A framework for exploration of relationship between the psychosocial and physical learning environment

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Abstract

In order to construct a shared body of knowledge, research involving the relationship between the psychosocial learning environment (PSLE) and the physical learning environment (PLE) needs a commonly-accepted conceptual framework. By means of a thematic literature review, we collected the main aspects of the PSLE and PLE, their definitions and their relations as identified by earlier research. These findings led to a conceptual framework that structures the dimension of the PSLE into the sub-dimensions of personal development, relationships, and system maintenance and change, and the dimension of the PLE into the sub-dimensions of naturalness, individualisation, and stimulation. For each of these sub-dimensions, the framework distinguishes an intended, implemented and attained representation. A conceptual PSLE-PLE Relationship (PPR) model enables relations to be visualised. The review confirms that PSLE and PLE are interrelated in interactions between different sub-dimensions and their representations. However, evidence regarding these relationships is still weak because of the limited number of studies and their methodological limitations.

Introduction

Schools are challenged to provide a learning environment for students that prepares them for participation in the knowledge society, including the skills to work collaboratively and be self-directed (Simons et al. 2000). Therefore, schools are changing

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their behaviouristic pedagogical approaches towards more-progressive and-constructivist approaches. Assuming that these contemporary pedagogical approaches put different demands on the physical learning environment (PLE), several countries have introduced investment programs for new school buildings (Cleveland and Fisher 2014). These school building programs are based on concepts for the PLE as suggested in various conceptual publications, including those of Fisher (2005) and Nair et al. (2013). In these concepts, clusters of learning spaces, not classrooms, are the building blocks of school buildings. The argument was that a cluster with interconnected, diverse learning spaces optimally supports the varied learning activities as propagated in the contemporary pedagogies, while segregated classrooms could hinder the implementation of these pedagogies.

At the time of implementation of these school building programs, there was hardly any evidence that underlying spatial concepts indeed support contemporary pedagogies (Cleveland 2016; Woolner et al. 2007). These spatial concepts can hinder or even impede a shift to different pedagogies because of their specific spatial structure (Cleveland and Fisher 2014). In their literature review, Blackmore et al. (2011) established the scarcity of empirical evidence suggesting that these spatial concepts are actually supporting contemporary pedagogies. They determined that little empirical research focuses on how the PLE is perceived and used and to what effect. The research field is in its infancy (Cleveland and Soccio 2015; Zandvliet and Broekhuizen 2017).

In view of uncertainty regarding whether these innovative spatial concepts really support contemporary pedagogical practices, the rigour of the spatial concepts, and the substantial financial investments being made, developing an evidence-based body of knowledge regarding the relationship between contemporary pedagogies and 'innovative' PLEs is of great academic and societal interest.

However, progress in this research field is seriously hampered by the fragmentation of studies across various disciplines (Ellis and Goodyear 2016; Woolner et al. 2007). An overarching conceptual framework is lacking (Brooks 2011; Cleveland and Soccio 2015; Zandvliet 2014). As a result, the literature shows a variety of conceptualisations, with different names for the same concepts. The present study aimed to eliminate this obstacle by constructing an encompassing framework and merging the various conceptualisations. For this purpose, a thematic literature review was conducted.

This article successively describes the theoretical background that has guided the thematic review, the methods followed, and the results processed in an overview of relevant aspects of pedagogical approaches and physical learning environments. It concludes with a determination of relations supported by empirical evidence and of relations that still require further investigation.

Theoretical background

The literature confirms the relationship between the PLE and pedagogical practice. However, there is unanimity about neither the nature of this relationship nor the delineation of these concepts. Therefore, this section describes the definitions and conceptualisations as applied by this review. Subsequently, the conceptual model is described and constructed to identify the relationships explored by the literature studied.

Definition and conceptualisation of PSLE (psychosocial learning environment)

Although emphasis varies, contemporary pedagogies view learning not as an isolated activity by the learner, but as a constructive, social and situated activity (De Kock et al. 2004) occurring in a learning environment (LE), including all aspects that define the context of the learning process. These aspects can be organised into various dimensions of the LE. Initially, research into the LE mainly focused on psychosocial dimensions (PSLE), defined as all psychological and social factors involved in the learning process (Cleveland and Fisher 2014). As Moos (1980) argues, students' and teachers' perceptions are the most reliable data source for determining the PSLE, because they reflect on long-term characteristics, neutralise incidental events, and give direct insight into mutual expectations regarding behaviour and production. For the PSLE, Moos distinguishes three sub-dimensions. *Personal development* refers to the directions of personal growth and self-enhancement, including students' autonomy and affinity with the learning content; *relationships* refers to the nature and intensity of personal relationships within the learning environment, the involvement of people, and feelings of being affiliated, accepted and supported; and *system maintenance and change* refers to order, control, expectations and responsiveness to change, including grouping of students and teachers, scheduling and regulation of the learning process. Much research has adopted Moos' classification (Fraser 1998), confirming the validity and authority of this conceptualisation of the PSLE.

Definition and conceptualisation of the PLE (physical learning environment)

Although LE research originally focused mainly on the PSLE (Cleveland and Fisher 2014), the PLE has always been recognised as another important dimension of the LE (Moos 1980). However, the literature is not unanimous in the delimitation of the PLE. For the purpose of this study, the PLE is defined as a school's built environments that are intended as learning places, including school buildings and learning spaces and their spatial structure, furniture, fittings and equipment. The literature on the PLE shows that, predominantly, the same aspects are identified, but that the wording and selection of aspects vary in different studies. Although similarities can be determined, consensus on the organisation of aspects in sub-dimensions is lacking. The conceptualisation of Barrett et al. (2015) encompasses almost all aspects that are mentioned in other literature and organises those into the sub-dimensions of naturalness, individualisations and stimulation. This classification has been derived from neuroscientific research into the way in which the brain processes the sensorially-perceived physical environment. The sub-dimension of naturalness refers to environmental aspects affecting physical comfort and well-being, including the climate conditions, light and links with nature. The sub-dimension of individualisation refers to the functional aspects supporting the learning and teaching activities of students and teachers, including the flexibility of the PLE, the connection between spaces, and users' control over use and design of the PLE. The sub-dimension of stimulation refers to aesthetic aspects stimulating learning behaviour, including the complexity of the PLE and the use of colours.

Three representations of PSLE and PLE

As described above, new pedagogical approaches have stimulated research into the necessity and effect of changing the PSLE, and the PLE, and into their mutual relationship. However, changing the PSLE and PLE requires a complex and long process comprising

a succession of phases in which policies are established and adaptations are designed, implemented, experienced and evaluated (Byers 2016b; Cleveland and Fisher 2014; van den Akker 2013). This process encompasses various levels, from the (inter) national level to the school level, class level and individual level of the student. Many actors are involved, with their own specific contributions and positions that vary with level and phase. Because of the complexity of the change process, including the different levels, actors and time-lines, aspects of the PSLE and PLE can manifest themselves differently or—because of misalignment—even in contradictory ways (Radcliffe 2008; van den Akker 2013).

The literature frequently addresses the gap between preferred perceptions—school-level, staff-intended PSLE—and the 'theory-in-use' or actual pedagogical practice – class level, teacher-implemented PSLE (Barr and Tagg 1995; Fraser 1998). This can be explained by various confounding factors, including the frequently-determined mismatch between the focus of national mandatory assessments on traditional, cognitive learning outcomes—national-level, intended PSLE—versus schools implementing a broader scope of learning outcomes—school level, intended PSLE (Byers et al. 2018b; Woodman 2016).

This illustrates the importance of distinguishing the different representations of the learning environment, categorised according to characteristics including the phases, levels and actors involved. Analogous to van den Akker's (2013) conceptualisation of the curriculum, our research distinguishes the intended, implemented and attained representations. The intended representation of both PSLE and PLE refers to staff ideals, described in formal policies and also known as preferred or ideal perceptions. The implemented representation refers to the PSLE and PLE as perceived by those bringing policy into observable, operational practice. The attained representation refers to users' experiences and performance assessments.

Nature of relationship between PSLE and PLE

As Lefebvre (1991) argues, the physical environment influences psychosocial experiences and behaviour. Therefore, the PLE influences the PSLE (Lackney 1997; Oblinger 2006; Scott-Webber 2004). However, an innovative PLE does not automatically lead to innovative pedagogical practice. Deterministic causal relations as claimed by popular and policy literature are not substantiated empirically (Blackmore et al. 2011; Mulcahy et al. 2015). As Fraser (1998) argues, behaviour is a function of personal characteristics in interaction with the environment. If teachers are not prepared for the pedagogical and technological use of innovative PLE, they tend to retreat to the safety of their well-known traditional teaching styles (Lackney 2008), adjusting the PLE within their possibilities by, for example, shaping classrooms with moveable interior elements. This illustrates that the pedagogical practice does influence the nature and use of the PLE and, thus, how the PLE is experienced (Blackmore et al. 2011). The relationship between the PSLE and PLE is therefore not causally deterministic, but instead is reciprocal and dynamically responds to changes in either the PSLE or PLE (Mulcahy et al. 2015; Zandvliet 2014).

Using this theoretical background, the following overarching question was formulated for the thematic review

- Which sub-dimensions and aspects of the PSLE and PLE have been identified by literature as being relevant for research into the relationship between the PSLE and PLE for modern learning environments?

Further sub-questions are:

- How can these different sub-dimensions and aspects of the PSLE and PLE be organised into an overarching PSLE–PLE Relationship (PPR) framework?
- According to the literature, which relationships between different sub-dimensions and aspects are supported by empirical evidence?

Methods

A thematic literature review was conducted to synthesise existing knowledge, using the literature review of Blackmore et al. (2011) as the starting point. The present search has been focused on new research literature published since then, with specific attention to the knowledge gap identified by Blackmore et al. and the use of PLE, including explanation of its use and effects.

For the search, keywords were derived from the research questions and classified into themes:

- the intended and implemented PSLE (including the keywords of pedagogy, learning practice, teaching activities, 21th century education);
- the intended and implemented PLE (including the keywords of learning space, school building, physical learning environment);
- the PPR as measured by the outcomes of the attained PLE and PSLE (including the keywords of impact on learning, learning outcomes, students' perception, post-occupancy evaluation).

Several search engines were used, including Science Direct, Web of Science, ERIC, Research Gate, Mendeley and Google Scholar. To optimise the search, Boolean operators were used, combining each keyword of a theme with keywords of one other theme or both other themes. The search frame was set to publications up to 10 years old (not older than 2007).

For the first search, the search engine of Web of Science was used. The combination of the search terms of the PLE and PSLE yielded 109 results, the combination PLE and PPR 33 results, and the combination of search terms of PLE, PSLE and PPR 11 results. Subsequently, the search engine of Science Direct was used. The combination of search terms of the PLE and PSLE yielded 88 results, the combination PLE and PPR 9 results, and the combination of search terms of PLE, PSLE and PPR zero results. Finally, the search engine of Google scholar was used. The combination of search terms of the PLE and the PSLE yielded 43 results, the combination PLE and PPR 4 results, and the combination of search terms of PLE, PSLE and PPR zero results.

The results of the first search included authoritative publications frequently cited in recent academic papers. The references of these publications were used to identify seminal works before the selected period. Once the main contributors to the discourse were detected, their names were combined with the keywords in order to trace more publications, providing insight into the evolution of the concepts. This forward and backward reference and author search yielded another 55 publications, making 352 in total.

After removing duplicate results, titles were checked to determine the connection with the research topic. If in doubt, the abstract was read. Subsequently, literature was selected based on inclusion and exclusion criteria as determined by the research team (this paper's authors), including the publication date, research topic, and review process that the data

sources used—preferring empirically retrieved data and the number of citations. A strict application of all five criteria was considered inappropriate because the research field draws on various disciplines which each has its own conventions for research and reporting. The review process and the data justification were not always clearly traceable. If all the criteria were applied strictly, too few publications would have remained or important publications would have been excluded. Therefore, we required that a minimum of four criteria should be met, resulting in a selection of 44 publications. Several of these selected publications referred to the same seminal works in this field of study. Additionally, the multidisciplinary research team members made suggestions for seminal works in their discipline that were assessed on various criteria, including the number of citations and relevance for this research. Thus, the selection was supplemented with 10 seminal works, resulting in 54 publications in total.

During the time between the search (2016/2017) and the completion of the present review (2019), new publications were identified through notifications and tips from search engines, research platforms and peer-researchers. For reviewing of these publications, the aforementioned protocol was applied also. To these new publications, another 10 publications were added to the selection. Eventually, hardly any supplementary information could be added, indicating that the saturation point had been reached. The 64 publications included in the selection are marked with an asterisk in the references list.

The selected literature was studied in detail. The information retrieved from each study was summarised in a table, that included the title, authors, year of publication, category of the publication, and a concise summary of the results and discussion. The quality of the papers was appraised on the basis of their academic quality, including the review procedure as checked earlier in the selection procedure, the completeness of the description of the research according to the academic standards, theoretical embedding, and the reliability and validity of the methodology, data collection and analysis. The interim results were discussed among the research team to establishing the findings, including the selection of the three most-relevant publications for each sub-question to be studied in-depth.

Next, an analysis table was constructed to record the information. Depending on the type of paper—either a primary or secondary source—aim, problem statement, research questions, conceptual framework, methodology, dependent and independent variables, results, arguments or main findings, and discussions were recorded in accordance with the methodology of Cronin et al. (2008).

Results

The following section first describes the sub-dimensions and aspects of the PSLE and the PLE respectively, followed by the description of the most salient relationships, supported by empirical evidence. Conceptualisations were examined and compared. Aspects argued to be relevant were incorporated into the theoretical framework described below.

Results for PSLE

Personal development

The sub-dimension personal development can be conceptualised through the aspects open-endedness, relevance/integration and environmental interaction.

Open-endedness refers to the learning goals and outcomes. According to De Kock et al. (2004), the recognition of learning being a constructive activity has implications for the learning goals, shifting from an orientation to delivering learning products, including knowledge reproduction and application—denoted as the cognitive learning functions—towards an orientation to the learning process, including students' self-regulation, engagement and reflection—denoted as the affective and metacognitive learning functions. This 'learning centredness' (OECD 2013) puts students' individual learning potential, interests and preferred learning styles at the centre. Consequently, learning outcomes shift from pre-defined end-products towards personalised, process-related learning outcomes.

Relevance/integration refers to the learning content, traditionally organised in subject matter areas. Student-centred approaches emphasise students' recognition of the relevance of the learning content (Vermunt and Verloop 1999). Therefore, the learning content should be abstractly presented not in subject matter areas, but in a multidisciplinary context similar to the reality outside school, where subject areas are not divided but interconnected (OECD 2013).

Environmental interaction refers to the interaction of the school's direct environment with learning, enabling students to provide an observable, meaningful contribution to the environment with their learning outcomes (Gruenewald 2003). Research on environmental interactive learning settings has established the positive effect on learning outcomes, including students' engagement and appreciation of the environment, greater learning motivation and potentially-deeper understandings (Zandvliet 2012, 2014).

Relationships

The sub-dimension relationships can be conceptualised through the aspects of teacher support, critical voice, student negotiation, group cohesiveness and student involvement.

Teacher support refers to teachers' competence to identify and to respond to individual learner's needs (OECD 2013; Vermunt and Verloop 1999). Conversely, learners must feel free to express their learning needs and to comment on the learning and teaching activities (referred to as *critical voice*). *Student negotiation* refers to the students' construction of knowledge by mutually assessing the viability of ideas. Performing cooperative tasks requires learners being mutually respectful, helpful and supportive (referred to as *group cohesiveness*). Therefore, learners must be interested in the learning content, attentive to others, participate in activities, undertake additional work and appreciate being a group member (referred to as *student involvement*).

System maintenance and change

The sub-dimension of *system maintenance and change* can be conceptualised through the aspects of *order and organisation* and *shared control*.

Order and organisation originally refers to the qualitative sub-aspects on the micro-level of the classroom, distinguishing the order and organisation of class activities, the clarity of rules, teachers' enforcement of rules, and the room for innovation in terms of unusual and varying activities planned by the teacher. Exploring the consequences of the new pedagogical insights for the PLE, much conceptual literature has been focused on quantitative sub-aspects of the *order and organisation*, including the categorisation of learning settings at the micro-level, and the school's organisation with regard to aspects of grouping, location and time at the meso-level. The most well-known conceptualisations of

learning settings are those constructed by Fisher (2005) and Thornburg (2004). Both distinguish various learning settings based on psychosocial characteristics including the type of psycho-social interaction, the number of students involved, the role division between the students, and the role of the teachers.

Against the backdrop of changing pedagogical visions, the traditional school's order and organisation of 'cells and bells' was critically reviewed, with the organisational units of the class, subject matter and hourly scheduling being questioned. Various authors have developed alternative models for schools' order and organisation based on the new pedagogical visions, including learner-centredness, collaborative learning and integration of subject matters. These models are based on block scheduling, team teaching, and grouping students and teachers into small learning communities, which are assumed to be supportive to multi-disciplinary activities and the fluent merging and splitting of learning settings (Nair et al. 2013).

Shared control originally referred to students' contribution to planning activities, which traditionally are the responsibility of the teacher. According to Foucault (1997), teachers' surveillance, or providing control over students, is inherent to the practice of teaching. In learning-centred PSLEs, learners are stimulated to be more self-regulating, or leaving a part of control to the student (Vermunt and Verloop 1999). However, this approach needs a rethinking of not only the monitoring of the learning processes of learners but also of managing the teaching processes. In small learning communities, teachers have to collaborate, losing their autonomy, sharing their control over the PSLE with colleagues, with the need to develop and maintain a collective, consistent pedagogical vision and practice, and the need to collectively solve daily practical issues including the mutual coordination of activities (Saltmarsh et al. 2015).

Results for PLE

Naturalness

The sub-dimension *naturalness* can be conceptualised through the aspects of *light, sound, temperature, air quality*, and *links to nature*

Light refers to the light conditions required for performing the learning activities, including the use and adjustability of natural and artificial light sources. *Sound* refers to the noise level and the acoustic qualities of the PLE, influencing intelligibility, concentration and students' behaviour. In open PLEs, acoustics are a critical factor that are directly correlated with the mutual disruption of different learning activities (Greenland and Shield 2011). *Temperature* refers to the air temperature that must be attuned to the learning activities and the associated physical effort; too high or too low temperatures directly affect the performance. *Air quality* refers to the degree of contamination of the air, determined by the ventilation rate, usually expressed by the CO_2 level. Studies confirm the positive relationship between CO_2 level and illness-related absenteeism. In addition, various studies indicate that learning performance improves with increased ventilation rates and higher outdoor air supply rate (Petersen et al. 2016; Wargocki et al. 2008). However, the influence of CO_2 on performance is limited (Snow et al. 2019). Therefore, CO_2 should be seen more as an indicator of the many pollutants in the air and not as the only factor connecting air quality with learning performance (Wargocki and Wyon 2017).

Links to nature refers to visual and physical connections with natural elements, stimulating positive feelings and social behaviour. A growing number of studies confirms the impact of the sub-dimension of naturalness on students' performance and wellbeing. However, the effect of each individual aspect in an isolated research setting is much stronger than in the complex reality of schools, where these aspects are experienced holistically (Barrett et al. 2015).

Individualisation

The sub-dimension *individualisation* can be conceptualised through the aspects of *fitness, flexibility, connection* and *ownership*.

Fitness refers to the usability of the PLE for the intended teaching and learning activities, including the functionality of furniture and its arrangement, as well as the availability and accessibility of equipment and technology (Brooks 2011; Radcliffe 2008).

Flexibility refers to the extent to which the PLE meets the various learning needs of students, that can differ for different students and change over time. In order to respond directly and appropriately to the learning needs of students, the PLE must support a variety of learning settings. For reasons of efficiency, learning spaces often are used for different learning settings simultaneously or sequentially. Simultaneous use requires a varied spatial arrangement—versatility. Sequential use requires the possibilities to easily and quickly rearrange the PLE—agility. By defining the term flexibility in this way, this research connects this aspect exclusively to the users' perspective of the daily pedagogical practice, and not to the perspective of providers and architects for whom flexibility could also refer to converting a PLE by renovation activities—convertibility—or transforming a PLE by flexible building elements—transformability—changing the nature of spatial connections (Woodman 2016).

Connection refers to the spatial configuration and interaction of learning spaces. Traditional classrooms are mostly too small to accommodate multiple arrangements efficiently (Bissell 2004). To avoid needless rearrangement, it is more efficient to compose a learning cluster of interconnected, differentiated learning spaces (Nair et al. 2013). To enhance communication, interaction and observation, these learning clusters must be open and transparent (Nair et al. 2013), only separating learning activities susceptible to interference. Depending on the time and the preferred extent of interaction, the adaptability and nature of the spatial connection might differ, ranging from separated to merged physically and from enclosed to fully transparent visually.

Ownership refers to the perception of the users' ability to manage and control the PLE, promoting feelings of safety, responsibility and belonging (Scott-Webber 2004). Therefore, in the spatial concepts, learning clusters are usually allocated exclusively to small learning communities. However, the concept of ownership differs depending on the user's perspective (Woodman 2016). Teachers mostly associate ownership with the possibility to personalise the PLE by exhibiting students' learning products, whereas students mostly associate ownership with being allowed to manipulate their PLE to their needs and insights, which indicates that there is a connection between the aspects *ownership* and *shared control*.

Stimulation

The sub-dimension *stimulation* can be conceptualised through the aspects *complexity* and *colour*. *Complexity* refers to the diversity of the PLE's physical presentation. The

peripheral perception of the PLE is asserted to influence learning as a 'third teacher', next to the parent and the teacher (Strong-Wilson and Ellis 2007). In the former century, this assertion gained prominence by the ideal–typical PLEs as developed by educational innovators, including Steiner, Froebel and Reggio Emilia. Applying the complexity science theory, Upitis (2004) argues that all system elements are involved in the learning process by complex interaction as 'agents' of development. Free, unintended interaction is essential for information transfer between the system elements. Therefore, the complexity of the PLE should challenge students to discover, through the presence of a diversity of formal and informal spaces where it is possible to experiment and ideas can be exchanged. Upitis (2004) identifies the aesthetic as an important element for bringing balance and order to complexity.

Colour refers to the colours used in the PLE. Research has shown that colours influence emotions and physiology, and also that colour preferences depend on personal characteristics (Higgins et al. 2005). Despite strong claims, the impact of these aspects is not unequivocally established in empirical practice and therefore is disputed (Blackmore et al. 2011)

PSLE–PLE Relationship (PPR) framework

The sub-dimensions and aspects identified above as being relevant for exploring the PSLE–PLE Relationship (PPR) have been merged into the PPR framework in Table 1, providing an initial overview that is organised into the dimensions of the PSLE and PLE, with their sub-dimensions on one axis and the three representations on the other axis.

Of the 64 publications included in the selection, 43 studies involved empirical research and most involved their own conceptualisation of the PSLE and PLE. Limited research has used existing conceptualisations, and this includes five studies using Moos's conceptualisation of the PSLE as experienced by students, and four studies using the Linking Pedagogy Space and Technology framework as constructed by Byers (2016b).

This review confirms that, within a research program or research group, conceptualisations and instruments are partly or completely adopted but, as noted by Volkmann and Stang (2015), exchange between research groups is limited. Additionally, research programs on the PSLE–PLE Relationship seems limited in number, concentrated in only a few countries, and mostly connected to national school building programs. Of the 43 primary empirical studies included in the selection, there is a relatively large number of studies from Australia (13) and the USA (12), followed by the UK (4), Canada and Malaysia (3) and various other countries with one or two studies.

Relations between the PSLE and PLE

To study the relations between the PSLE and PLE, we constructed the PSLE–PLE Relationship (PPR) conceptual model to depict the reciprocal relation between the PSLE and the PLE, as well as to identify the intended, implemented and attained representations of both the PSLE and PLE (Fig. 1). The PPR framework and PPR model have been used to study which relationships—between the sub-dimensions in their different representations—have been explored by empirical studies.

Consistent with the literature review of Blackmore et al. (2011), our review confirms that much research has methodical limitations. Compared with the PPR framework, most studies have been incompletely operationalised.

Table 1 PSLE–PLE Relationship (PPR) conceptual framework

Dimension	Intended Ideal/formal	Implemented Perceived/operational	Attained Experienced/assessed
Psychosocial LE			
Personal development			
Open-endedness	Key stage levels defined in the National Curriculum[a]	Teachers' perceptions regarding ownership of learning goals[c]	Assessed progress on reading, writing & maths[a], assessed performance on maths[c], students' attitude towards learning
Relevance/integration	National education policy's vision on (inquiry-based, explorative) learning[d]	Teachers' perceptions regarding challenging students[c], integrating assessments[c]	Students' curiosity and self-motivation[c], students' experience being challenged towards 'deeper levels of thinking'[c], students' enjoyment and positivity about their learning[c]
Environmental interaction		Teachers' perceptions regarding links to wider world[c]	
Relationships			
Teacher support	National education policy's description of preferred teacher-student interaction[d]	Teachers' perceptions on supportive teaching style, catering to student's needs[c], observed teaching behaviour; time spent on feedback and questioning; moving around—being proximate and accessible to students[b]	
Critical voice			
Group cohesiveness		Observed learning behaviour; time spent on peer feedback and discussion[b]	
Student negotiation	National education policy's preference for collaborative learning[d]	Teachers' perceptions on creating a supportive learning environment[c], observed learning behaviour; time spent on collaboratively creating, appraising, testing and refining[b]	Student-experienced interdependence[c]

Table 1 (continued)

Dimension	Intended Ideal/formal	Implemented Perceived/operational	Attained Experienced/assessed
Student involvement		Observed learning behaviour, time being engaged, disengaged or off-task[b]	Students' attitude to taking initiatives[c], students' attitude to tackling challenges[c], students' willingness to work beyond the zone of proximal development[c], students' persistence[c]
System maintenance and change			
Shared control		Teachers' perceptions regarding fostering self-regulation[b,c]	Student-experienced teacher's capacity to foster student self-regulation[c]
Order and organisation		Observed simultaneity and variety of learning activities[a], observed time spent on the various teaching and learning activities[b], teachers' perception regarding the necessary sequence of learning activities[c]	Student-experienced time spent in teaching and learning modalities[c], student-experienced encouragement using own initiative[c]
Physical LE *Naturalness*			
Light		Observed glazing orientation, glazing/floor area ratio, sight obstruction (glare), distance to windows, quality and quantity of electrical light[a]	Teacher-experienced quality of the light conditions[a,d]
Sound		Recorded noise from inside and outside[a], acoustical characteristics including size, shape and sound absorption of the room	Teacher-experienced quality of the sound conditions[a]
Temperature		Recorded temperature[a]	Teacher-experienced thermal comfort[a]
Air quality		Recorded CO_2 level[a], relative humidity[a], natural and mechanical ventilation capacity[a]	Teacher-experienced air quality[a,d]
Links to nature *Individualisation*		Observed views of nature[a]	Teacher-experienced links to nature[a]

Table 1 (continued)

Dimension	Intended Ideal/formal	Implemented Perceived/operational	Attained Experienced/assessed
Fitness	Experts' vision on fitness, specified in spatial models prescribed by the national government[d]	Recorded building scale, outdoor area, floor area and shape related to number of students[a], ergonomic quality $ purpose-designed furniture[a], width of traffic area related to movements[a], type of furniture[c], furniture arrangements[b,c], position and number of focus points[c], availability and versatility of technology[c], time of use of technologies[b]	Teacher-experienced fitness of the building, traffic areas, learning spaces and furniture[a,b,d]; students' perceptions using ICT: experienced availability, accessibility and fitness[c]; users' perceptions of the ergonomic quality of furniture[d]
Flexibility	Experts' vision on flexibility, specified in spatial models prescribed by the national government[d]	Observed rearrangement possibilities[a], alternative learning activities within the building[a], variety of spaces[a]	Teacher-experienced flexibility of the PLE[a,b], for modifying groupings and shifting arrangements[b,d]
Connection	Experts' vision on connection between spaces, specified in spatial models prescribed by the national government[d]	Observed multiple zones within one space[a], clear wayfinding[a], attractive and useful adjacent spaces, including breakout spaces and storage spaces[a], type of connection between learning spaces[b]	teacher-experienced quality of interconnections of 'ormal, supportive and informal learning spaces[a,b,d], including using spaces simultaneously for spreading and differentiating activities and student groupings[b], teacher-experienced impact of modification of space separations[b], teacher-experienced impact of visibility[b]
Ownership		Observed shading control[a], sun heat control[a], central heating control[a], control of mechanical and/or natural ventilation[a], distinctive design features[a], display opportunities[a]	Teacher-experienced control over the PLE[a], teachers' affiliation with the PLE[a], students' perceptions regarding their influence on changing the space[c]
Stimulation			
Complexity		Observed fabric variety[a], visual diversity of layout, furniture, displays and decorations[a]	Teacher-experienced complexity of the PLE[a]

Table 1 (continued)

Dimension	Intended Ideal/formal	Implemented Perceived/operational	Attained Experienced/assessed
Colour		Observed variety and composition of colours used on design, decoration and furniture[a]	Teacher-experienced stimulation through the colours used[a]

Indicatively filled with indicators derived (not necessarily explicitly operationalised as such) from the description of the research of

[a]Barrett et al. (2015)
[b]Byers et al. (2018b)
[c]Imms and Byers (2016)
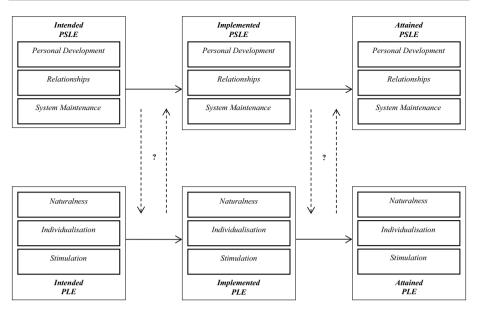[d]Veloso and Marques (2017)

Fig. 1 PLSE-PLE Relationship (PPR) model

Of the reviewed 43 empirical studies:

- 17 studies operationalised one or more subdimensions of the PSLE, with a limited operationalisation of the PLE and most cases distinguishing the PLE as traditional or innovative, without substantiation for measured aspects.
- 6 studies operationalised one or more subdimensions of the PLE, with a limited operationalisation of the PSLE and, in most cases, only measuring cognitive learning outcomes.
- 14 studies operationalised a limited number of aspects of both the PSLE and PLE, or were unclear in defining the aspects measured.
- Only 6 studies operationalised both the PSLE and PLE by more than one sub-dimension.

Research mostly has been limited to one or two representations. Of the selected empirical studies, only Mulcahy et al. (2015) explored all three representations. Longitudinal research projects with repeated data collection over a longer period of time are scarce, with only 7 of the 43 studies conducted over a period of a year or longer. Nevertheless, this review still identifies a growing body of empirical knowledge regarding the relation between the PSLE and PLE.

In the following paragraphs, the most salient relationships between sub-dimensions are described and supported by the results of empirical research. For each of these relationships, one or more studies are referred to instead of attempting to give a complete description of the reviewed literature. The studies referred to are characterised by a fairly extensive operationalisation of the sub-dimension studied and well-documented methods and analyses.

Naturalness (implemented PLE) related with assessed Personal Development (attained PSLE)

Of the 43 reviewed empirical studies, three studies involved the relationship between indoor environmental quality and cognitive learning outcomes. Marchand et al. (2014) and Barrett et al. (2013, 2015) support that *naturalness* affects *personal development*. However, Barrett et al. (2015) found that, in the PLEs of schools, the impact of an aspect is less apparent than in laboratory research, for which the impact of that specific aspect is measured in isolation. Barrett et al. (2015) argue that, in complex reality, information of all aspects is holistically processed by the brain and, therefore, the impact as of the sub-dimension as a whole, not as the impact of separate aspects, must be measured.

Stimulation and Individualisation (implemented PLE) related with Relationships and System Maintenance & Change (implemented PSLE)

Of the 43 reviewed empirical studies, 22 focused on the relationship between the implemented PLE and implemented PSLE, including studies focused on the context of a classroom (13), or learning cluster (5) or laboratory (2). Their results provide evidence that the composition, furniture and fittings of learning spaces have an impact on teaching and learning activities, including the grouping of students.

The studies of classrooms involved comparing educational practices in traditionally-arranged classrooms directed to one focal point of the teaching position, with those in an innovatively-arranged room equipped with varied and flexible furniture, multiple focus points and modern technologies. The results of these studies support the evidence that teachers use more student-centred pedagogies in innovative PLEs. Studies by Byers et al. (2018b) and Jorion et al. (2016) are illustrative and indicate that, compared with traditionally-arranged classrooms, teachers use more student-centred pedagogies in innovatively-arranged rooms. Only the study of Beery et al. (2013) could not establish an effect. The researchers suspect that the teacher's preferred pedagogy is the strongest predictor of actual educational practice, and that redesigning the space alone is not enough to change educational practice. At best, it can be stimulating and facilitating. The influence of teacher characteristics on the actual use of the PLE has also been recognised in other studies. Of the 22 studies, eight explicitly examined the assertion of Lackney (2008) that students' and teacher's competencies influence the effective use of the PLE, with positive results. The findings of Fisher and Newton (2014) confirm that teachers need to develop new 'spatial' competencies when they move into new learning spaces. Teachers have to learn how to exploit the benefits of the innovative PLE for pedagogical gains (Byers et al. 2018b; Woodman 2016). It takes time to develop new pedagogical and social practices, especially when switching from teaching in a classroom to team teaching in a learning cluster and when sharing the same PSLE and PLE with other teachers (Cleveland 2016; Saltmarsh et al. 2015). This evolving process can be stimulated by involving teachers and students in the design and maintenance of their PLE. The research of Woodman (2016) found that this involvement can promote student understanding of how to use the PLE effectively.

Stimulation and Individualisation (implemented PLE) related with Personal Development, Relationships and System Maintenance & Change (attained PSLE)

Of the 43 reviewed empirical studies, 17 studies focused on the impact of implemented the PLE sub-dimensions *stimulation* and *individualisation* on one or more subdimensions of the attained PSLE. Of these studies, 12 measured cognitive learning outcomes, with seven taking into account the possible moderating effect of student characteristics, seven applying cognitive learning outcomes as the only indicator for the attained PSLE, and the other five also measuring student experiences regarding the sub-dimensions *relationships* and *system maintenance & change*, and three taking into account the possible moderating effect of teacher characteristics. Because impact was measured differently in different studies, it is not possible to compare and combine the results. Nevertheless, the findings

from these research projects indicate positive effects of the sub-dimensions of *stimulation* and *individualisation* on the attained PSLE. In the exemplary research of Imms and Byers (2016), the attained PSLE was measured among students who took the same course in traditionally-arranged and open and flexibly-arranged classrooms, respectively. In the latter, students experienced changing teacher-student relationships, recording a shift from teacher-centric to more student-centred pedagogy. Additionally, students were feeling more engaged with their learning and performed better on both cognitive and metacognitive learning outcomes.

Relationships and System Maintenance & Change (implemented PSLE) related with experienced Stimulation and Individualisation (attained PLE)

Although none of the reviewed studies explicitly focused on the impact of the implemented PSLE on the experienced PLE, research findings give indications of such a relationship. Whereas some teachers experience innovative PSLEs as stimulating and supporting, other teachers feel alienated because the PLE hinders their preferred traditional approach (Cleveland 2016). The research of Mulcahy et al. (2015) indicates that the appreciation of teachers for the innovative learning environment shows greater variability than the experiences of school leaders and students, who generally prefer innovative environments. Teachers have to implement the intended learning environment in practice, but the appropriateness of that learning environment is often much more uncertain for them than for the school leaders who have constructed that learning environment. Mostly, teachers have had little or no involvement in the development of the new learning environment. The acceptance of this new learning environment is then highly dependent on the willingness and ability of teachers to abandon their well-known pedagogical practice and views and adopt those of school leaders and policy makers. Based on their research, Mulcahy et al. (2015) argue that the PLE does not determine social practices but, rather, social practices give space a meaning through habituation and interaction by the users (Woolner et al. 2012).

The research of Veloso and Marques (2017) illustrates this point. Under the Portuguese Secondary School Modernisation Programme, laboratories were reconstructed according to a standard design that offers more flexibility than the old layouts. However, the research reveals that teachers were critical of the mismatch between their preferred pedagogy and the universal solutions dictated by the programme. The aforementioned studies suggest that the success of change is strongly linked with users' ownership of the innovation (Higgins et al. 2005).

The experienced PLE is also influenced by ownership as defined by the system organisation. The research of Woodman (2016) reveals that, if spaces are not assigned to a specific learning community, teachers feel discouraged about changing the PLE, and students do not feel affinity with the space.

Discussion

The cited studies illustrate the complexity of the relationship between the PSLE and PLE, with the sub-dimensions and their aspects interwoven in a complex way. The review also reveals that, compared with the PPR framework, the empirical studies reviewed have been operationalised incompletely, but complete operationalisation could be too elaborative. With so many identified sub-dimensions and aspects and a multitude of possible relationships, there is potential for collecting excessive amounts of data and therefore impede

effective and meaningful analysis (Cleveland and Fisher 2014). Focussing the research design on a limited set of aspects and relations is inevitable, thereby leaving certain aspects, sub-dimensions or representations of the PRR-framework out of scope. Processing the operationalisation into the PPR framework helps to determine which sub-dimensions and aspects are excluded from a specific study, which can be helpful if there are unexpected results. For example, the research of Barret et al. (2015) into the impact of the PLE on learning outcomes lacks a comprehensive analysis of the implemented and attained PSLE. Contrary to expectations, the research established weak impact of the sub-dimensions of individualisation and stimulation. The authors presume that this might be explained by the predominant pedagogical approach, emphasising learning in the classroom. An analysis of the implemented PSLE could have supplied more insight. This aspect was excluded by the researchers, but appears to be relevant for understanding the unexpected outcome.

The relevance of aspects can vary by educational level. The present review did not strictly classify the findings by educational levels. For different educational levels, the same aspects were mentioned, but the literature was not always clear on this point. Various authors, including Cleveland (2016) and Mulcahy et al. (2015) mention the resistant school cultures of secondary education. This could be explained by the transition to innovative PSLEs requiring a changed culture of practice, including the introduction of a flexible timetable and changing the organisational unit from specific subject areas to learning communities of a group of students, which is an organisational form well-known in primary education. Therefore, when studying secondary schools with changing PSLEs, special attention must be paid to possible differences between the various representations of the PSLE, because it takes time to implement staff intentions and formal policies in the pedagogical practice of teachers and, eventually, in students' learning experiences.

Relations between different sub-dimensions and aspects can be difficult to examine because of the many aspects involved that either mediate or moderate relations. Studying the most direct relations is preferable because relations that are mediated and moderated by other aspects can only be studied by neutralising their influence on the results. This can be illustrated by the research into the relationship between the implemented PLE and attained PSLE in terms of learning outcomes. Much research has been focused on the relation between the PLE and cognitive learning outcomes. With student and teacher characteristics and their relationships being the strongest predictor of learning outcomes (Blackmore et al. 2011), this relation can only be determined in a reliable way if the mediating effects of these aspects are taken into account, both in the research design and data analysis (Brooks 2011). However, acknowledging the implemented PSLE as the main predictor of learning outcomes, and in view of the growing evidence that the implemented PSLE and the implemented PLE are interrelated, research can better be focused on this relationship rather than the relationship between the implemented PLE and learning outcomes.

As our literature search reveals, the number of empirical studies of the relationship between the implemented PLE and PSLE is growing. However, our literature search also confirms the observation of Hall (2013) that much research is focused on the scale of a classroom and only a little research is focused on learning clusters. The spatial configuration of these learning clusters has rarely been extensively analysed to support the conceptual literature's claim that innovative PSLE's need these radically different PLE's. Further development of current research instruments is required, enabling effective representation and analysis of the spatial configuration of learning clusters and facilitating more in-depth empirical research into the relationship between the implemented PSLE and PLE.

Conclusion

This thematic literature review started with research questions regarding which sub-dimensions and aspects in the literature are considered relevant for research into: the relation between the PSLE and the PLE; how these aspects have been conceptualised; and which relations are supported by empirical evidence. This review of 43 empirical studies establishes that research on the PSLE-PLE relationship is still in its infancy. Although the literature broadly identifies the same aspects as being relevant for studying the PSLE–PLE relationship, a variety of conceptualisations, with different categorisation of the aspects, are used. Most conceptualisations are incomplete, focussing either on the PSLE, the PLE or a limited number of sub-dimensions. By processing all relevant aspects and sub-dimensions as identified by research from the various disciplines, the PPR framework overcomes these shortcomings. Offering a complete and balanced overview, the PPR-framework can make researchers aware of aspects and relations that they overlooked until now and the possible effects of this on their research results.

Additionally, this review explored relations between various representations of the PSLE and the PLE, focussing on the assertions justifying the spatial concepts as developed for innovative PSLEs. This review establishes that the body of evidence confirming these assertions is growing, but also that the impact of the sub-dimensions of the PLE on the various representations of the PSLE differs for different PLE sub-dimension. Much research has focused on the relationship between aspects of implemented PLE naturalness and attained PSLE in terms of cognitive learning outcomes.

Recent research projects suggest that aspects of implemented PLE's individualisation and stimulation impact pedagogical practice in the implemented PSLE and indirectly impact learning outcomes in the attained PSLE. However, because of the limited number of studies and their methodological limitations, the evidence is still weak. Follow-up studies are required to further explore this relationship. These studies might also provide a firmer basis for an 'overarching theoretical model' for research into the PSLE–PLE relationship in order to construct powerful, innovative learning environments to support learning.

Appendix

See Table 2.

Table 2 Overview of explored relationships in empirical research arranged according to conceptualisation of PPR framework

Authors	Title	Dependent/independent variable					
		Intend PSLE	Implem PSLE	Attain PSLE	Intend PLE	Implem PLE	Attain PLE
Ahmad et al. (2014)	Predictive Relationship between Physical and Psychosocial Aspects of Science Laboratory Learning Environment among Secondary School Students in Malaysia			DV			IV
Ahmad et al. (2012)	Relationship Between Physical and Psychosocial Aspects in Science Laboratory Learning Environment		DV				IV
Al-Ayash et al. (2016)	The influence of color on student emotion, heart rate, and performance in learning environments			DV		IV	
Arndt (2012)	Design of Learning Spaces: Emotional and Cognitive Effects of Learning Environments in Relation to Child Development		IV	DV			IV
Barrett et al. (2013)	A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning			DV		IV	DV
Barrett et al. (2015)	The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis			DV		IV	DV
Beckers et al. (2015)	A conceptual framework to identify spatial implications of new ways of learning in higher education	IV			DV	DV	
Beckers et al. (2016)	Learning space preferences of higher education students	IV			IV		DV
Beery et al. (2013)	The impact of learning space on teaching behaviors		DV			IV	
Blyth et al. (2012)	Modernising Secondary School Buildings in Portugal					IV	DV

Table 2 (continued)

Authors	Title	Dependent/independent variable					
		Intend PSLE	Implem PSLE	Attain PSLE	Intend PLE	Implem PLE	Attain PLE
Bradbeer et al. (2017)	The "state of play" concerning New Zealand's transition to innovative learning environments: preliminary results from phase one of the ILETC project		DV			IV	
Brooks (2011)	Space matters: The impact of formal learning environments on student learning			DV		IV	
Byers et al. (2018)	Empirical evaluation of different classroom spaces on students' perceptions of the use and effectiveness of 1-to-1 technology		DV			IV	DV
Byers et al. (2018a)	Comparative analysis of the impact of traditional versus innovative learning environment on student attitudes and learning outcomes			DV		IV	DV
Byers et al. (2018b)	Evaluating teacher and student spatial transition from a traditional classroom to an innovative learning environment		DV	DV		IV	
Byers et al. (2014)	Making the Case for Space: The Effect of Learning Spaces on Teaching and Learning			DV		IV	DV
Cleveland (2016)	Addressing the Spatial To Catalyse Socio-Pedagogical Reform in Middle Years Education			DV		IV	DV
Craig-Hare et al. (2012)	Learning Spaces to Support 21 st Century Learners		DV			IV	
Duarte et al. (2014)	Site-specific focus groups: analysing learning spaces in situ					IV	DV
Fisher et al. (2014)	Visual Environment, Attention Allocation, and Learning in Young Children: When Too Much of a Good Thing May Be Bad			DV		IV	
Greenland and Shield (2011)	A survey of acoustic conditions in semi-open plan classrooms in the United Kingdom.		DV			IV	DV

Table 2 (continued)

Authors	Title	Dependent/independent variable					
		Intend PSLE	Implem PSLE	Attain PSLE	Intend PLE	Implem PLE	Attain PLE
Ibrahim and Fadzil (2013)	Informal Setting for Learning on Campus: Usage and Preference					IV	DV
Imms and Byers (2016)	Impact of classroom design on teacher pedagogy and student engagement and performance in mathematics			DV		IV	
Jorion et al. (2016)	Promoting Collaboration Using Team Based Classroom Design			DV		IV	
Lackney (2008)	Teacher Environmental Competence in Elementary School Environments	IV	DV				
Lee and Smith (1997)	High School Size: Which Works Best and for Whom?			DV		IV	
Mäkelä and Helfenstein (2016)	Developing a conceptual framework for participatory design of psychosocial and physical learning environments	DV		IV	DV		IV
Marchand et al. (2014)	The impact of the classroom built environment on student perceptions and learning			DV		IV	DV
Matthews et al. (2010)	The impact of social learning spaces on student engagement		DV	DV		IV	DV
Mulcahy et al. (2015)	Learning spaces and pedagogic change: envisioned, enacted and experienced.	DV	DV	DV		IV	
Newton et al. (2012)	More than a survey: an interdisciplinary post-occupancy tracking of BER schools		DV	DV		IV	
Newton and Cleveland (2015)	The other half of the picture : post—occupancy evaluation for alignment of space and pedagogy	IV	DV	DV		IV	DV
Saltmarsh et al. (2015)	Putting "structure within the space": spatially un/responsive pedagogic practices in open-plan learning environments	IV	DV	DV			

Table 2 (continued)

Authors	Title	Dependent/independent variable					
		Intend PSLE	Implem PSLE	Attain PSLE	Intend PLE	Implem PLE	Attain PLE
Tanner (2008)	Effects of school design on student outcomes			DV		IV	
Taylor (2009)	Effects of studio space on teaching and learning: Preliminary findings from two case studies			DV		IV	
Veloso and Marques (2017)	Designing science laboratories: learning environments, school architecture and teaching and learning models				IV		DV
Walker et al. (2011)	Pedagogy and Space: Empirical Research on New Learning Environments		DV	DV		IV	DV
Whiteside et al. (2010)	Making the Case for Space: Three Years of Empirical Research on Learning Environments		DV	DV		IV	DV
Woodman (2016)	Re-placing flexibility		DV			IV	DV
Woolner et al. (2012)	Changed learning through changed space: When can a participatory approach to the learning environment challenge preconceptions and alter practice?			DV		IV	DV
Zandvliet and Broekhuizen (2017)	Spaces for learning: Development and validation of the school physical and campus environment survey.					IV	DV
Zandvliet (2014)	PLACES and SPACES: case studies in the evaluation of post-secondary, place-based learning environments			IV	DV		IV
Zandvliet (2012)	Development and validation of the Place-Based Learning and Constructivist Environment Survey (PLACES)	DV		IV			

PSLE psychosocial learning environment, *PLE* physical learning environment, *Intend* intended, *Implem* implemented, *Attain* attained, *DV* dependent variable, *IV* independent variable

References

References marked with an asterisk indicate studies included in the review

*Ahmad, C. N. C., Osman, K., & Halim, L. (2012). Relationship between physical and psychosocial aspects in science laboratory learning environment. *Procedia Social and Behavioral Sciences, 46,* 1500–1505. https://doi.org/10.1016/j.sbspro.2012.05.329.

*Ahmad, C. N. C., Osman, K., Halim, L., & Noh, N. M. (2014). Predictive relationship between physical and psychosocial aspects of science laboratory learning environment among secondary school students in Malaysia. *Procedia Social and Behavioral Sciences, 116,* 158–162. https://doi.org/10.1016/j.sbspro.2014.01.185.

*Al-Ayash, A., Kane, R. T., Smith, D., & Green-Armytage, P. (2016). The influence of color on student emotion, heart rate, and performance in learning environments. *Color Research and Application, 41*(2), 196–205. https://doi.org/10.1002/col.21949.

*Arndt, P. A. (2012). Design of learning spaces: emotional and cognitive effects of learning environments in relation to child development. *Mind, Brain, and Education, 6*(1), 41–48. https://doi.org/10.1111/j.1751-228X.2011.01136.x.

*Barr, R. B., & Tagg, J. (1995). From teaching to learning. *Change, 27*(6), 12–25.

*Barrett, P., Davies, F., Zhang, Y., & Barrett, L. (2015). The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis. *Building and Environment, 89,* 118–133. https://doi.org/10.1016/j.buildenv.2015.02.013.

*Barrett, P., Zhang, Y., Moffat, J., & Kobbacy, K. (2013). A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning. *Building and Environment, 59,* 678–689. https://doi.org/10.1016/j.buildenv.2012.09.016.

*Beckers, R., Van der Voordt, T., & Dewulf, G. (2015). A conceptual framework to identify spatial implications of new ways of learning in higher education. *Facilities, 33*(1/2), 2–19. https://doi.org/10.1108/F-02-2013-0013.

*Beckers, R., Van der Voordt, T., & Dewulf, G. (2016). Learning space preferences of higher education students. *Building and Environment, 104,* 243–252. https://doi.org/10.1016/j.buildenv.2016.05.013.

*Beery, T. A., Shell, D., Gillespie, G., & Werdman, E. (2013). The impact of learning space on teaching behaviors. *Nurse Education in Practice, 13*(5), 382–387. https://doi.org/10.1016/j.nepr.2012.11.001.

Bissell, J. (2004). Teachers' construction of space and place: The method in the madness. *Forum, 46*(1), 28. https://doi.org/10.2304/forum.2004.46.1.6.

*Blackmore, J., Bateman, D., Loughlin, J., O'Mara, J., & Aranda, G. (2011). *Research into the connection between built learning spaces and student outcomes.* Melbourne: Education Policy and Research Division, Department of Education and Early Childhood Development.

*Blyth, A., Almeida, R., Forrester, D., Gorey, A., & Hostens, G. (2012). *Modernising secondary school buildings in Portugal.* Paris: OECD Publishing. https://doi.org/10.1787/9789264128774-en.

*Bradbeer, C., Mahat, M., Byers, T., Cleveland, B., Kvan, T., & Imms, W. (2017). The "state of play" concerning New Zealand's transition to innovative learning environments: Preliminary results from phase one of the ILETC project. *Journal of Educational Leadership and Practice, 32*(1), 22–38.

*Brooks, D. C. (2011). Space matters: The impact of formal learning environments on student learning. *British Journal of Educational Technology, 42*(5), 719–726. https://doi.org/10.1111/j.1467-8535.2010.01098.x.

*Byers, T. (2016a). A quasi-experimental and single-subject research approach as an alternative to traditional post-occupancy evaluation of learning environments. In W. Imms, B. Cleveland, & K. Fisher (Eds.), *Evaluating learning environments* (pp. 117–130). Rotterdam: Sense Publishers. https://doi.org/10.1136/bmj.2.2169.258.

Byers, T. (2016b). Development of an observation metric for linking pedagogy, technology and space. In B. Cleveland, H. Mitcheltree, & W. Imms (Eds.), *What's working?* (pp. 77–88). Melbourne: LEaRN, University of Melbourne.

*Byers, T., Hartnell-Young, E., & Imms, W. (2018a). Empirical evaluation of different classroom spaces on students' perceptions of the use and effectiveness of 1–to–1 technology. *British Journal of Educational Technology, 49*(1), 153–164. https://doi.org/10.1111/bjet.12518.

*Byers, T., Imms, W., & Hartnell-Young, E. (2014). Making the case for space: The effect of learning spaces on teaching and learning. *Curriculum and Teaching, 29*(1), 5–19. https://doi.org/10.7459/ct/29.1.02.

*Byers, T., Imms, W., & Hartnell-Young, E. (2018b). Comparative analysis of the impact of traditional versus innovative learning environment on student attitudes and learning outcomes. *Studies in Educational Evaluation, 58,* 167–177. https://doi.org/10.1016/j.stueduc.2018.07.003.

*Byers, T., Imms, W., & Hartnell-Young, E. (2018c). Evaluating teacher and student spatial transition from a traditional classroom to an innovative learning environment. *Studies in Educational Evaluation, 58,* 156–166. https://doi.org/10.1016/j.stueduc.2018.07.004.

*Cleveland, B. (2016). Addressing the spatial to catalyse socio-pedagogical reform in middle years education. In K. Fisher (Ed.), *The translational design of schools* (pp. 27–49). Rotterdam: Sense Publishers.

*Cleveland, B., & Fisher, K. (2014). The evaluation of physical learning environments: A critical review of the literature. *Learning Environments Research, 17*(1), 1–28.

*Cleveland, B., & Soccio, P. (2015). Evaluating the pedagogical effectiveness of learning spaces. In R. H. Crawford & A. Stephan (Eds.), *Living and learning: Research for a better built environment.* 49th International Conference of the Architectural Science Association *2015* (pp. 507–516).

*Craig-Hare, J., Hobin, L., Landever, A., Mispagel, K., & Parscale, G. (2012). *Learning spaces to support 21st century learners*. International Society of Technology in Education annual meeting.

Cronin, P., Ryan, F., & Coughlan, M. (2008). Undertaking a literature review: A step-by-step approach. *British Journal of Nursing, 17*(1), 38–43.

*De Kock, A., Sleegers, P., & Voeten, M. J. M. (2004). New learning and the classification of learning. *Review of Educational Research, 74*(2), 141–170.

*Dovey, K., & Fisher, K. (2014). Designing for adaptation: The school as socio-spatial assemblage. *The Journal of Architecture, 19*(1), 43–63. https://doi.org/10.1080/13602365.2014.882376.

*Duarte, A., Veloso, L., Marques, J., & Sebastião, J. (2014). Site-specific focus groups: Analysing learning spaces in situ. *International Journal of Social Research Methodology, 18*(4), 381–398. https://doi.org/10.1080/13645579.2014.910743.

Ellis, R. A., & Goodyear, P. (2016). Models of learning space: Integrating research on space, place and learning in higher education. *Review of Education, 4*(2), 149–191. https://doi.org/10.1002/rev3.3056.

*Fisher, K. (2005). *Linking pedagogy and space: Proposed planning principles* (Resource document). Melbourne: Department of Education and Training (Victoria). www.eduweb.vic.gov.au/edulibrary/public/assetman/bf/Linking_Pedagogy_and_Space.pdf. Accessed 7 January 2019.

*Fisher, A. V., Godwin, K. E., & Seltman, H. (2014). Visual environment, attention allocation, and learning in young children: When too much of a good thing may be bad. *Psychological Science, 25*(7), 1362–1370. https://doi.org/10.1177/0956797614533801.

*Fisher, K., & Newton, C. (2014). Transforming the twenty-first-century campus to enhance the net-generation student learning experience: Using evidence-based design to determine what works and why in virtual/physical teaching spaces. *Higher Education Research and Development, 33*(5), 903–920. https://doi.org/10.1080/07294360.2014.890566.

Foucault, M. (1997). Space, knowledge, power. In N. Leach (Ed.), *Rethinking architecture* (pp. 367–679). London: Routledge.

Fraser, B. J. (1998). Classroom environment instruments: Development, validity and applications. *Learning Environments Research, 1,* 7–33. https://doi.org/10.1023/A:1009932514731.

*Greenland, E. E., & Shield, B. M. (2011). A survey of acoustic conditions in semi-open plan classrooms in the United Kingdom. *The Journal of the Acoustical Society of America, 130*(3), 1399–1410. https://doi.org/10.1121/1.3613932.

Gruenewald, D. A. (2003). The best of both worlds: A critical pedagogy of place. *Educational Researcher, 32*(4), 3–12. https://doi.org/10.3102/0013189X032004003.

*Guney, A., & Al, S. (2012). Effective learning environments in relation to different learning theories. *Procedia Social and Behavioral Sciences, 46,* 2334–2338. https://doi.org/10.1016/j.sbspro.2012.05.480.

Hall, C. (2013). *The impact of new learning spaces on teaching practice: Literature review*. Melbourne: Academic Development Group, College of Business, RMIT University.

*Higgins, S., Hall, E., Wall, K., Woolner, P., & McCaughey, C. (2005). *The impact of school environments: A literature review.* London: Design Council. http://128.240.233.197/cflat/news/DCReport.pdf.

*Ibrahim, N., & Fadzil, N. H. (2013). Informal setting for learning on campus: Usage and preference. *Procedia Social and Behavioral Sciences, 105,* 344–351. https://doi.org/10.1016/j.sbspro.2013.11.036.

*Imms, W., & Byers, T. (2016). Impact of classroom design on teacher pedagogy and student engagement and performance in mathematics. *Learning Environments Research, 20*(1), 139–152. https://doi.org/10.1007/s10984-016-9210-0.

*Jorion, N., Taeyaerts, D., & Jeanes, W. (2016). Promoting collaboration using team based classroom design. *Creative Education, 07*(05), 724–729. https://doi.org/10.4236/ce.2016.75076.

Lackney, J. A. (1997). *The relationship between environmental quality of school facilities and student performance. Energy smart schools: Opportunities to save money, save energy and improve student*

performance. A Congressional Briefing to the U.S. House of Representatives Committee on Science (Resource document). ERIC Education Resources Information Center. https://files.eric.ed.gov/fulltext/ED439594.pdf. Accessed 7 January 2019.

*Lackney, J. A. (2000). Thirty-three educational design principles for schools & community learning centers (Resource document). ERIC Education Resources Information Center. https://files.eric.ed.gov/fulltext/ED450544.pdf. Accessed 7 January 2019.

*Lackney, J. A. (2008). Teacher environmental competence in elementary school environments. *Children, Youth and Environments, 18*(2), 133–159.

*Lee, V. E., & Smith, J. B. (1997). High school size: Which works best and for whom? *Educational Evaluation and Policy Analysis, 19*(3), 205–227. https://doi.org/10.2307/1164463.

Lefebvre, H. (1991). *The production of space* (Vol. 142). Oxford: Blackwell.

*Mäkelä, T., & Helfenstein, S. (2016). Developing a conceptual framework for participatory design of psychosocial and physical learning environments. *Learning Environments Research, 19*(3), 411–440. https://doi.org/10.1007/s10984-016-9214-9.

*Marchand, G. C., Nardi, N. M., Reynolds, D., & Pamoukov, S. (2014). The impact of the classroom built environment on student perceptions and learning. *Journal of Environmental Psychology, 40,* 187–197. https://doi.org/10.1016/j.jenvp.2014.06.009.

*Matthews, K. E., Adams, P., & Gannaway, D. (2010). The impact of social learning spaces on student engagement. In K. Nelson (Ed.), *Proceedings of the 12th Annual Pacific Rim First Year in Higher Education conference* (pp. 1–10). Brisbane: Queensland University of Technology. Retrieved from http://fyhe.com.au/past_papers/papers09/content/pdf/3A.pdf.

Moos, R. (1980). Evaluating classroom environments. *Studies in Educational Evaluation, 6*(3), 239–252.

*Mulcahy, D., Cleveland, B., & Aberton, H. (2015). Learning spaces and pedagogic change: Envisioned, enacted and experienced. *Pedagogy, Culture and Society, 23*(4), 575–595. https://doi.org/10.1080/14681366.2015.1055128.

*Nair, P., Fielding, R., & Lackney, J. A. (2013). *The language of school design: Design patterns for 21st century schools* (3rd ed.). Minneapolis: Designshare Inc.

*Newton, C., & Cleveland, B. (2015). The other half of the picture: Post-occupancy evaluation for alignment of space and pedagogy. In R. H. Crawford & A. Stephan (Eds.), *Living and learning: Research for a better built environment: 49th International Conference of the Architectural Science Association* (pp. 588–597). The Architectural Science Association and The University of Melbourne. Retrieved from http://fyhe.com.au/past_papers/papers09/content/pdf/3A.pdf.

*Newton, C., Wilks, S., Hes, D., Aibinu, A., Crawford, R. H., Goodwin, K., et al. (2012). More than a survey: An interdisciplinary post-occupancy tracking of BER schools. *Architectural Science Review, 55*(3), 196–205. https://doi.org/10.1080/00038628.2012.697864.

*Oblinger, D. G. (2006). Space as a change agent. In D. G. Oblinger (Ed.), *Learning spaces* (pp. 1.1–1.4). Washington DC: Educause. https://doi.org/10.1007/978-3-642-01039-2.

OECD. (2013). The nature of learning principles revisited. *Innovative learning environments* (pp. 153–184). Paris: OECD Publishing.

Petersen, S., Jensen, K. L., Pedersen, A. L. S., & Rasmussen, H. S. (2016). The effect of increased classroom ventilation rate indicated by reduced CO_2 concentration on the performance of schoolwork by children. *Indoor Air, 26*(3), 366–379. https://doi.org/10.1111/ina.12210.

Radcliffe, D. (2008). A pedagogy-space-technology (PST) framework for designing and evaluating learning places. In D. Radcliffe, H. Wilson, D. Powell, & B. Tibbetts (Eds.), *Learning spaces in higher education: Positive outcomes by design* (pp. 9–16). Brisbane: The University of Queensland.

*Saltmarsh, S., Chapman, A., Campbell, M., & Drew, C. (2015). Putting "structure within the space": Spatially un/responsive pedagogic practices in open-plan learning environments. *Educational Review, 67*(3), 315–327. https://doi.org/10.1080/00131911.2014.924482.

*Scott-Webber, L. (2004). *In sync: Environmental behavior research and the design of learning spaces*. Michigan: Society for College and University Planning.

Simons, P. R.-J., van der Linden, A. A. M., & Duffy, T. (Eds.). (2000). *New learning*. Dordrecht: Kluwer Academic Publishers.

Snow, S., Boyson, A. S., Paas, K. H. W., Gough, H., King, M. F., Barlow, et al. (2019). Exploring the physiological, neurophysiological and cognitive performance effects of elevated carbon dioxide concentrations indoors. *Building and Environment, 156,* 243–252. https://doi.org/10.1016/j.buildenv.2019.04.010.

Strong-Wilson, T., & Ellis, J. (2007). Children and place: Reggio Emilia's environment as third teacher. *Theory Into Practice, 46*(1), 40–47. https://doi.org/10.1207/s15430421tip4601_6.

*Tanner, C. K. (2008). Effects of school design on student outcomes. *Journal of Educational Administration, 47*(3), 381–399. https://doi.org/10.1108/09578230910955809.

*Taylor, S. S. (2009). Effects of studio space on teaching and learning: Preliminary findings from two case studies. *Innovative Higher Education, 33*(4), 217–228. https://doi.org/10.1007/s10755-008-9079-7.

Thornburg, D. (2004). Campfires in cyberspace: Primordial metaphors for learning in the 21st century. *International Journal of Instructional Technology and Distance Learning, 1*(10), 1–12.

*Upitis, R. (2004). School architecture and complexity. *Complicity An International Journal of Complexity and Education, 1*(1), 19–38.

*Van den Akker, J. (2013). Curricular development research as a specimen of educational design research. In T. Plomp & N. Nieveen (Eds.), *Educational design research* (pp. 53–70). Enschede: SLO—Netherlands Institute for Curriculum Development. Retrieved from http://international.slo.nl/publications/edr/.

*Van Merriënboer, J. J. G., McKenney, S., Cullinan, D., & Heuer, J. (2017). Aligning pedagogy with physical learning spaces. *European Journal of Education, 52*(3), 253–267. https://doi.org/10.1111/ejed.12225.

*Veloso, L., & Marques, J. S. (2017). Designing science laboratories: Learning environments, school architecture and teaching and learning models. *Learning Environments Research, 20*(2), 221–248. https://doi.org/10.1007/s10984-017-9233-1.

*Vermunt, J. D., & Verloop, N. (1999). Congruence and friction between learning and teaching. *Learning and Instruction, 9*(3), 257–280. https://doi.org/10.1016/S0959-4752(98)00028-0.

Volkmann, S., & Stang, R. (2015). Global trends in physical learning space research. *Bibliothek forschung und praxis, 39*(2), 235–239. https://doi.org/10.1515/bfp-2015-0026.

*Walker, J. D., Brooks, D. C., & Baepler, P. (2011). Pedagogy and space: Empirical research on new learning environments. *EDUCAUSE Quarterly, 34*(4), 96.

Wargocki, P., & Wyon, D. P. (2017). Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork. *Building and Environment, 112,* 359–366. https://doi.org/10.1016/j.buildenv.2016.11.020.

Wargocki, P., Wyon, D. P., Lynge-Jensen, K., & Bornehag, C. G. (2008). The effects of electrostatic particle filtration and supply-air filter condition in classrooms on the performance of schoolwork by children (RP-1257). *HVAC&R Research, 14*(3), 327–344. https://doi.org/10.1080/10789669.2008.10391012.

*Whiteside, A. L., Brooks, D. C., & Walker, J. D. (2010). Making the case for space: Three years of empirical research on learning environments. *EDUCAUSE Quarterly, 33*(3), 999.

*Woodman, K. (2016). Re-placing flexibility. In K. Fisher (Ed.), *The translational design of schools* (pp. 51–79). Rotterdam: Sense Publishers.

*Woolner, P., & Hall, E. (2010). Noise in schools: A holistic approach to the issue. *International Journal of Environmental Research and Public Health, 7*(8), 3255–3269. https://doi.org/10.3390/ijerph7083255.

*Woolner, P., Hall, E., Higgins, S., McCaughey, C., & Wall, K. (2007). A sound foundation? What we know about the impact of environments on learning and the implications for building schools for the future. *Oxford Review of Education, 33*(1), 47–70. https://doi.org/10.1080/03054980601094693.

*Woolner, P., McCarter, S., Wall, K., & Higgins, S. (2012). Changed learning through changed space: When can a participatory approach to the learning environment challenge preconceptions and alter practice? *Improving Schools, 15*(1), 45–60. https://doi.org/10.1177/1365480211434796.

*Zandvliet, D. B. (2012). Development and validation of the Place-Based Learning and Constructivist Environment Survey (PLACES). *Learning Environments Research, 15*(2), 125–140. https://doi.org/10.1007/s10984-012-9110-x.

*Zandvliet, D. B. (2014). PLACES and SPACES: Case studies in the evaluation of post-secondary, place-based learning environments. *Studies in Educational Evaluation, 41,* 18–28. https://doi.org/10.1016/j.stueduc.2013.09.011.

*Zandvliet, D. B., & Broekhuizen, A. (2017). Spaces for learning: Development and validation of the school physical and campus environment survey. *Learning Environments Research, 20*(2), 175–187. https://doi.org/10.1007/s10984-017-9228-y.