



Original research

Flexible learning spaces reduce sedentary time in adolescents

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ABSTRACT

Objectives: Many schools internationally are replacing traditional classrooms (TC) with innovative flexible learning spaces (FLS) to improve academic outcomes. Via a stealth approach, there may be additional unintended health benefits if students reduce their total and prolonged sitting. The aim of this study was to compare student sitting patterns between TC and FLS.

Design: School-based cross-over trial.

Methods: Students at nine secondary schools ($n = 191$, M age = 13.2 ± 1.0 years) wore activPAL accelerometers in both a traditionally furnished and arranged classroom (TC), and a FLS containing a variety of furniture and layout options, utilizing student-centered pedagogies, for the duration of one double classroom lesson ($M = 76$ min). The lesson content and teacher were consistent across both conditions. Data were analyzed using multilevel mixed-effects linear regression.

Results: In FLS, students spent less class time sitting (mean = 18%; 95% CI: $-20.8, -15.0$), and accumulated more breaks in sitting (2.1; 95% CI: 0.8, 3.5 per 60 min), more bouts of intermittent (≤ 9 min) sitting (2.2; 95% CI: 0.8, 3.6 per 60 min), and fewer bouts of prolonged (≤ 30 min) sitting (-0.2 ; 95% CI: $-0.3, -0.1$ per 60 min), than in TC. Students also spent more class time standing (15%; 95% CI: 12.7, 18.0) and stepping (3%; 95% CI: 2.0, 3.1) in FLS than TC.

Conclusion: The results suggest that, by stealth, elements of FLS including a variety of furniture and resources, and greater use of student-centered pedagogies, facilitate improvements in adolescents' sedentary profiles during class time. This may translate into beneficial health impacts over a longer period given the health benefits of reducing total and breaking up prolonged sitting.

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Practical implications

- Total and prolonged sitting was significantly reduced in flexible learning spaces.
- Students accumulated more bouts of intermittent sitting and more breaks in sitting.
- The effect of flexible learning spaces on sitting was larger for females.
- The affordances of flexible learning spaces can enhance student sedentary profiles.

1. Introduction

International Guidelines^{1–3} for young people recommend limiting sedentary time and breaking up prolonged sitting frequently,

yet prevalence data stands in contrast to these recommendations. By mid-adolescence, students sit for up to 70% of the school day,⁴ and spend significantly more time sitting for bouts longer than 30 min. during school hours, compared with non-school hours.⁵ Young people who are sedentary for prolonged periods may have poorer physical, mental, social and academic profiles.^{6,7} Reduced school-day sitting enhances cognitive function,⁸ and breaking-up sitting improves cardio-metabolic health, reducing the risk of metabolic syndrome and type 2 diabetes.⁹

The layout and furniture typically available in Traditional Classrooms (TC), coupled with pedagogical approaches that have historically been teacher-led and didactic in nature, leave students with limited options other than to sit for the majority of class time across the school day.¹⁰ However, due to the modifiable nature of the learning environment, schools are increasingly being recognized as a setting in which this trend in sedentary behavior can be disrupted.¹¹ *Physical Activity Design Guidelines for School Architecture*¹² now recommend learning spaces that provide room

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Fig. 1a. A traditional classroom.

for movement, a flexible layout, adjustable furniture and that promote student choice.

Two approaches to reducing in-class sedentary behavior are currently in vogue. One is trialing the use of standing desks, with studies reporting mixed results and limited evidence available in the secondary school setting.^{4,13} Another is the integration of activity breaks into lessons; however, such interventions have shown little success among the adolescent population.¹⁴ This may be attributed to the absence of an ecological approach, with interventions failing to address the broader school environment at a physical, social and institutional level.¹⁴ Investigating the nexus between the built learning environment, pedagogy, and sedentary behavior, particularly in secondary schools is in its infancy,¹⁵ although recognition of the role of pedagogical approaches used in classrooms and the influence they exert on students' use of furniture and movement during class time, is increasing.¹⁶

To better meet the needs of 21st-century learners, schools internationally, and many in Australia are adapting their teaching practices and modifying the built classroom environment, into 'flexible learning spaces' (FLS).¹⁷ These spaces contain a variety of furniture options in a relatively open space, which can be configured in different ways. The teaching approaches in this setting are increasingly student-centered, prioritizing collaboration, and engaging students as co-creators of the learning experience.¹⁸ Flexible learning spaces are environments characterized by flexibility in both form and function, from a physical and pedagogical perspective.¹⁹ This shift in how learning environments are designed and the teaching and learning that occurs within them, raises questions around the flow-on effect these spaces may have on in-class sedentary behaviour and movement. Adolescents taught in FLS have reported opportunities for increased autonomy to change posture frequently and move around the space.¹⁶ How-

ever, it is not known if this results in less total and prolonged sitting. The aim of this study was to objectively measure and compare adolescent sitting patterns between TC and FLS. It was hypothesised that adolescent students in flexible learning spaces would demonstrate, (i) reduced overall sitting time, (ii) a decrease in longer bouts of sitting, (iii) more overall breaks in sitting, and (iv) an overall increase in standing and stepping throughout the lesson.

2. Methods

The protocol was approved by the University of Wollongong's Human Ethics Research Committee (HE16/021) and the New South Wales (NSW) State Education Research Applications Process. The reporting of this paper followed the STROBE statement.²⁰

This was a school-based cross-over trial. Grade 7–9 classes from 12 public schools in NSW, Australia were invited to participate. Informed parental consent was obtained and information collected on the students' age, sex, cultural background and postcode of residence, to determine socioeconomic status.

2.1. Traditional classrooms – built environment

Traditional classrooms were a standard single classroom ($M = 50 \text{ m}^2$), typically contained a desk and chair for each student, arranged in rows or a u-shape facing the front. Students chose their seat upon entering the room and generally remained there during the lesson (Fig. 1a).

2.2. Traditional classrooms – pedagogical approach

The teaching style was primarily teacher-led. Students generally worked individually on set tasks and received frequent input



Fig. 1b. A flexible learning space.

and additional instruction from the teacher. Students had limited reasons or options to stand or move around throughout the lesson.

2.3. Flexible learning spaces – built environment

Flexible learning spaces were a combination of standard- and double-sized classrooms ($M=83\text{ m}^2$) and incorporated a range of furniture such as grouped tables, standing workstations, ottomans, couches, and write-able tables and walls. The majority of FLS lacked a distinct front of the classroom, with resources including smartboards and whiteboard walls available around the room (Fig. 1b).

2.4. Flexible learning space – pedagogical approach

The teaching approach in the flexible learning spaces was student-centered and group-work focused. Students were given instructions from the teacher regarding the lesson plan and objectives at the commencement of the class, and further guidance throughout the lesson. In addition students were also afforded considerable freedom to choose how to go about their learning. Together with the furniture available, this teaching approach created opportunities and incentives for students to move throughout the lesson.

ActivPAL™ (PAL Technologies Limited, Glasgow, UK) accelerometers were used to assess time spent in different postures (sitting, standing and stepping), the length of sitting bouts, and number of breaks in sitting. The activPAL is a reliable and valid instrument that objectively captures adolescent's sitting, standing and stepping activities, as total time for each posture, and can assess bouts of sitting.²¹

Students were observed in both a TC and on another day a FLS, for the duration of two consecutive lessons on each occasion ($M=76\text{ min}$). Participating teachers were aware that the ActivPAL accelerometer measured sitting, standing and stepping however the hypothesis of the study was not discussed with them. ActivPALs were secured to the upper thigh using medical adhesive tape and worn for the entire lesson in both conditions. Students undertook their lesson as usual. Teachers taught in a manner typical of how they would normally conduct their lessons in the respective learning spaces. Subject included English, mathematics, geography, and history. Data collection in each school took place within 1–2 weeks, between 2016 and 2017, and the lesson content and teacher were

consistent across both conditions. Schools determined which condition was assessed first. Participating students and teachers had all spent significant time teaching and learning in both traditional classrooms and their school's flexible learning space and quickly adjusted to the distinct ways of working in the two different environments.

ActivPAL data were downloaded using associated software (Version 7.2.32). Event files were reduced using a customized Excel macro to calculate each participant's time spent sitting, standing, and stepping, the number of breaks in sitting (i.e. postural transitions from sitting to another posture), and the number of bouts of sitting for the following categories: $\leq 9\text{ min}$, 10–19 min, 20–29 min, and $\geq 30\text{ min}$.

Analyses were conducted in STATA (Version 13). To account for any differences in activPAL wear-time, outcome variables were calculated as a percentage of class time or min/hr. Multilevel mixed-effects linear regression was used to determine differences in sitting, standing and stepping, bouts and breaks in sitting between TC and FLS. Models tested within-child differences and adjusted for classroom size. To account for clustering schools were included as a random effect in the model. Sex interactions were used to test effect differences between conditions. To demonstrate the magnitude of the difference between conditions, standardized effect sizes (Cohen's d) were calculated, based on adjusted means and standard deviations using traditional classroom values as the denominator.²² Effect sizes of approximately 0.2, 0.5 and 0.8 were considered small, medium and large respectively.²²

3. Results

Nine schools participated in the study and of 243 students invited, 203 consented (83%). Twelve participants were absent for both conditions, therefore valid data were obtained for 191 students (94%) in at least one condition. Complete cases were available for 171 students. In the TC condition, after accounting for absenteeism ($n=10$), activPAL malfunction ($n=6$), and download error ($n=4$); data were obtained from 171 students. In the FLS condition after accounting for absenteeism ($n=13$) and activPAL malfunction ($n=1$); data were obtained from 177 students. The analytical sample included 191 students, and contained a relatively even spread of female and male participants from a range of socio-economic, cultural and ethnic backgrounds.

Table 1
Changes in posture and sitting bouts and breaks, between traditional classrooms and flexible learning spaces.

Outcome variable	Traditional classroom (M, 95% CI) (n = 171)	Flexible learning space (M, 95% CI) (n = 177)	Mean difference in change between spaces (M, 95% CI)	Effect size (Cohen's D)	p-Value
Posture					
Sitting (%)	93.42 (89.95, 96.89)	75.51 (72.07, 78.96)	-17.90 (-20.79, -15.02)	-1.47	0.001
Standing (%)	5.00 (2.03, 7.98)	20.36 (17.40, 23.32)	15.36 (12.68, 18.03)	1.37	0.001
Stepping (%)	1.58 (0.78, 2.37)	4.13 (3.33, 4.92)	2.55 (2.02, 3.07)	0.99	0.001
Number of bouts/breaks in sitting					
≤9 min bouts (perhour)	6.86 (5.21, 8.51)	9.05 (7.42, 10.69)	2.20 (0.78, 3.60)	0.32	0.002
10–19 min bouts (perhour)	0.66 (0.46, 0.85)	0.81 (0.62, 0.99)	0.15 (-0.04, 0.34)	0.23	0.118
20–29 min bouts (perhour)	0.24 (0.14, 0.34)	0.23 (0.13, 0.33)	0.01 (-0.11, 0.09)	-0.04	0.860
≥30 min (perhour)	0.31 (0.23, 0.40)	0.11 (0.03, 0.19)	-0.20 (-0.29, -0.12)	-0.65	0.001
Breaks in sitting (perhour)	8.07 (6.45, 9.68)	10.20 (8.59, 11.80)	2.13 (0.75, 3.51)	0.26	0.003

Note: M = mean; CI = confidence interval. Models were adjusted for clustering and space size. Boldface indicates statistical significance ($p < 0.05$).

Table 2
Changes in sitting and standing by sex between traditional classrooms and flexible learning spaces.

Outcome variable	Sex	Traditional classroom (M, 95% CI)	Flexible learning space (M, 95% CI)	Difference in change between spaces (M, 95% CI)	Mean difference in change between sexes (95% CI) female vs male	Effect size (Cohen's D)	p-Value
Sitting %	Female	94.66 (90.81, 98.51)	74.57 (70.74, 78.40)	-20.09 (-23.46, -16.72)	-5.96 (-10.56, -1.36)	-1.74	0.011
Sitting %	Male	91.35 (87.59, 95.11)	77.22 (73.51, 80.94)	-14.13 (17.26, -10.99)		-1.13	
Standing %	Female	4.15 (0.73, 7.58)	21.16 (17.76, 24.57)	17.01 (13.86, 20.17)	6.76 (2.46, 11.07)	1.61	0.002
Standing %	Male	7.63 (4.29, 10.97)	17.88 (14.59, 21.17)	10.25 (7.31, 13.19)		0.89	

Note: M = mean; CI = confidence interval. Models were adjusted for clustering and space size. Boldface indicates statistical significance ($p < 0.05$).

Table 1 shows mean total sitting, standing and stepping as a proportion of lesson time. A significant difference was found in the overall proportion of class time students spent sitting, standing and stepping between the two conditions (all $p < 0.001$). Compared to TC, students spent 18% (95% CI: -20.8, -15.0) less class time sitting in FLS, which was a large effect and equivalent to 11 min per 60 min of class time. Students also spent 15% (95% CI: 12.7, 18.0) more class time standing in FLS compared to TC, which was a large effect and equivalent to 9 min per 60 min of class time. Compared to TC, students spent 3% (95% CI: 2.0, 3.1) more class time stepping in FLS, which was also a large effect and equivalent to 2 min per 60 min of class time.

Students accumulated more ≤9 min bouts (2.2; 95% CI: 0.8, 3.6 per 60 min) and fewer ≥30 min (-0.2; 95% CI: -0.3, -0.1 per 60 min) bouts of sitting in FLS than in TC. These differences reflected statistically significant, small and moderate effects, respectively. Differences in bouts of sitting for 10–19 min and 20–29 min between conditions were not significant. Students accumulated more breaks in sitting in FLS compared to TC (2.1; 95% CI: 0.8, 3.5 per 60 min), which was a statistically significant, small effect (Table 1).

There were significant sex interactions for sitting ($p = 0.011$) and standing ($p = 0.002$) time. Differences between conditions were larger among females than among males (Table 2). Compared to TC, males in the FLS spent less class time sitting (-14.1%; 95% CI: -17.3, -11.0) and more class time standing (10.3%; 95% CI: 7.3, 13.2), equating to 8 min and 6 min per 60 min of class time, respectively. These differences resulted in small effects. However, in the FLS, females spent even less class time sitting (-20.1%; 95% CI: -23.5, -16.7) and even more class time standing (17.01%, 95% CI: 13.9, 20.2) compared to TC, equating to 12 min and 10 min per 60 min of class time, respectively. These differences resulted in large effects.

4. Discussion

Large effects were found between flexible learning spaces and traditional classrooms in the proportion of class time spent in each posture. Students sat significantly less in FLS, interrupted their sit-

ting more frequently, had fewer bouts of prolonged sitting and stood and moved significantly more, relative to TC. These outcomes show that modifications to the built learning environment of secondary school classrooms, coupled with student-centered pedagogy, positively effects the time adolescents spend sitting during class time and change how sedentary behavior is accrued. The greater frequency of short ≤9 min bouts of sitting, and breaks in sitting, and the smaller frequency of long bouts of sitting for ≥30 min show that FLS can assist adolescents to meet sedentary guidelines that advocate for a reduction in prolonged sitting.

To our knowledge, this is the first study investigating the effect of secondary school FLS on total and prolonged sitting. Although classroom standing desks have shown some promising results in the primary school setting, research examining the impact of standing desks on sitting time in secondary schools is lacking.¹³ Previous research among young adolescents reported that this furniture modification can reduce sitting by ~36 min across a 6-h school day.²³ The 11 min/h lower level of sitting in FLS compared to TC observed in this study suggests that if students spend 4–5 h per school day in FLS, this would equate to a ~45–55 min reduction in sitting during school hours. Other approaches to reducing adolescent classroom sitting such as activity breaks, show small or no effects.²⁴ Further, they rely on the motivation of individual teachers to incorporate additional activities into their lessons which raises questions about long-term sustainability.

Both females and males sat significantly less in FLS, however, the effects were larger for females. Longitudinal studies have found that sedentary behavior begins to increase from the age of school entry²⁵ and that this trend continues with age,²⁶ with a ~10–20 min per day per year increase in sitting reported, as students transition to secondary school.²⁷ In addition, females become increasingly more sedentary than males during early adolescence.²⁸ It is therefore particularly noteworthy that the beneficial effects on sitting and standing between spaces were larger in females than males. Further, sedentary behavior during adolescence predominantly replaces light-intensity physical activity.²⁵ As such, some of the light-intensity physical activity being lost throughout the day

during adolescence could potentially be maintained through the implementation of FLS, particularly for females.

In adults prolonged sitting time has been associated with premature cardiovascular and all-cause mortality, independent of physical activity.²⁹ Frequent interruptions in sedentary time, independent of the mean intensity of such breaks in sitting, are beneficially associated with metabolic risk factors particularly adiposity measures, triglycerides, and 2-h plasma glucose.³⁰ Further, regularly breaking up prolonged sitting with short bouts of activity (<2 min) was found to be more effective in lowering postprandial glucose and insulin concentrations than single continuous bouts (30 min) of physical activity.³¹ In adolescent populations, acute experimental research has also shown cardio-metabolic benefits of frequent interruptions to sitting.^{9,32} With the greater frequency of breaks in sitting found in FLS compared to TC, this study shows that the affordances of secondary school FLS can facilitate frequent interruptions in sedentary time, and accommodate short bouts of low-intensity physical activity (e.g. walking around the space or standing at a white board wall), thus maximizing potential health gains, through the effect on cardio-metabolic biomarkers.^{33,34}

Environmental psychology underpins the notion that human behavior and the built environment are closely interrelated and that physical and social environments are intrinsically interlinked.³⁵ FLS allow students to capitalize on opportunities to break up sitting by increasing the variety of furniture and resources to include standing workstations, group tables, writeable walls, and structuring lessons that facilitate student autonomy and engagement with the space and its users. A key element that differentiates FLS from TC is that teachers actively relinquish their control over where and how students work.¹⁶ This democratization of space achieved by de-emphasizing hierarchy³⁶ enables students to capitalize on the affordances of the physical environment to break up prolonged sitting and move more throughout the classroom.

A strength that differentiates this novel approach is that the findings were not the result of an intervention introduced to schools for a limited duration, that relied on the motivation of individual teachers to incorporate standing desks or physical activity breaks for a health gain. Instead this was an investigation of school-led changes to both the physical and pedagogical learning environment. FLS are thus scalable and sustainable because in contrast to a typical health research intervention where long-term 'buy-in' is required from participants, schools and teachers are already making these changes to their learning environments because of anticipated educational benefits. With the significant funding available for refurbishments and the professional development opportunities being offered, flexible learning environments are likely to become the standard approach.

The comprehensive nature of this approach, which addresses multiple levels of the school ecology, beyond replacing traditional desks with stand-biased furniture, is a further strength. As more schools receive the financial and professional development support offered by Departments of Education for the implementation of FLS, the findings are likely to be replicated in increasing numbers of schools. In addition, the effects may be even greater since participating schools had made changes without significant support and consequently, the benefits may not have been maximized. Further, the potential advantages of FLS extend beyond reducing sitting, to include learning benefits, as they facilitate increased engagement, collaboration, and interaction.¹⁶ As such the benefits of reduced sitting in FLS are obtained by stealth, as a side benefit to quality learning environments;³⁷ the primary reasons schools are implementing them. This effectively results in a "win-win" situation where schools obtain the outcomes they are pursuing and as an unintended consequence, there are cardio-metabolic health benefits to be gained from interrupting prolonged sitting.⁹

A limitation of this study is that the activPAL wear time was restricted to the duration of a double lesson in both conditions, because secondary school students in Australia move between several different faculty specific classrooms throughout the day. Since the objective was to measure in-class sedentary behavior and movement within particular learning environments, this study design was considered most practical. However, because this study design was not the gold standard for establishing cause and effect, further experimental research such as randomized trials are needed, to examine the effects of habitual sitting over longer time frames in FLS.

5. Conclusion

The results show that by stealth, elements of FLS including the incorporation of a variety of furniture and resources, accompanied by greater use of student-centered pedagogies, can facilitate significant improvement in adolescents' sedentary behaviour profiles during class time. This may translate into beneficial health impacts over a longer period given the health benefits of breaking up prolonged sitting. Further research is required to unpack how to leverage the opportunities created by FLS to ensure that decision making around the design and fit-out of school refurbishments and new builds, and pedagogical approaches used; maximize the potential health gains that can be obtained from these innovative learning environments.

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References

1. Australian Government, Department of Health. Make Your Move – Sit Less Be Active for Life! Australia's Physical Activity and Sedentary Behaviour Guidelines.
2. ParticipACTION. *Canadian 24-Hour Movement Guidelines for Children and Youth*, 2016. p. 1–2 (January 2015).
3. Department of Health. Physical activity guidelines for children and young people. *Obes Health Living* 2011; 11. Fact sheet 3. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/213739/dh_128144.pdf.
4. Hinckson E, Salmon J, Benden M et al. Standing classrooms: research and lessons learned from around the world. *Sport Med* 2016; 46(7):977–987. <http://dx.doi.org/10.1007/s40279-015-0436-2>.
5. Straker L, Abbott R, Mathiassen S. Teaching our children to sit or be active? Sedentary behavior, light activity and moderate/vigorous activity at and away from school. *J Sci Med Sport* 2012; 15:312. <http://dx.doi.org/10.1016/j.jsams.2012.11.680>.
6. Tremblay MS, LeBlanc AG, Kho ME et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *Int J Behav Nutr Phys Act* 2011; 8(1):98. <http://dx.doi.org/10.1186/1479-5868-8-98>.
7. Carson V, Hunter S, Kuzik N et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update 1. *Appl Physiol Nutr Metab Appl Physiol Nutr Metab* 2016; 41(June):240–265. <http://dx.doi.org/10.1139/apnm-2015-0630>.
8. Penning A, Okely AD, Trost SG et al. Acute effects of reducing sitting time in adolescents: a randomized cross-over study. *BMC Public Health* 2017; 17(1):1–12. <http://dx.doi.org/10.1186/s12889-017-4660-6>.
9. Fletcher EA, Salmon J, McNaughton SA et al. Effects of breaking up sitting on adolescents' postprandial glucose after consuming meals varying in energy: a cross-over randomised trial. *J Sci Med Sport* 2018; 21(3):280–285. <http://dx.doi.org/10.1016/j.jsams.2017.06.002>.
10. Hadgraft N, Owen N. Sedentary behavior and health broadening the knowledge base and strengthening the science. *Res Q Exerc Sport* 2017; 88(2):123–129. <http://dx.doi.org/10.1080/02701367.2017.1305257>.
11. Naylor PJ, McKay HA. Prevention in the first place: schools a setting for action on physical inactivity. *Br J Sports Med* 2009; 43(1):10–13. <http://dx.doi.org/10.1136/bjsm.2008.053447>.

12. Brittin J, Sorensen D, Trowbridge M et al. Physical activity design guidelines for school architecture. *PLoS One* 2015; 10(7):1–31. <http://dx.doi.org/10.1371/journal.pone.0132597>.
13. Minges KE, Chao AM, Irwin ML et al. Classroom standing desks and sedentary behavior: a systematic review. *Pediatrics* 2016; 137(2):e20153087. <http://dx.doi.org/10.1542/peds.2015-3087>.
14. Morton KL, Atkin AJ, Corder K et al. The school environment and adolescent physical activity and sedentary behaviour: a mixed-studies systematic review. *Obes Rev* 2016; 17(2):142–158. <http://dx.doi.org/10.1111/obr.12352>.
15. Ucci M, Law S, Andrews R et al. Indoor school environments, physical activity, sitting behaviour and pedagogy: a scoping review. *Build Res Inf* 2015; 43(5):566–581. <http://dx.doi.org/10.1080/09613218.2015.1004275>.
16. Kariippanon KE, Cliff DP, Lancaster SL et al. Perceived interplay between flexible learning spaces and teaching, learning and student wellbeing. *Learn Environ Res* 2017; 1–20. <http://dx.doi.org/10.1007/s10984-017-9254-9>.
17. Mulcahy D, Cleveland B, Aberton H. Learning spaces and pedagogic change: envisioned, enacted and experienced. *Pedagog Cult Soc* 2015; 23(4):575–595. <http://dx.doi.org/10.1080/14681366.2015.1055128>.
18. NSW Government, Department of Education. *Future Classrooms Unveiled*, 2015 [https://www.nsw.gov.au/news-and-events/news/future-classrooms-unveiled/](https://www.nsw.gov.au/news-and-events/news/future-classrooms-unveiled).
19. Byers T, Mahat M, Liu K et al. *Systematic Review of the Effects of Learning Environments on Student Learning Outcomes*, 2018 <http://www.ilet.com.au/publications/reports>.
20. von Elm E, Altman DG, Egger M et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *J Clin Epidemiol* 2008; 61(4):344–349. <http://dx.doi.org/10.1016/j.jclinepi.2007.11.008>.
21. Dowd KP, Harrington DM, Donnelly AE. Criterion and concurrent validity of the activPAL™ professional physical activity monitor in adolescent females. *PLoS One* 2012; 7(10). <http://dx.doi.org/10.1371/journal.pone.0047633>.
22. Cohen J. *Statistical Power Analysis of the Behavioural Sciences*, In: Cohen J, editor, New York, Academic Press, 1988.
23. Aminian S, Hinckson EA, Stewart T. Modifying the classroom environment to increase standing and reduce sitting. *Build Res Inf* 2015; 43(5):631–645. <http://dx.doi.org/10.1080/09613218.2015.1058093>.
24. McMichan L, Gibson A-M, Rowe DA. Classroom-based physical activity and sedentary behavior interventions in adolescents: a systematic review and meta-analysis. *J Phys Act Health* 2018; 15(5):383–393. <http://dx.doi.org/10.1123/jpah.2017-0087>.
25. Reilly JJ. When does it all go wrong? Longitudinal studies of changes in moderate-to-vigorous-intensity physical activity across childhood and adolescence. *J Exerc Sci Fit* 2016; 14(1):1–6. <http://dx.doi.org/10.1016/j.jesf.2016.05.002>.
26. Brodersen NH, Steptoe A, Boniface DR. Trends in physical activity and sedentary behaviour in adolescence: ethnic and socioeconomic differences. *Br J Sports Med* 2007; 41(3):140–144. <http://dx.doi.org/10.1136/bjsm.2006.031138>.
27. Pearson N, Haycraft E, Johnston JP et al. Sedentary behaviour across the primary-secondary school transition: a systematic review. *Prev Med (Baltim)* 2017; 94:40–47. <http://dx.doi.org/10.1016/j.ypmed.2016.11.010>.
28. Costigan SA, Barnett L, Plotnikoff RC, Lubans DR. The health indicators associated with screen-based sedentary behavior among adolescent girls: a systematic review. *J Adolesc Health* 2013; 52(4):382–392. <http://dx.doi.org/10.1016/j.jadohealth.2012.07.018>.
29. Dunstan DW, Barr EL, Healy GN et al. Television viewing time and mortality: the Australian diabetes, obesity and lifestyle study (AusDiab). *Circulation* 2010; 121(3):384–391. <http://dx.doi.org/10.1161/CIRCULATIONAHA.109.894824>.
30. Healy GN, Dunstan DW, Salmon J et al. Breaks in sedentary time. *Diabetes Care* 2008; 31(4):661–666. <http://dx.doi.org/10.2337/dc07-2046>.
31. Peddie MC, Bone JL, Rehner NJ et al. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. *Am J Clin Nutr* 2013; 98(2):358. <http://dx.doi.org/10.3945/ajcn.112.051763>.
32. Belcher BR, Berrigan D, Papachristopoulou A et al. Effects of interrupting children's sedentary behaviors with activity on metabolic function: a randomized trial. *J Clin Endocrinol Metab* 2015; 100(10):3735–3743. <http://dx.doi.org/10.1210/jc.2015-2803>.
33. Howard B, Winkler EA, Sethi P et al. Associations of low- and high-intensity light activity with cardiometabolic biomarkers. *Med Sci Sports Exerc* 2015; 47(10):2093–2101. <http://dx.doi.org/10.1249/MSS.0000000000000631>.
34. Carson V, Ridgers ND, Howard BJ et al. Light-intensity physical activity and cardiometabolic biomarkers in US adolescents. *PLoS One* 2013; 8(8). <http://dx.doi.org/10.1371/journal.pone.0071417>.
35. Weinstein CS. The physical environment of the school: a review of the research. *Rev Educ Res* 1979; 49(4):577–610. <http://dx.doi.org/10.3102/00346543049004577>.
36. Waldrup B, Cox P, Deed C et al. Teacher adaptation to open learning spaces. *Learn Environ Res* 2013; 18(3):217–231. <http://dx.doi.org/10.1007/s10984-015-9181-6>.
37. Robinson TN, Sirard JR. Preventing childhood obesity: a solution-oriented research paradigm. *Am J Prev Med* 2005; 28(2 Suppl. 2):194–201. <http://dx.doi.org/10.1016/j.amepre.2004.10.030>.