality in elementary schools, 1% in middle schools and 12% in high schools.[215] Another study found a link between student achievement in English and mathematics and the quality of the facilities and stated that a 10-unit change in a facility condition index resulted in a decrease in math and reading scores. This study also found that chronic absences increased with the worse quality buildings.[216] Research has found that schools with low structural quality and high rates of mobility contribute to reduced academic achievement. A study stated that for English and math test scores, an interaction between building quality and student stability showed that schools with lower building quality and lower student stability had lower scores.[217] Finally, a study found that school facility conditions predicted student attendance, even when controlling for other important

variables such as SES, teacher quality, school size, and ethnicity. This study found that school attendance was a mediator in the relationship between building condition and academic achievement. The mediation was complete in ELA and partial in math scores.[218]

The cost of maintenance of school facilities has also been addressed. A dissertation found that there was no relationship between the percentage of general fund expenditures school maintenance and scale score growth of state standardized test scores and found no significant differences between schools from different socioeconomic groups. Nonetheless, this study found that facility capital and student learning were positively related for 3 of the 10 CST tests.[249]

Other studies have found that aspects such as construction/renovation year, or occupancy didn't influence student performance.[22] Similarly, a study found that when comparing new schools to old schools in a program to renovate schools in the UK, new school buildings had no effect on student attainment, at least in the short-term. Nonetheless. When allowing for heterogeneous impacts, they found a small lagged effect in the earliest cohort of schools.[250] These findings seem to support the idea that good building conditions are more important than "newness" when referring to school facilities.

The conditions of classrooms are of special importance for students' academic experience. A study looking at traditional and portable classrooms found that yearly attendance was 2% higher in traditional classrooms when compared to portable classrooms ($p < 0.01$). Similarly, yearly decrease in absence was 2.5% higher in traditional classrooms ($p < 0.01$).[27] The California Portable study from 2004 found that both portable and traditional classrooms had IEQ problems. Nonetheless, the study stated that most of the solutions needed were low cost and would go a long way with improved operation and maintenance. Among the main recommendations of this report are quieter HVAC units and low emitting building materials. The study also recommended 4 approaches to tackle IEQ problems which are: 1) direct and assist schools to comply with state regulations, 2) develop and promote best practices for schools' design, maintenance and operations, 3) improve support for facilities and staff 4) establish guidelines for school environmental health.[251]

Energy efficiency and green building

The association between sustainable buildings and student performance has been addressed in a few studies but has failed to find significant results. For instance, a study analyzed the association of LEED certification with student test scores but found no associations. The author states that this may be due to green certified buildings not having acquired they IEQ credits necessary to provide environments that foster learning.[213] Similarly, another study found no significant associations between energy efficiency and student performance, but it did find positive associations between thermal and visual comfort and student performance.[252]

Despite this results, other studies have pointed out the benefits of green schools. A paper argued that green schools may lead to semi-natural classrooms that help enhance the indoor environmental quality of the space, and that energy efficiency standards could also impact students' perceptions of the schools, benefiting school climate, and student performance and well-being.[219] Similarly, allowing users to actively adapt their environment to their preferences has rendered some results. In a study in the Netherlands, researchers found a significant relation between the frequency of teacher's light switch behavior and energy consumption. The study found that schools consumed less electricity the more frequently teachers turned on the lights. Nonetheless, the study stated that a larger sample was needed to confirm their findings.[253]

Ventilation systems maintenance and COVID-19

Ventilation in classrooms requires maintenance and adjustment to accommodate a changing number of students.[100] Even if a classroom has natural ventilation and needs no cooling or heating, studies recommend including a mechanical system to guarantee appropriate ventilation rates.[26] For example, a study found that only schools with mechanical supply and exhaust ventilation met the ventilation standard.[100] Similarly, a review on ventilation in schools stated that schools could not just rely on opening windows to provide minimum ventilation rates. The review noted that in some studies, sensors have proven valuable to address this issue.[26] In another study, classrooms with regulated mechanical ventilation had a better performance than classrooms with unregulated natural ventilation.[22] Along with ventilation conditions, a study associated building materials, classroom age, outdoor air and other factors with elevated pollutant levels[251], which schools may address through maintenance practices.

Classrooms are at risk of having very low or high relative humidity levels. Research has associated extremely low levels of relative humidity (below 30%) with health issues such as dry eyes, nose and throat, and increasing virus survival in the air.[103] Similarly, research has associated extremely high levels of relative humidity (above 60%) with the appearance of fungi and mold.[105] Therefore, maintenance is critical to avoid these extreme values. For example, a study found that annual maintenance of HVAC systems in schools had higher odds of having RH levels above 60% than quarterly maintenance and found differences in RH depending on the system used. In addition, the study found that classrooms with a direct expansion (Dx) split system had a higher risk of low RH (< 30%), compared to those with a chilled water system. Finally, classrooms in buildings between 11 and 40 years old had a higher risk of low RH (< 30%) compared to younger buildings.[254]

In the COVD-19 pandemic, ventilation and systems maintenance in schools became a more pressing issue. As a result, multiple institutions and researchers took on the task of understanding the transmission pathways of the virus in the built environment. They developed research and task forces to set up guidelines to control the spread of the virus in schools and universities[197, 206, 255, 256], aiming to reopen educational facilities safely.[202–204]

Ventilation played a significant role in all these reports. For example, researchers in the Harvard TH Chan School of Public Health issued a 5-step guide to checking ventilation rates in classrooms[257], as well as a set of reports addressing the measures schools should take to reopen safely.[205] In this report, they included healthy classroom measures addressing personal controls such as mask-wearing and hand washing. In addition, their recommendations on healthy buildings included a large set of strategies. Among these strategies were increasing outdoor air ventilation, filtering indoor air, supplementing air filtering with portable air cleaners, verifying ventilation and filtration performance, considering advanced air quality techniques, using Plexiglas as a physical barrier, installing no-contact infrastructure, keeping surfaces clean, and focusing on bathroom hygiene.[205] The recommendation of using Plexiglass as a physical barrier was discarded by the CDC in 2021 after more information on the pathways for virus transmission became available.

Researchers also provided general guidelines based on previous knowledge in this area. For example, an early article that looked at the built environment and how to reduce the transmission of the virus recommended enhancing HVAC systems and proper filter installation and maintenance, as well as sustaining adequate levels of humidity, ventilation through windows, daylight and UV light, as possible control measures.[258] Other reviews followed, highlighting the importance of ventilation, filtration and humidification as a result of the first studies that dealt with the transmission of the virus in public spaces.[259] By the end of 2020, researchers argued that there was robust evidence to support the idea that engineering controls, such

as enhanced ventilation and filtration were a key element to limit the spread of the virus that caused the COVID-19 pandemic. They argued that public buildings such as hospitals, offices and schools could use engineering controls in addition to other strategies to limit the spread of the virus.[208] Among the main recommendations are increasing outdoor air exchanges, eliminating air recirculation, supplementing ventilation with portable air cleaners, and avoiding overcrowding.[208] In schools, research also supports natural ventilation as a strategy to prevent the spread of the virus by diluting particles in the air.[260]

Similarly, professional organizations like ASHRAE created an epidemic task force to provide recommendations for the safe reopening of K-12 schools and universities. The guidelines included inspection and maintenance of HVAC systems, ventilation, filtration, air cleaning, energy use considerations and water system precautions.[206] The CDC also created a website with the most up-to-date guidelines for schools to reopen their facilities safely. Among their key takeaways, as of November 5 2021, ventilation and respiratory etiquette remained essential layers of the overall prevention strategy to keep students safe in schools.[261] This isn't just a local trend, a review looking at the guidelines put out by organizations all over the world related to HVAC found common recommendations, especially regarding the importance of ventilation to respond to the COVID-19 pandemic. Nonetheless, the review also found some conflicting details related to the optimal ventilation rates, as there are still many uncertainties surrounding the mechanisms of transmission of the virus.[262] In the United States, The Center for Green Schools recommends that schools aim for at least six air changes per hour for a 1000 ft classroom[197], including a combination of mechanical and natural ventilation strategies.[196]

Currently, most schools have implemented different combinations of these measures. For example, a recent report stated that to prevent the spread of COVID-19, schools had adopted measures addressing three areas: increasing fresh air through the mechanical ventilation system, increasing outdoor air through operable windows and removing airborne contaminants through filtration.[263] The most frequently adopted measures had to do with increasing the efficiency of mechanical ventilation. In contrast, the least prioritized ones had to do with addressing the operability of the windows.[263] Similarly, a recent report presented evidence supporting the idea that ventilation investments could be cost-effective and better than deep cleaning as a measure to prevent COVID-19.[199] Its recommendations included investing in healthy air now to outlast the pandemic. The report recommended actions such as improving ventilation by bringing in as much as outdoor air as the HVAC system allows, using HEPA filters in classrooms and common spaces, using only proven technologies like filters and ultraviolet germicidal, stopping enhanced cleaning, installing mechanical ventilation where they don't have it, and upgrading the ones they have.[199] These guidelines align with ASHRAE and the CDC regarding managing COVID in schools.[255, 256, 264] Researchers have stated that with all these measures in place, along with other recommended controls, in person schooling is as safe for children with asthma and allergies, as it is for children who don't have any respiratory health issues.[265]

Ventilation system improvements and maintenance had been proven to be necessary and cost-effective, even before the COVID-19 pandemic. For example, a study from 2013 in California elementary schools calculated that by increasing the schools' average ventilation rates (4 L/s-person) to the state standard, school absence would decrease by 3.4% in the state. These upgrades would cost $4 million, but the annual attendance-linked funding would increase by $33 million, making the upgrades cost-effective.[24] Previous research calculated that Increasing ventilation rates could have an annual capital cost of less than 0.1 % of public education spending in the US.[26] A European Union report rendered similar findings, coming from the point of view of poor

indoor climate and child health. The report states that children's exposure to dampness and mold at home could be estimated to have a macroeconomic impact of US$62 billion over the next 40 years. For schools, they calculated that a slight improvement in ventilation rates of 0.5 L/s-person would increase EU-28 GDP by USD 24.4 billion by 2050. Even more, a more substantial upgrade of 2.5 L/s-person would represent an increase of USD 120.5 billion in EU-28 GDP by 2050 and USD 281.4 billion by 2060.[201]

Highlights

1. Ventilation investments are a necessary and long-lasting measure to prevent COVID-19 and support student performance and general health.[24, 26, 196–208]
2. Building disrepair has been associated with student performance and absenteeism.[209–218]
3. Green schools haven't been directly associated with increased student performance, but their enhanced IEQ, relation to nature and energy efficiency are beneficial for students.[213, 219–221]

Classroom Environment

Spatial Environment

Active learning and flexible classrooms

Classrooms involve multiple parameters that influence student learning. Architects have often used case studies or their own experience to create recommendations for better classroom design from the design perspective. For example, a study found a positive relationship between student success and the perceived quality of classrooms, front office and information technology, classroom conditions, and cleanliness. However, this study also found that offices and meeting rooms or closed environments created more negative student success results.[212] Another study investigating the engagement levels of students in grades 9 to 12 found a significant effect of the physical environment on engagement and teaching practices for teachers and students. It concluded that space design made a difference and increased academic engagement.[266] Some recommendations for the design of classrooms include incorporating small, quiet group study spaces with shared screens or other technology and larger, reconfigurable flat-floor rooms with movable furniture and room dividers. In addition, social spaces serving as lounge and informal study areas and makerspaces for hands-on craft and experimentation are also recommended.[267]

The differences between traditional classrooms and Active Learning Classrooms (ALC), which incorporate flexible furniture and technology, are among the most common issues under study regarding classroom arrangements. Some of the key design elements to designing classrooms for active learning are the versatility of learning space, interior design and learning environment, modern IT/AV technologies, interior lighting, comfortable furniture, acoustic design and interior temperature.[268] Research has pointed out some of the benefits of ACL classrooms: increased student-to-student visibility to enhance interactions, improving acoustics, inspiring creativity, and using technology to enhance engagement.[269] For example, a study found that ACL classrooms could improve students' health by sitting less and spending more time standing and moving.[232] In addition, research has found that physical activity benefits primary students' academic behavior and academic performance.[230]

Some studies have found that students perform better in ALC.[231–233] For example, a previous review found three studies that reported significant associations between flexible learning spaces and improvement in academic performance with moderate effects. They showed that academic results in English, math, humanities were higher in flexible spaces than in traditional classrooms.[232] Similarly, a study in a university setting found that students in ALC's outperformed those students in traditional classrooms, even when students in traditional classrooms initially had better scores.[233]

Behavior and engagement are also affected by classroom arrangements. For example, studies have found that adolescents in flexible learning spaces

were more engaged, on-task, self-reported feeling more autonomy, and collaborated and interacted more than students in traditional classrooms.[232] Similarly, a university study found that the classroom configuration directly influenced student self-ratings of engagement when comparing a class with the same instructor in a traditional classroom and an ALC classroom.[270]

Research has found that ALC classrooms increase student visibility, which studies have associated with various positive effects. For example, a study observed that traditional classrooms had "golden zones" or rows with the best sightlines and acoustics, and "shadow zones," or areas typically at the back of the room, where the combination of light, sightlines, and acoustics make learning and engagement more difficult. The study found that ALCs effectively diminished shadow zones in the classroom while emphasizing golden zones.[271] In addition, ALCs enable students to connect more directly with each other and with the professor.[231, 272] In a study, taking away the idea of a "front" of the classroom made the ALCs feel more democratic and flexible, enabling students to take more ownership over the space.[272] In another study, flexible and well-designed spaces were correlated to increased student group work, asking questions in class, and helping classmates understand concepts.[227]

Students seem to prefer flexible learning spaces[273], and in some cases, instructors have shown a preference for these spaces too.[231] In addition, easily movable and reconfigurable furniture combinations that can change between a lecture format and small group work formats can improve the classroom experience.[192] In a study, eight graders reported a preference for learning spaces with more informal hands-on learning, which provided opportunities to move about (including outdoor space), personalization and ownership on their work, and opportunities for more group work.[273] Some aspects that influence student preferences include movable furniture, use of whiteboard space, and ability to conduct group work and communicate more openly.[231]

Nonetheless, there are still questions regarding the efficiency of different classroom arrangements. For example, a research study in a university found significantly more positive perceptions among students and instructors immediately after an intervention where they reconfigured a classroom from a traditional classroom to a flexible space.[274] Positive perceptions had to do with increased access to the instructor and more group work and communication. Nonetheless, after a couple of semesters, perceptions of the classroom dropped back to the initial levels.[274] Similarly, an intervention with fourth graders changing the classroom arrangement during a class period improved student engagement in the first part of the lesson. However, by the end of the lesson, students' disruptive behavior increased again.[275] Thus, it appears that classroom arrangements can increase positive perceptions and engagement, but the duration of these effects is not well known yet.

Flexible spaces and pedagogy

There is a central role of the pedagogical approach to enable the full potential of a flexible classroom.[222] Research has found that flexible learning environments enable improved performance but have some challenges regarding how teachers use the space.[222] In some cases, teachers do not change their teaching behaviors despite being in flexible classroom settings.[223] Nonetheless, in other cases, teachers have consciously changed their pedagogies to make their classes more interactive and collaborative or have naturally adapted their classes to more flexible settings.[224]

Simply having active learning spaces does not guarantee student engagement, performance, or attendance.[225, 226] Conversely, simply implementing a new curriculum or pedagogy on its own is not as impactful.[226] Furthermore, a study stated that even with flexible and well-designed spaces, the quality

of the teacher might be the most critical factor for student engagement.[227]

An intentional program of stakeholder engagement, teacher training, and ongoing support is necessary to supplement active classroom design.[225] In addition, teachers need support to adapt to teaching in new flexible environments.[228] For example, a study in a university setting found a meaningful link between the design of interactive learning classrooms (ILS) (with particular emphasis on technology-equipped spaces) and the resulting teacher pedagogy / teaching practice, which influenced student engagement and performance. Furthermore, the study found that the ILS design promoted activities that had the most considerable influence on student engagement and partially explained students' perceptions of the effectiveness of their instructors.[229]

Technology and flexible furniture

Technology and furniture in classrooms affect student learning and engagement.[227] Children prefer classrooms with flexible furniture compared to traditional classrooms and traditional furniture.[276] For example, research has found that whiteboards (either entire walls of whiteboard space or traditional mounted whiteboards) are among the most vital components of classroom spaces, along with folding/ rolling/movable furniture, for maximum spatial flexibility.[277] Flexible furniture allows for the best use of space to create a learning environment that can change based on the educational needs of the space.[276, 278] In addition, flexible furniture provides more opportunities for student autonomy, and it can improve student choice, perceptions, active learning, and movement.[276] Nonetheless, it is unclear what kinds of flexible furniture are better. For example, a study compared three types of furniture and found that overall, no one type of furniture proved the same effect on measures of attention, work neatness, and work completion for all the students. In addition, students responded differently to furniture based on their learning needs, abilities and personal preferences, and their self-reported measures of performance varied as well.[279]

Studies have found evidence of positive influences of technology in the classroom. In a study, more modern classrooms had the highest achieving students compared to less modern or obsolete environments.[215] Another study found that information technology in a classroom increased students' learning ability.[191] Nonetheless, high technology capabilities can come at a heavy cost to institutions[280, 281] and require additional training for teachers to take full advantage of their benefits.[281, 282] Some studies argue that advanced classroom technologies are not the main drivers for deeper learning but rather are a tool to supplement other more impactful attributes, such as movable furniture, discussion-based learning environments, and collaboration.[280] For example, a study compared Practical Learning Classroom (PALS), ALC, and traditional classrooms and found that the most important attributes of the PALS were hardware and non-technology features. Some of these features included clustered student tables that enabled group work or the ability to share work via whiteboards or shared computer hardware.[283] In this study, students in ALC performed similarly as students in PALS, and both of them outperformed students in traditional classrooms.[283]

Ergonomic furniture

Ergonomics is an important issue to consider regarding classroom furniture. Studies have found that there is often a mismatch between school furniture dimensions and children's anthropometric measurements 237,240,284,285. Inadequate furniture can cause developmental, posture, and health problems 238. Musculoskeletal disorders in children, such as neck pain or back pain, have been associated with the overall satisfaction with classroom furniture, desks backrest and height 286. For example, a study found that using ergonomic furniture at primary schools allowed for a decrease in back pain and musculoskeletal disorders 237. Another study found

a negative relationship between children's success in moving chairs in a classroom and the weight of the furniture.[287] Uncomfortable furniture can negatively influence student performance if it creates back pain that affects concentration.[238]

The furniture design may have positive effects on health. For example, high furniture, sit-stand furniture, and tilt tables and seats create positive effects in children[235, 236], such as increased caloric expenditure, step count, and comfort.[234, 235] Promoting appropriate sitting behaviors in classrooms may also benefit children's health.[239, 240] Furniture in classrooms should have age-appropriate dimensions or be adjustable to fit children in different stages of development.[240] Similarly, it should be easily maintained, comfortable, durable, provide safety, stability, and create the best learning environment for students.[237]

Storage and display

The way teachers display student work in the classroom can affect student performance. A study with preschoolers found that when teachers overly decorated the walls, they became visual disturbances. In these classrooms, children were more distracted, spent more time off-task, and displayed smaller learning gains.[288] Exaggerated classroom displays may even affect classroom lighting conditions. For example, a study in primary schools in Australia found that windows were often obstructed by student work, while artificial lighting wasn't always used when light levels were below the standard.[118] This study pointed out the responsibility of teachers, as they oversaw the furniture and pedagogical displays. In addition, the study found that with the introduction of new interactive whiteboards, schools required better daylight and glare control.[118]

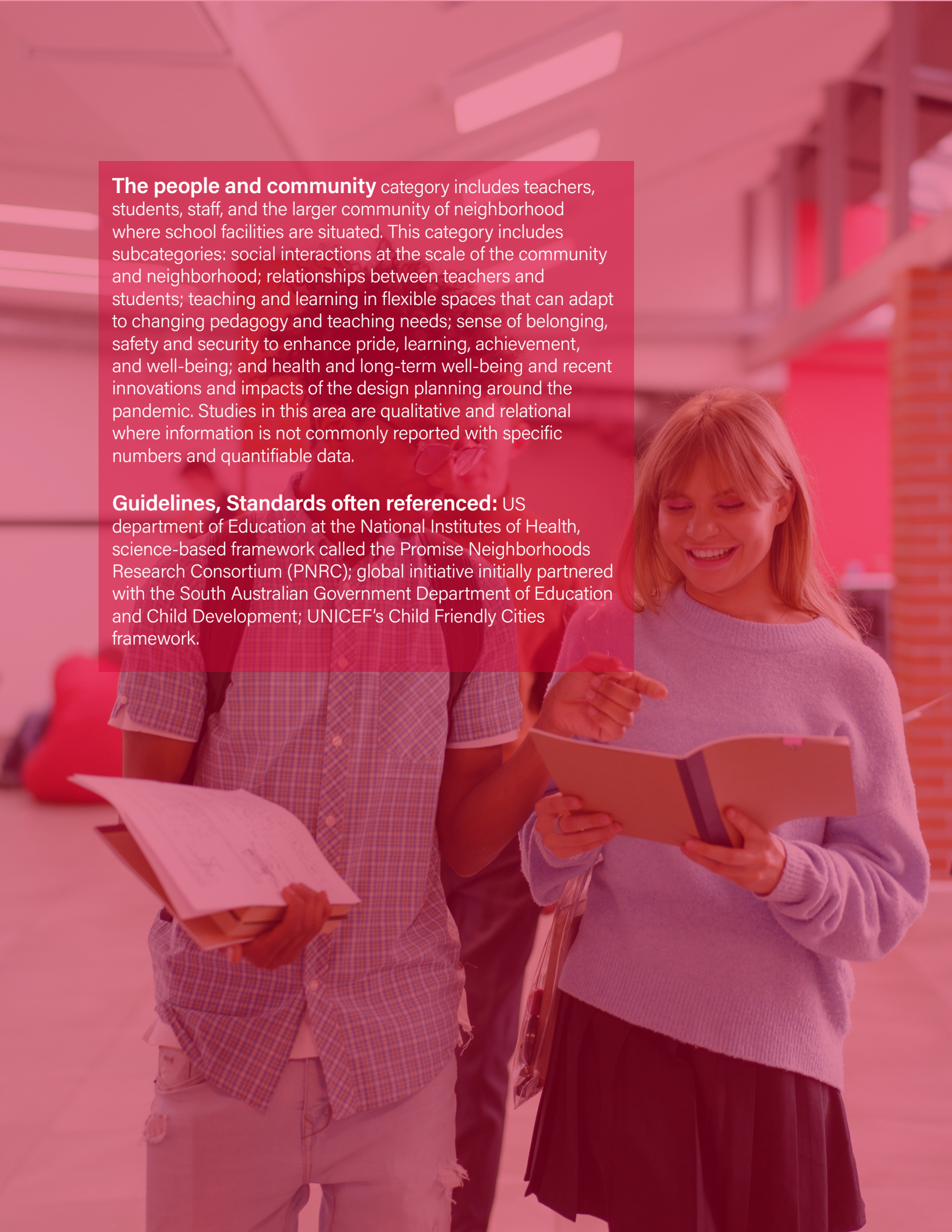
Color

Color is vital in functional learning, as research has found that it impacts attention, achievement, general behavior[289, 290], cooperative behavior in preschoolers[291], and mood.[292] For example, in a multilevel analysis study, color accounted for 18% of the proportion increase in a student's learning progression among six relevant environmental factors. Therefore, this report recommended light walls with some areas painted in brighter colors to produce an adequate level of stimulation in the classroom.[293]

Studies regarding color, mood, and performance have approached the problem from different methodologies and rendered inconclusive results. For example, a study comparing warm and cold-hue colored walls on a virtual classroom found that cold hue colors increased arousal and improved attention and memory tasks performance, while yellowish-green and purple hues allowed for the best performance.[294] In a different study, 8 and 9-year-old children performed better in attention tests in a purple classroom, and the order of best to worst performance based on wall color was purple, blue, green, yellow, and red.[295] A study investigating the effect of color on emotion found that red caused the brain to enter a more excited state and sometimes even slowed the heart rate. Finally, a study found that if someone entered a room in a negative mood, the color could increase this mood and affect performance.[292]

Highlights

1. Flexible learning spaces allow students to be less sedentary, enable improved student performance, but may present pedagogical challenges.[222–230]
2. Classrooms that incorporate technology, such as Active Learning Classrooms may increase student engagement and performance.[191, 215, 229, 231–233]
3. Ergonomic furniture positively impacts student health.[234–240]



The people and community category includes teachers, students, staff, and the larger community of neighborhood where school facilities are situated. This category includes subcategories: social interactions at the scale of the community and neighborhood; relationships between teachers and students; teaching and learning in flexible spaces that can adapt to changing pedagogy and teaching needs; sense of belonging, safety and security to enhance pride, learning, achievement, and well-being; and health and long-term well-being and recent innovations and impacts of the design planning around the pandemic. Studies in this area are qualitative and relational where information is not commonly reported with specific numbers and quantifiable data.

Guidelines, Standards often referenced: US department of Education at the National Institutes of Health, science-based framework called the Promise Neighborhoods Research Consortium (PNRC); global initiative initially partnered with the South Australian Government Department of Education and Child Development; UNICEF's Child Friendly Cities framework.

Executive Summary

People and Community

KEY FINDINGS:

1. The influence of the greater community around a school indirectly impacts the student due to the economic, social, and physical stressors on parents, teachers, and school staff.[296–303]
2. Neighborhoods and built environment surrounding the school can create spaces for youth to participate in activities which have been shown to help develop social emotional health and encourage prosocial behavior.[304–311]
3. Creating a sense of community with strong access to services helps children to engage in healthy behaviors.[304, 312–323]
4. Teacher support (training, physical space, and supportive relationships) contributes to a better workplace and effective teaching.[320, 324–331]
5. The student-teacher relationship is key in supporting social-emotional learning, encouraging prosocial behaviors, and creating more engaged and motivated learning.[332–338]
6. When students feel supported, have a sense of belonging, and have opportunities to engage in activities, they can have increased well-being as well as better completion and academic outcomes.[319, 323, 338–344]
7. Teachers need flexible and adaptable teaching spaces to accommodate changing pedagogy, new cohorts, as well as enhancing creativity for learning experiences.[272, 275, 302, 345–349]
8. Physical space for positive interactions as well as visual promotion of activities, awards, and future aspirations contribute to school belonging and pride.[187, 324, 350–354]
9. Engagement and motivation, social and emotional skills, and prosocial behavior which encourages learning is influenced by the relationship of people, physical space, and time.[355–360]
10. Safety and security encompass the environmental and spatial visual cues from departure from the home, on the way to school and on school grounds and the physical building.[348, 361–363]
11. Students who feel a sense of ownership and belonging to the school and community have social and academic success as well as long term trajectories of individual well-being and contributions to society.[342, 356, 364–368]
12. Familiarity with the physical layout and uses of school buildings encourages activity that contributes to the feeling of community and pride in the school, also yielding a sense of security during emergencies.[369, 370]
13. Buildings and grounds used within and outside of school hours contribute to student well-being, increased physical and mental health, positive relationships, and increased access to student services.[305, 371–378]
14. The number of students participating in high risk and unhealthy behaviors can be decreased by having monitored activities in and out of school hours.[376, 379–387]
15. The long-term health and educational trajectories of youth can be influenced by the school community and resources it provides.[388–396]

Social Interactions

People and Community

The impact of the student expands beyond the context of the self. The awareness of the contexts in which the students are developing, and learning can allow for a better understanding in the ways that children can act in different environments and settings. There are also complex relationships and multilevel surroundings that impact the development of a child. The Bronfenbrenner ecological framework is an ecological model of human development with five systems.[397] The microsystem which includes the family, teacher, and peers is the most direct and immediate influence on the child's development. The mesosystem is the interconnections between the microsystems include the relationship between peers and family as well as parents and teachers. The exosystem are the links that are in social settings that do not directly involve the child but influences their experiences like parents going every day into a hostile work environment which in turn increases stress and possibly cohesive parent child interactions. The macrosystem is a cultural context that has an indirect influence on the child which includes socioeconomic status, ethnicity, geographic location of the neighborhood. Last is the chronosystem which are patterns of events that influence transitions such as divorce, traveling for work, or even a pandemic. Each of these systems impacts how the child learns from both an academic and developmental perspective.

The community, neighborhoods, and the built environment

Stress from environmental factors including poverty and discrimination impacts the health of all family members. Poverty is a risk factor for many physical illnesses and mental health disorders as well as harmful to many aspects of the development of a child.[296, 297, 318] Problem behaviors in youth include influences from poverty,[298] discrimination,[299] and neighborhood deprivation.[300] Neighborhood deprivation associated with an increase in academic failure, more antisocial behavior, and increase in chronic health conditions.[398, 399] Neighborhood characteristics influence those living and working in the neighborhood and that includes the teachers and staff that create a space of learning for students.[301, 302] It is predicted that by 2050 two out of three people will be living in urban settings[400] and though there are many positive economic and social opportunities, there are several societal problems that can happen like high rates of crime, lack of access to nature, and increased health disparities.[303]

In a meta-analysis focused on improving the health of youth through community and evidence based developments, of the most efficacious strategies they found,[46] which included access to places for physical activity, quality preschool/early childhood education, sexual health education and additional strategies with medium to large effect sizes on improving psychological and behavioral health including cognitive development, social

and emotional competence and less psychological and behavioral problems.[312] A network of scientists supported by the US department of Education at the National Institutes of Health created a science-based framework called the Promise Neighborhoods Research Consortium (PNRC) to promote community level efforts to help youth develop and increase wellbeing in disadvantaged and distressed neighborhoods.[316] It looks at influences that are distant from the youth like income, resources, and physical environment as well as close influences including family, school, and peers that are important to youth cognitive development, social and emotional ability, and overall wellbeing. The Promise Neighborhoods program[401] is a greater program modeled from the success of the Harlem Children's Zone.[317] In this framework, the primary outcomes are cognitive development, social and emotional competencies, mental health, and physical health.[402]

The design of livable cities tries to encourage health and wellbeing, including access to basic needs like affordable housing, services, schools/childcare, and infrastructure.[304] Neighborhoods and the planning of the environment around schools helps to create community and spaces for youth to learn skills beyond the classroom.[318, 403, 404] Though the influence and family environment are important in development, the neighborhood, and the way it is built has a great impact on child development.[405, 406] The feeling of security begins with the travel from home to school and the pathway parents and children navigate.[305–307] Research suggests that limited access to green spaces in urban areas can decrease the opportunities for children to be a part of prosocial and positive interactions as well as fewer places to engage in physical activity[348, 407, 408] while having access to nature could help to promote positive development.[409, 410]

UNICEF has developed the Child Friendly Cities framework which includes six key areas; active participation, safety, health, education, belonging, play and leisure. This global initiative has initially partnered with the South Australian Government Department of Education and Child Development to pilot this model[411] and is now implemented in Spain, India, Sweden, and several other countries.[308] Safe passage to school also encourages healthy habits and activity in students and can lead to the creation of safe spaces outside school grounds like green spaces and playgrounds.[309] In the city of Denver, they created learning landscapes for creating community tailored child friendly outdoor play environments in neglected parks and school yards in collaboration with the University of Colorado and in 1998 invested $20 million with about $450,000 per a school yard and then in 2003 the voters passed a $10 million dollar bond to continue funding. To access these outdoor environments, many of which are in schools, it was important to find safe routes to schools so that students could find ways to access the learning landscapes and schools through a collaborative process with the surrounding community.[310] These initiatives help enhance the health and wellbeing of children[310, 311] while in turn creating livable cities and have implications as populations continue to grow.

School community

Students, particularly adolescents, spend more time in school than any other place and engage in learning multiple skills and are influenced in every aspect of development in school.[319] School is a community and a sense of belonging, the organization of communal spaces can create a place where all students have ownership and feel belonging, or feel isolated and victimized, which can lead to delinquency.[319–321, 412] Making space for teachers to have autonomy of design and the flexibility to be creative, can allow for the adaptation of different cohorts of students which change from year to year.[272, 345–347] Students need physical space to be able to play and connect,[302, 348] have spaces with monitored positive interactions, and ways to work together outside of the academic classroom to create a sense of community.[302]

The physical environment influences the social interactions of students, teachers, and staff and

a space for more than just academics but the development of the whole child. Schools are a place where children can have integrated social services and educational opportunities thus allowing for a community to belong to.[322, 413, 414] Community schools are an example of a model that has been popular around the world and developed to offer support for families and better education for youth in low-income neighborhoods.[313, 415] An evaluation of a sample that was representative of 254 schools examined the relationship between communal school organization, bonding in students, and disorder in the school and showed mediation of bonding with school organization and school disorder.[412] A more integrated approach which came from the No Child Left Behind policies is called the full-service community school which coordinates programs and community support within the school. It addressed the need for the frustration of schools in less socioeconomically advantaged areas and tried to help with the disparity of schools with more resources[314, 416] with studies suggesting that this model increased academic engagement and reduced problems with behavior.[315]

Highlights

1. The influence of the greater community around a school indirectly impacts the student due to the economic, social, and physical stressors on parents, teachers, and school staff.
2. Neighborhoods and built environment surrounding the school can create spaces for youth to participate in activities which have been shown to help develop social emotional health and encourage prosocial behavior.
3. Creating a sense of community with strong access to services helps children to engage in healthy behaviors.

Relationships

People and Community

Relationships are the key to all aspects of the development of children and schools are the place they spend more time than home. School is where students are with their friends, shape their identities, and prepare for the future. It is also the place where relationships influence psychological wellbeing and development.[319, 339] Some of the most influential relationships are between students and their teachers[332] and this relationship is pivotal in socio-emotional development, the development of prosocial behaviors, and academic completion.

Student-teacher relationships

Some of the most important influences on youth in schools are teachers[333] with qualifications and experience influencing achievement and graduation rates[334] while the quality of teachers differs across diverse social groups.[417] A national study found that a lack of meaningful positive relationships with adults in school was one of the main reasons for dropping out of high school.[335] Teacher support both in academics and socio-emotionally is vital[336] to the teacher-student bond[337] and can be instrumental or an obstruction to the student.

The quality of the teacher and student relationship has been shown to influence student motivation and engagement in learning, socio-emotional development,[332, 338] and a sense of belonging[340] in longitudinal and cross-sectional studies. Engagement is important for resilience in academics which can lead to increased achievement which is related to positive school experiences.[341] A positive and supportive classroom climate can lead to better student motivation and engagement as well as overall wellbeing.[338, 339] Studies support that learning which is challenging for students is important for engagement and achievement[323] and meaningful work related to experiences helps to promote motivation in learning as well as increases bonding with other students.[332] In addition, studies show that teachers with more self-efficacy in being able to teach all students in the class in the subjects that they teach have students that also feel more efficacious in the ability to learn.[338]

Extending out of the classroom the teacher-student relationship helps to develop school belonging and peer bonding in the perspective of creating schools as communities.[342, 343] An integrative model suggests that the attachment that students have with adult staff shapes student connection with peers and can contribute to behavioral choices that potentially nurture commitment to school and peers leading to participation in activities and the avoidance of risky behaviors.[344]

Teacher-teacher/staff relationships

The physical structure and people infrastructure that is built on all levels and contexts are at the core of how teachers can be supported in their work with the changes in educational standards that come from national and local policies as well as the differing needs of students.[418] Educational change can be challenging[226, 419] and time-consuming failing to allow for adaptation and innovation.[176] There is also the importance of the physical structure and location of the school that needs to be able to work with the educational changes[420] and a relationship between activities that take place in the school.[325, 326] The functionality and change of physical and organizational structures not addressing pedagogic perspectives[421] can fail to increase teacher efficacy and motivation[188] thus potentially losing teachers to more familiar and traditionally structured schools.[327] The ability for school staff to monitor common areas can help to facilitate school climate and give autonomy and ownership to students. Just as the built environment for the classroom is important for the ability to teach, the design of the common areas of the school facilitate relationships and interactions between peers that teachers and school staff can support.[320] Reviews focused on educational settings and architectural views have proposed new ways to understand the relationship between spaces and activities,[354, 422] the evolution of teaching and learning in modified settings,[183, 184] and the reciprocal nature of space and approach to teaching.[328] There is the opportunity for school staff to be supported in the physical environments in which they work and use space as a tool for possibilities in pedagogical adaptation and innovation.[324]

It is important for teachers to be supported by other teachers and staff. Supportive school culture helps to increase the wellbeing of teachers.[329] Understanding the social structures and cultural context of the communities where they work as well as having useful trainings that address types of pedagogy, shared team culture, and the practice of school procedures help with trust and self-efficacy of knowing what to do in a range of situations.[330] Teaching is hard and there is a growing concern about new teacher attrition[423] ways to retain existing teachers. There is a value in having intergenerational learning from colleagues of all ages and experience levels.[424] In Belgium and Finland, teachers took part in a pilot where they were taught skills of intergenerational learning and eight themes emerged: practical information, classroom management, knowledge content, pedagogy, self-regulation, attitudes, teacher values, and community building. This small study reinforced the understanding that development does not come from only formal training but much of it happens with supportive discussions with colleagues and everyday implementation of practice.[424] When surveys asked about the most helpful things for teachers, mentorship and sharing with other teachers and staff were the most helpful[330, 331] and least helpful things were lack of materials and training as well as unsupportive administration.[331]

Highlights

1. Teacher support (training, physical space, and supportive relationships) contributes to a better workplace and effective teaching.
2. The student-teacher relationship is key in supporting social-emotional learning, encouraging prosocial behaviors, and creating more engaged and motivated learning.
3. When students feel supported, have a sense of belonging, and have opportunities to engage in activities, they can have increased well-being as well as better completion and academic outcomes.

Teaching and Learning

People and Community

Classroom and school

Teaching encompasses not only the academic milestones but also the socio-emotional benchmarks of children. Teachers need pedagogical approaches that can match the overall developmental milestones while adapting to individual students as well as group dynamics.[349] Teachers need to have classrooms that are adaptable and flexibility to be able to adapt their spaces to accommodate differing needs of students and changes in pedagogical approaches.[275] With a structured framework of goals and rules, teachers who have the autonomy to be innovative and creative within their approaches to pedagogical approaches can enhance the learning experience.[425] Classroom design on teacher pedagogy has had this reciprocal relationship but due to the complex dynamic of this relationship it has been difficult to study.[347]

Schools were traditionally built focused on technical facilities and performance with little input or regard for pedagogical performance.[426] The functionality and change of physical and organizational structures not addressing pedagogic perspectives[421, 427] can fail to increase teacher efficacy and motivation,[428] thus, potentially losing teachers to more familiar and traditionally structured schools.[327] Add to this the complexity of technology in the classroom. For example, in elementary schools, teachers are often responsible for more than 30 students, need to teach multiple subjects, meet the needs of the students, and troubleshoot while interacting with technology. All these things put together can make it difficult and complex to manage the classroom and make it difficult to give all the students the attention needed.[429]

The design of classroom technologies can facilitate learning.[350] The ability for the teacher to utilize the technology more effectively can be learned. The physical space has impact on student outcomes[430] and training of routines and how to integrate all the elements needed in teaching can be taught.[187] There is the opportunity for school staff to be supported in the physical environments in which they work and use space as a tool for possibilities in pedagogical adaptation and innovation.[324] For example, open spaces allow for different configurations to be developed and modified to emphasize different relationships and approaches.[351, 420] New school buildings have the potential to facilitate flexible teaching and new learning experiences[352, 353] and the continued development of student-centered learning can contribute to innovation of space, pedagogy, and innovation in teaching.[354]

School climate

Belonging has been shown to be important to many aspects of the whole child and school climate is about the group experience and the experience which creates the overall environment of the school. School climate includes support of the teacher, connectedness with peers and with

school, understanding of rules, and acknowledging diversity.[355] School climate influences student wellbeing and is an interplay between relationships, teaching and learning, and physical space.[356]

School-wide applications with multi-tiered system of support have been introduced to schools across the country called positive behavioral interventions and supports (PBIS). It has shown through many rigorous randomized trials in elementary schools to have significant impact on bullying, discipline problems, school climate, and academic performance.[357, 358] PBIS focuses on change throughout the school by consistently preventing behavior problems in students and promoting a positive school environment.[359] This is done by having staff, teachers, and students having similar expectations and provides incentives for students meeting expectations.[360]

Highlights

1. Teachers need flexible and adaptable teaching spaces to accommodate changing pedagogy, new cohorts, as well as enhancing creativity for learning experiences.
2. Physical space for positive interactions as well as visual promotion of activities, awards, and future aspirations contribute to school belonging and pride.
3. Engagement and motivation, social and emotional skills, and prosocial behavior which encourages learning is influenced by the relationship of people, physical space, and time.

Belonging, Safety & Security

People and Community

The ability for a student to find personal success in development and academia includes an environment in which they can feel safe and secure. The physical environment of the area surrounding the school, the neighborhood, and the school itself provide the foundation for spaces that give a visual sense of security. The design and use of the school which is accessible provides flexible use can provide a way for students to have a sense of inclusion and belonging providing a psychological sense of safety. The ways that students, teachers, and staff interact with the physical space with pride and ownership through activities like cleaning, showing school pride, and practice of what to do in emergencies can empower students and the greater school to come together and protect one another.

Safety and security

The neighborhood around the school and the feeling of safety as an influence can impact the feeling of security on the way to school.[348] The safety concerns of parents on the journey from home to school fall into several domains of general, road, and personal safety. A questionnaire was sent to 840 parents of 4th graders from 81 schools in Texas. Less than 19% of the parents reported that their children walked to school on most days of the week and that if the neighborhood around the school had a more favorable built environment of safe road crossings with available and maintained sidewalks then they were more likely to allow their kids to walk.[361] When trying to understand why parents used private vehicles to send children to school instead of walking or more sustainable autonomous ways for youth to go to school, 2000 households in Georgia living a mile from school with children aged 5 to 15 stated safety was the greatest concern.[431] In neighborhoods it is a multidimensional problem. Youth need safe places for physical activity and places to play. Outdoor spaces open to the community like playgrounds and parks help can help neighborhoods feel like a community with places to gather. With less place to spend time outdoors in green spaces and play areas in the neighborhoods children don't get to casually meet friends and regular physical activity.[362]

Building safety and security is more important due to terrorism, natural disasters, and internal violence. Further methodologies and practice for design used for commercial buildings need to be applied to schools and academic institutions.[363] Crime prevention through environmental design (CPTED) is a strategy that gains input from students and researches the gaps.[432] Nine hundred middle and high school students participated in a study looking at the relationship between CPTED and perceived safety. The results suggested that the CPTED approach may be an effective way to help with feelings of safety and psychological wellbeing in a majority of students.[369] A survey of 4,717 students from 50 middle schools participated

in an assessment associating the physical characteristics of schools, perceptions of students, and violent behaviors made preliminary links of safety concerns and absenteeism and is the beginning of a tool that can assess multiple facets of security.[433]

The increase of visible security measures is being used more for a sense of security.[434] Safety cues on the grounds of the campus also include the addition of technology and cameras used by officers to monitor the physical premises as well as the activities that happen at the school. Schools that are maintained and code compliant can contribute to a boost in student achievement.[435] A School climate survey completed by 54, 350 from 98 middle and high schools in Maryland in addition to observation both on site asked students about their perceptions of equity, safety, and support. Cameras were viewed as a tightening of measure by which to protect students can be viewed as safety but not for all students, especially those of minority groups. They found that cameras used inside were related to lower perceptions of safety and those outside were perceived as a moderate level of security. However, the presence of cameras and safety officers were associated with higher perceptions of safety for white students and not black students.[436] Since the mid 1990's safety and security in American schools has led to officers stationed within the schools and zero tolerance discipline policies. There is a need for youth to have structure and support as they grow into independent and autonomous people, however zero tolerance is controversial. It is overly restrictive while taking little consideration into intentions or context.[437, 438] At one time zero tolerance policies were one of the most used approaches to firearms and was then applied to illegal drugs, medications, and other behaviors.[439] School police officers are placed in schools with the authority to arrest and the growth of this trend[440] has also paralleled the growth of student behavior becoming criminalized. Though arrests of students have increased each year zero tolerance policies have been in place, graduation rates,[441] academic achievement and cohesion in the student population has declined.[442] There are more officers that occupy schools with high populations of students of color[443] and these under-served youth are disproportionately targeted for suspension or expulsion.[259] These officers are supposed to serve three functions: teacher, informal counselor or mentor, and law enforcer. These are conflicting roles requiring different skill sets with little comparative training.[444–446] The goal would be to create alternative ways to ensure school safety without the very present visible security measures.[447] There are alternatives to this type of discipline which provide both structure and support while allowing students to feel safe and respected.[438, 448]

Ownership and belonging

Being a victim of bullying at school can create a feeling of being unsafe and studies have shown students with lower levels of school engagement, adjustment psychologically and achievement academically.[449] A big part about feeling safe is the emotional space of feeling a sense of belonging in a community and ownership in a space that reinforces positive activities and behaviors. Bullying impacts the individual but also the climate of the school as well.[364] School climate has several definitions,[356] but has been described as the expectations, beliefs, and values that help students feel safe physically, socially, and emotionally.[450] The US department of education developed a three-domain model of school climate which includes engagement, safety, and environment.[451]

Schools help students create their social networks, learn to fit in to a group, and can help feel belonging. Belonging is the feeling of being respected, supported, and included by others.[366] It has been shown to have an impact on parts of life including cognitive functioning, academic outcomes,[367] school completion, prosocial behavior.[342] The benefits of school belonging also include mental and overall wellbeing,[452] and psychosocial outcomes such as happiness and self-esteem. It is also a protective

factor and related to reduced bullying, emotional distress, and engaging in risk taking behaviors.[453]

The feeling of inclusion for students of minority groups can impact the academic trajectory and wellbeing of students. In a study that lasted two years amongst junior high youth, adolescents who perceived more discrimination from teachers, staff, and peers had a decrease in reported grades and increase in psychological distress.[368]

Highlights

1. Safety and security encompass the environmental and spatial visual cues from departure from the home, on the way to school and on school grounds and the physical building.
2. Students who feel a sense of ownership and belonging to the school and community have social and academic success as well as long term trajectories of individual well-being and contributions to society.
3. Familiarity with the physical layout and uses of school buildings encourages activity that contribute to the feeling of community and pride in the school, also yielding a sense of security during emergencies.

Health

People and Community

The impact of the school has immediate and long-term health impacts on students, teachers, and the community at large. The vibrancy and availability of opportunities and resources in the community surrounding the school can impact on the support the school community receives. Use of space that helps to provide monitored activities for students beyond school hours while parents are still working and away. Policies that help to protect youth from starting risky habits of the use of drugs and alcohol while encouraging healthy activities help to encourage students to achieve more academically.

Extracurricular activities, physical activity and health

Physical Activity is important to cognitive function which includes memory and attention in youth by improving brain function through physiological mechanisms[454] and higher-level executive functions such as decision making and creativity.[455] Studies that look at programs in schools that integrate physical activity and social emotional engagement engage additional skills of self-regulation.[379–381] Sports have also been shown to be protective of adolescent risk behaviors and a study of 1,816 adolescent youth showed positive association between intense participation and externalizing behaviors moderated by prosocial and risk-taking peers.[382]

The way that neighborhoods and schools are designed and built can allow for healthier lifestyles and contribute to the reduction of chronic disease.[383, 384] Open safe spaces for play can encourage physical activity levels.[371] The whole child model of the integration of school and wrap around services that address the physical and emotional needs of youth create an easy to access and unified approach to have students healthy and ready to learn.[372] This includes family and school interventions that support social emotional development outside of school. A meta-analysis found that there were significant effects of family-school interventions on children's mental health and socioemotional development.[456] Research on the built environment on child physical activity,[457] obesity,[458] and physical activity on psychosocial and cognitive development[459, 460] shows benefits to the health of the child. Children able to move safely through the neighborhoods in walkable communities with safe crossing, paths to walk and local places to play and interact are likely to be more physically active than those in communities that are not as walkable.[305, 373]

The intensity of involvement which includes range of participation as well as time devoted to activities may contribute to the ability for students to balance academic and nonacademic pursuits and be conscientious in their behaviors.[385, 386] In a longitudinal study about participation in extracurricular activity of 11,720 students beginning in 10th grade that if the breadth and intensity of involvement increased in 12th grade then eight years later there

was a link with educational attainment.[386] The neighborhood and the school are interconnected and a study in Iceland that looks at the value of school-community interactions has created opportunities for youth to have activities at the school and in the community. Activities for students were developed with the belief that learning expands beyond the school[374] and included physical activity, cultural learning,[375] and developing an experienced workforce creating an economic and educational benefit for school and community.[376] A three-year ethnographic study followed a cyclical model of collaboration, feedback, and implementation found that when working across school boundaries expanded school learning, shared the responsibility of education for students of all needs, created global networks through technology, and the school is a place that contributes and matters to the community. The community extended beyond the school grounds while responsibility and support for youth were not only the responsibility of teachers, staff, and families but also the people living in the greater community.[376]

Overall well-being and longitudinal impacts on health

Some of the costliest problems to society are youth problem behaviors which include antisocial behavior, risky sexual behavior, drug and alcohol use or misuse, or incompletion of school[461, 462] which can lead to healthcare costs, destruction of property, and impact on the workforce. One problem behavior can lead to another[388] and the more serious the problem compounded with multiple problems makes improvements in behavior more difficult.[461] Many problems stem from coercive relationships which is the act of using forceful or threating behaviors to influence others. Often this behavior is cyclical between parent and child.[389] Children with reported exposure to this type of interaction can express themselves in aggressive ways which means they can have trouble learning self-regulation skills and have difficulty with impulse control[463] which can lead to behavior problems and have difficulty in school with teachers and peers. When youth don't feel like they belong they can feel rejection and connect with others who feel the same way and become deviant peer groups.[390]

Living in high poverty areas can have lifelong health impacts such as lower birth weights, higher infant mortality, more child abuse, more pregnant teens, higher dropout rates for high school, more injuries, and increased criminal activity. Even if the separate families are not poor themselves, living in the areas increases the risks.[404, 464] The risk of poverty into adulthood increases when students attend schools with a higher percentage of youth in poverty regardless of the socioeconomic status of their own family.[405, 406] There is an association between adult health and a child's socioeconomic advantage or disadvantage. A life-course study in New Zealand followed the physical health of 1000 individuals from the age of three to twenty-six. It found that in comparison of those growing up in families in low socioeconomic status had lower cardiovascular health and increased substance misuse compared to families in high socioeconomic status. These authors believe that protecting children against the effects of disease that stems from the stress of growing up in low socioeconomic families could reduce disease as adults.[391] There are predictors of positive development in adults. Family interventions can give parents the skills and prevent the development of physical and mental health problems. A study found that children raised in poverty who reported having nurturing mothers did not have a similar cardiovascular risk as many other life course studies focused on youth raised in poverty.[465] Additional positive developments that can help to change the trajectory of the health impacts of growing up in low socioeconomic neighborhoods and families[392] include the ability to have successful relationships,[393] have a sense of life satisfaction,[394] trust and tolerance of others,[395] and take up the role of being a citizen.[466]

Though there are greater environmental and societal impacts of the stressors families face but having the school become a more integrated with the

community and focused on services and education of youth, there is the opportunity for the role of the physical space to become an important space for the community. Predictors of wellbeing can include a sense of community at school and is associated with many positive student outcomes.[377, 378] Belonging can be created through school values which help to promote a sense of community and promote academic motivation and mental health promotion.[467] Families and schools can learn to be more nurturing and help with the health and academic trajectories of youth and their socioemotional development.[298, 468] and help to create prosocial relationships and spaces.[469] Healthy development integrates physical development, social development, cognitive, and active development. Monitoring and limit setting in positive ways can help prevent diverse problems.[387] When children feel a sense of belonging[470] and are exposed to stimulating and positive environments then fundamental skills can be developed and can lead to healthy and productive adults.[396, 471, 472]

Highlights

1. Buildings and grounds used within and outside of school hours contribute to student well-being, increased physical and mental health, positive relationships, and increased access to student services.
2. The number of students participating in high risk and unhealthy behaviors can be decreased by having monitored activities in and out of school hours.
3. The long-term health and educational trajectories of youth can be influenced by the school community and resources it provides.

Gaps and Future Research

Next Steps

The limitations of this white paper are described as "gaps" in the literature review yet are offered as ideas for future research opportunities.

Holistic research

Most of the studies in the literature only examined one or two issues yet impacts on learning does not necessarily occur because of one or two variables. Future research could look at the school environment holistically, studying multiple elements or parameters simultaneously. Very few studies addressed more than one or two items of the Indoor Environmental and Spatial Quality categories of the school and classroom, or how the community and people affect learning. Even recent reviews, like Manca and colleagues (2020), which explores the influences of building/ architectural features, furniture, outdoor spaces, and indoor environmental features on student experience of the school, mostly include studies that investigate one matter at a time.[473] Previous reviews have commented on this issue,[474–477] arguing that most of the current research fails to understand the total environment of the school. To overcome this, Higgins and colleagues (2007) created a framework where learning is in the center, and is surrounded by four elements (environment, communication, products, and services), where the school as a larger system where different actors and settings interplay.[474] A different theoretical framework comes from the literature review developed by Blackmore et. al (2011), where they pair up building life cycle phases, such as design, transition and implementation, consolidation, and sustainability, with how practitioners, learners and spaces interact, moving their attention from the design of the building to the needs of the learner.[477]

Barrett and colleagues (2015) also studied the influence of multiple parameters on student performance. They developed the Stimulation, Naturalness, and Individualization (SIN) conceptual model and used it in the Holistic Evidence and Design (HEAD) project in schools in the United Kingdom.[352, 475] Their study found that the physical characteristics of the classrooms explained 16% in the variation of learning progress in writing, reading, and mathematics over a year. They used the SIN model and found that some subcategories were accounting for most part of the learning performance difference. For Naturalness, the study showed that light, temperature, and air quality accounted for almost 50% of the learning performance difference seen in students. For Individualization, the subcategories of ownership and flexibility accounted for 25% of the performance increase. Finally, for stimulation, accounted for the remaining 25% difference, measured through color and complexity Barrett's studies also found that classroom design mattered more than whole school factors, in terms of student performance.[352, 475]

These are some of the few studies that include multiple parameters on the environmental and spatial characteristics of schools, and their impact on student learning. The relationships between these factors, and how they interplay with the community of the school is complex and difficult to study, which explains the scarcity of holistic research. Nonetheless, further studies could address these issues using mixed methods and previous methodologies, such as the one developed by Barrett and colleagues,[352, 475] to expand our understanding of the multiple impacts that school facilities have on learning and engagement.

Consistency in measurements and metrics

Studies also lacked consistency in metrics and measurements, so comparisons were challenging, particularly when student achievement or performance metrics changed between studies. Literature review collected as many types of studies as possible, yet specific metrics on achievement, health, environmental parameters are often treated separately. Few studies looked at impacts on learning over time. Longitudinal studies are needed to examine "lasting" impacts on learning and engagement on cohorts of students versus point in time only short-term impacts.

Interdisciplinary research

Many architectural firms involve clients through participatory design, yet the literature does not document the long-term value of such research. Future research might examine district resources and quality of facilities change and enhance the community economy.

- Involvement of key stakeholders in the design: architects, engineers, contractors, educators, students, facility managers, and community partners in a participatory approach
- School district resources/quality facilities and how the economy has been enhanced (old vs. new) attractiveness, curb appeal, glue of the school and beyond.
- Technical, Supply chain, facilities/maintenance

Pairing of pedagogy and the physical environment

Another limitation is that we found no studies that looked at how the curriculum and program might guide design of facilities, with research needed on flexible spaces for different teaching styles and learning modes. Flexible spaces for different teaching styles and learning modes.

Given the expansive scope of this search and the short time frame of this project, the review is a start to the needs and potential for interdisciplinary and collaborative research and development of schools. The focus of this review was primarily targeting documents focused on schools serving students below the university level and if no studies can be found workplace and higher education settings may be considered for inclusion. This paper is about seeking current research and potential future projects in support of physical space, environment, and learning.

Methodology

Criteria for including and excluding studies

Criteria for including and excluding studies

Types of study design

This review was an expansive search of the current research. This search included book chapters, dissertations, reports, opinion pieces, systematic reviews, and meta-analyses. Studies that included case studies and studies with experimental or controlled quasi-experimental designs were also included.

Types of participants

Students at school age will vary from country to country but primarily cover students in preschool, primary/elementary school, and secondary/middle/high schools. Studies with sample populations of higher education will be used to provide samples of innovation for the target population if no additional research can be found.

Types of outcomes

The primary outcomes of interest are the relationship of learning engagement and performance to:

- Indoor Environmental Quality (IEQ) refers to all the factors that influence the occupants' sensory experience of a place and includes thermal comfort, indoor air quality (IAQ), lighting (daylighting and electric lighting), views, and acoustics.
- Spatial Environment includes school design characteristics of the buildings and grounds, school operations and maintenance that influence the functioning and operations of building systems and surroundings, as well as the spatial design of classrooms and within classrooms such as furnishings and arrangements.
- People and Community includes social interactions, relationships, teaching/learning, belonging, safety and security, health and recent innovations and impacts of the design planning around the pandemic.

Types of settings

The review will include studies conducted focused on schools, neighborhoods, and communities. Programs in and out of school will be included.

Methodology

Search strategy

Search strategy

Search limits

Studies and papers will be identified through searches of electronic databases, relevant academic journals, reports, expert consultation, and gray literature sources. In addition, bibliographies of eligible studies and relevant reviews will help to identify additional articles. Citation searches will include websites as well as research specific search engines. Once studies have been identified, they will be entered into a document that will be maintained in a file that includes information about the documents identified through various sources. Reviewers will screen each study and record eligibility on a database. Relevant and selected studies will convert into an annotated bibliography.

Sources

Electronic databases

The following are the electronic databases used to search:

- Sciencedirect
- Google Scholar
- Web of Science
- JSTOR
- Cochrane Central Register of Controlled Trials (CENTRAL)
- Cochrane Database of Abstracts of Reviews of Effects (DARE)
- Education Resources Information Center (ERIC, via ProQuest)
- Education Database (via ProQuest)
- International Bibliography of the Social Sciences (IBSS, via ProQuest)
- PsycINFO (via ProQuest)
- PsychARTICLES (via Proquest)
- PubMed
- Social Services Abstracts (via Proquest)

The strategy for searching electronic databases used search terms specific to the key ideas presented in this white paper. Due to the overwhelming scope of this search, terms will focus on the relationship of learning and engagement with indoor environmental quality, spatial environment, and people with community.

Methodology

Sources

Research Registers and Websites
Research registrars and websites specific to architecture and education will be used.

Grey literature
Grey literature searches will be conducted to find unpublished studies that meet the inclusion criteria which include dissertation and these, conference proceedings, reports, and relevant websites.

Google & Google Scholar
Search using key words and to screen relevant articles on the first three pages of the search results.

Conference abstracts & Reports
Conference abstracts, proceedings, and presentations will be reviewed to identify potentially relevant studies.

Manual searches
The latest books and articles from top journals will be manually checked towards the end of the retrieval process.

Expert consultation
Consultants and authors of prior documents will be contacted to obtain relevant studies and all recommended documents will be considered.

Reference lists
The reference lists from prior books and documents will be reviewed for potential qualification in the review.

Search terms
When approaching this review, it was important to identify potentially current studies and research. The approach included guidance from the consultants and by using a modified version of the Pearl Harvesting method 478 to help generate and refine search terms. A review of the compiled terms will be assessed by the authors and missing terms were added.

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