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Title:
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Date:
2025

Citation:
Murphy, D., Imms, W. & Mahat, M. (2025). Deeper learning by design: secondary pupils' study approaches across innovative and traditional learning spaces. Learning Environments Research, 28 (3), pp.773-793. https://doi.org/10.1007/s10984-025-09546-z.

Persistent Link:
https://hdl.handle.net/11343/357203

Learning Environments Research
https://doi.org/10.1007/s10984-025-09546-z

ORIGINAL PAPER

Deeper learning by design: secondary pupils' study approaches across innovative and traditional learning spaces

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Received: 8 April 2023 / Accepted: 30 June 2025

Abstract

Open and flexible school design, commonly labelled 'innovative', has gained popularity in the opening decades of this century, partly due to beliefs such physical spatial arrangements can help engender 'twenty-first century skills' such as critical thinking and deep learning. While the basis of such a link has often not been well articulated, established learning approach theory and research provide a rationale for why innovative learning space can create a context more conducive to deep learning. This study investigated the possible existence of such a relationship by examining learning approaches adopted by students across 23 secondary schools in Australia and New Zealand comprised of either predominantly innovative or traditional designs. Contemporary innovative school designs were associated with greater adoption of deep learning. Teachers working in schools where innovative design predominates reported greater adoption of dispositions and practices correlated with higher student achievement and deeper learning approaches. The paper concludes with discussion of implications for future learning environment research.

Keywords Deep learning · Learning environments · Learning approaches · Learning environments · Deep learning · Teacher mind frames

Introduction

The opening decades of the twenty-first century have seen a shift in school architecture in favour of open and flexible designs. Common features of contemporary learning spaces are less formal, more open and flexible layout with reconfigurable furniture and differentiated spaces enabling a wider variety of teaching approaches. Driving this trend has been a belief these design attributes, commonly labelled 'innovative', are conducive to the development of twenty-first century learning skills, including collaboration, creativity, critical thinking and deep learning. There is a widely held view that today's school students must develop these attributes to succeed amid rapid technological change and globalisation. Australian and New Zealand education authorities have endorsed a link between open and flexible learning spaces and these learning objectives (Murphy, 2020) but the nexus finds

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Published online: 28 July 2025

its most fervent support among educationalists and architects working in the field of learning space design. In its second compendium of exemplary education facilities, published in 2001, the Organisation for Economic Cooperation and Development (OECD) drew a link between the evolution of school design and social, economic and technological change which had rendered ‘existing educational buildings and tried and tested approaches for new building…no longer appropriate’ (OECD, 2001, p. vii). More emphatically, Nair (2011) declared the traditional classroom obsolete and unable to ‘deliver the creative and agile workforce the twenty-first century demands’ (para. 4).

Exactly how innovative school design aligns with current educational imperatives is often not well articulated. Dane (2016) observed flexibility and openness increased collaboration and technology rich activity among university students. Polycentric, less formal classroom design is thought to displace the position of the teacher, encouraging independent learning, collaboration among students and a view of the teacher as a facilitator rather than imparter of knowledge consistent with constructivist modes of learning (Alterator & Deed, 2016; Imms et al., 2016). Flexibility and multimodality enable differentiation of instruction to match individual students’ proficiency levels and learning preferences, as well as, self-directed learning, all widely endorsed contemporary educational objectives (Australian Government, 2018; Blyth, 2018; OECD, 2017).

A limited body of research evaluating the current wave of innovative school design has found some positive relationships between open and flexible space and learning outcomes. Case studies have detected improved academic performance and engagement after students were relocated to innovative learning spaces (Byers et al., 2014; Föβl et al., 2016; Whiteside et al., 2010). Larger quantitative studies across school systems have found open and flexible learning spaces facilitating individual and small group learning associated with higher test scores (Barrett et al., 2015; Tanner, 2008). In regard to twenty-first century learning attributes that provide the rationale for the expansion of innovative learning spaces, findings are limited. Surveying principals of 822 schools across Australian and New Zealand, Mahat and Imms (2021) found those leading schools comprising greater proportions of open and flexible space believed their students more likely to engage in deep approaches to learning.

Research on educational effects of contemporary innovative learning spaces has been criticised as disjointed and patchy (Bradbeer et al., 2017; Byers et al., 2018). Goodyear et al. (2018) state ‘academic research is lagging behind the innovative practical activities of architects and educational leaders,’ and ‘millions of dollars of taxpayers’ funds are being invested in building and renovation projects with questionable educational underpinnings’ (p. 22).

Cases of teachers and principals reacting negatively to more open, less formal learning spaces and retrofitting walls or using furniture to reinstate cellular classroom structures have been attributed to inability of principals to engage staff in the educational vision devised for the new schools, absence of professional development for teachers on how to use the new spaces and teachers’ rejection of the deprivatisation of their practice (Clarke, 2016; Daniels et al., 2017). This lack of consideration of teachers in the transition to new learning environments is reflected in the body of evaluative research, which has been criticised for failing to operationalise the role of teaching (Blackmore et al., 2011; Gislason, 2010; Lee & Tam, 2011).

By underappreciating the importance of teaching and claiming educational benefits incommensurate with research findings, innovative learning space proponents risk repeating the experience of the open plan school movement of the 1970s and 80s. This saw the creation of larger common teaching spaces intended to promote creativity, independence and self-confidence among students, although usually without the flexibility and breakout spaces favoured in contemporary school architecture. Research in this era found very few positive effects of open schooling on achievement, particularly measured through test scores (Neumann, 2003; Weinstein, 1979). Findings on purported relationships between open plan and creativity were mixed (Forman & McKinney, 1978; Ramey & Piper, 1974; Wright, 1975) although positive effects on behaviour and affective attributes were more common (Horowitz & Otto, 1973; Sommer & Olsen, 1980; Weinstein, 1979). Unable to substantiate claimed educational benefits, the open plan wave receded in the 1980s. Failure to adequately train and support teachers for the transition to large, multiclass settings is repeatedly cited as a reason for the open plan movement's demise (Gislason, 2009; Rodwell, 1998; Socol, 2014). Evaluation of open plan schooling was also criticised for neglecting to investigate how variance in pedagogical approach moderates the influence of the physical environment on learning and this oversight should not be repeated in the current era (Atkin, 2011; Imms et al., 2016).

It is important to avoid repeating mistakes of the past and creating a public policy hazard whereby billions of dollars are invested building and refurbishing schools on an educational rationale without sound foundation. Accordingly, more generalisable research testing claims that contemporary innovative learning spaces improve learning, particularly the acquisition of twenty-first century skills, and studying how teaching varies across different space types, is needed. This study addresses this gap.

Theoretical framework

The learning environment broadly defined entails many factors known to influence outcomes. Variations in light, temperature, air quality and noise levels have been found to affect students' attainment, concentration and affective response (Barrett et al., 2015; Heschong Mahone Group, 1999; Klatte et al., 2010; Uline et al., 2009). The claim of proponents of innovative learning space design however is that open and multimodal physical layout is conducive to acquiring twenty-first century skills and the current study focuses on testing this purported nexus. The well-established educational concept of deep learning is employed to gauge learner attributes advocates claim should be more common in innovative learning spaces. The moderating effect of variation in teaching approach across different learning space types is investigated using Hattie's (2012) concept of teacher mind frames; ways of thinking about and approaching teaching he identified as more likely to positively impact learning following his synthesis of meta-analyses of influences on achievement.

Deep learning

Learning approach theory provides a framework for assessing the quality of what students learn rather than the quantity of it. Key theorists (Biggs, 1987; Pask, 1976; Marton & Säljö, 1976; Entwistle & Ramsden, 1983), initially researching separately from the 1970s but later integrating their work, observed a distinction between surface and deep approaches students adopt towards learning tasks. The deep approach entails a desire to understand subject matter and is characterised by relating of new content to existing knowledge, critical interaction, development of logical argument and knowledge transfer. The surface approach is characterised by preference for memorising taught content for assessment by applying a basic level of effort and without intention to identify underlying principles or patterns (Beattie, et al., 1997).

Self-report instruments validated for measuring approaches to learning, including Biggs' (1987) Study Process Questionnaire (SPQ, tertiary level) and Learning Process Questionnaire (secondary) and Entwistle and Ramsden's (1983) Approaches to Study Inventory, have been applied widely, finding deep approaches associated consistently with higher attainment (Entwistle & Kozéki, 1985; Khezri azar et al., 2010; Watkins, 2001). As well as developing a coherent body of knowledge, use of these instruments has identified classroom correlates of deep approaches. These include constructivist pedagogy (Dart et al., 2000; Yerdelen-Damar & Aydun, 2015), problem-based learning (Biggs, 1991; Newble & Hejka, 1991), teachers' provision of feedback and clear explanations (Karagiannopoulou & Christodoulides, 2005; Smith et al., 2008), independent learning and student autonomy (Nijhuis, et al., 2008; Selmes, 1986), openness and teacher-student rapport (Entwiste & Tait, 1990), trust, cooperation and helpful relationships (Dart et al., 2000) and inter-student collaboration (Chan & Watkins, 1994). This accumulation of findings prompted learning approach theorists to declare, in the words of Entwistle and Waterson (1988), that 'the learning environment has profound effects on studying' (p. 264). Similarly, Biggs et al. (2001) stated

> It is therefore quite inappropriate to categorise students as 'surface' or 'deep' learners on the basis of SPQ responses, as if an approach score measured a stable trait of the individual. SPQ responses are a function of both individual characteristics and the teaching context…Thus, an approach to learning describes the nature of the relationship between student, context, and task (pp. 136–7).

Contemporary innovative learning spaces characterised by openness and flexibility are more conducive than traditional classrooms, with their rigid arrangements of desks, to multiple teaching and learning contexts associated with adoption of deep learning, including independence, use of feedback, building of trustful relations, collaboration, reciprocity, openness and rapport. Encompassing critical thinking and reasoning, which are routinely included in prescriptions of attributes learners need to succeed in contemporary society (Dumont & Istance, 2010; Fullan & Scott, 2014; Zhao, 2013), and demonstrated to vary with learning context, deep learning is an appropriate construct to employ in testing the claim that innovative learning spaces can facilitate development of twenty-first century skills.

Teacher mind frames

Reflecting on his synthesis of meta-analyses of influences on learning, Hattie (2008) noted a majority of the most effective were teacher qualities or teaching practices. Subsequently, he determined a set of ten teacher mind frames he characterised as 'theories of practice' that, if adopted by teachers and reflected in their work, 'are more likely to have major impacts on learning' (Hattie, 2012, p. 181–2):

1. I focus on learning and the language of learning
2. I see assessment as informing my impact and next steps
3. I build relationships and trust
4. I engage as much in dialogue as monologue

5. I am an evaluator of my impact
6. I am a change agent
7. I collaborate with my peers
8. I give and help students understand feedback
9. I strive for challenge and not merely 'doing your best'
10. I explicitly inform students what successful impact looks like (Hattie & Zierer, 2018).

While most are self-explanatory, mind frame 1 concerns differentiation of teaching and assessment strategies to meet students' learning abilities and preferences. While the mind frames contain elements common to other contemporary models of effective teaching practice (Danielson, 2014; Darling-Hammond, 2012; Terhart, 2011), they provide a particularly appropriate framework for investigating how teaching might interact with innovative learning space design to influence learning approaches. In research that directly informed Hattie's development of the mind frames, work of students taught by teachers certified under the United States National Board of Professional Teaching Standards exhibited significantly more attributes of deep learning, assessed using Biggs and Collis' (1982) structure of the observed learning outcome (SOLO) taxonomy, than those taught by non-certified teachers (Smith et al., 2008). Dimensions of teaching distinguishing most clearly between certified and non-certified teachers were challenging students, use of monitoring and feedback and use of deep representations (multiple strategies to make learning relevant and anticipate difficulties); all teaching approaches encompassed by the mind frames Hattie later settled on. The mind frames encompass several teaching approaches that can be considered compatible with open and flexible design and that have demonstrated positive associations with deep learning including use of feedback, building of reciprocal relations (Karagiannopoulou & Christodoulides, 2005), teacher openness (Entwistle & Tait, 1990), building trust (Dart et al., 2000) and collaboration (Watkins & Hattie, 1990).

A model for how innovative learning space and teacher mind frames might interact to encourage deep learning

How innovative space and greater adoption of the mind frames among teachers might increase the likelihood of students adopting a deep approach to their studies can be explained using the sequential 3P model of learning advanced by Biggs (1993). As illustrated in Fig. 1, the model posits that 'presage' personal and contextual factors influence the 'process' of learning, or the approach a student takes to the learning task. 'Product' encompasses outcomes of the learning process, primarily students' work, the quality of which may be assessed using a framework such as the SOLO taxonomy (Biggs & Collis, 1982). The main thrust of learning is forward as indicated by the arrows.

Elements tend to be in equilibrium and students' personal characteristics largely stable. The latter are known to influence adoption of learning approaches: research has shown deep learning to be positively influenced by intrinsic academic motivation (Marton & Säljö, 1984) and parents' education level (Biggs, 1987) and surface approaches associated with anxiety (Fransson, 1977).

Under the 3P model, the classroom climate is a presage factor influencing the learning process, and climate characteristics that have demonstrated a positive association with deep learning—trust, rapport, openness and student collaboration—can be considered aligned with, or more easily facilitated in, open and flexible learning spaces that enable multiple learning modes rather than a rigid arrangement of chairs and tables in rows facing

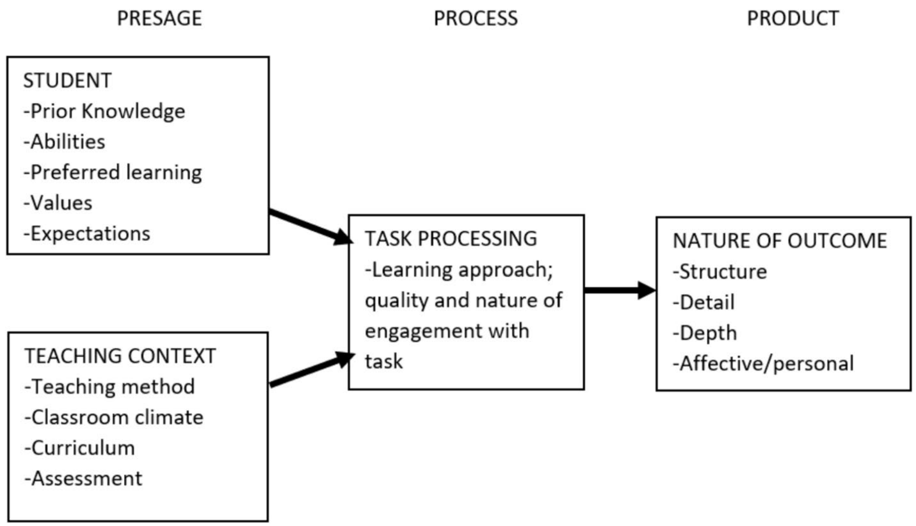

Fig. 1 3P model of learning (from Biggs, 1993)

a teacher. Similarly, collaborative teaching, dialogue, feedback and differentiation—all teaching correlates of deep learning encompassed by Hattie's mind frames—can be considered better aligned with informal physical arrangement. Biggs' 3P model thus provides a theoretical basis for why being taught in innovative learning spaces by teachers reporting greater adoption of Hattie's mind frames could on average support greater adoption of deep learning approaches.

Aims

The aims of this study were to: (1) gauge differences in students' adoption of deep and surface approaches to learning across innovative and traditional learning spaces, (2) compare how teachers approach their work across traditional and innovative learning spaces employing Hattie's concept of teacher mind frames and (3) investigate if teachers' adoption of the mind frames interacts with learning space type to influence students' learning approaches.

Methods

Participants

Given the key outcome of interest in the study was variation in deep learning, it was conducted in secondary schools. Piaget (1952) ascribed the age at which formal reasoning and deduction become possible in children as 11–12, and in explicating the SOLO taxonomy, Biggs and Collis (1982) put the age at which students develop the ability to interrelate concepts at 13–15 years. These cognitive capacities are prerequisite for deep learning; hence, variation in learning approaches is more evident among secondary school students.

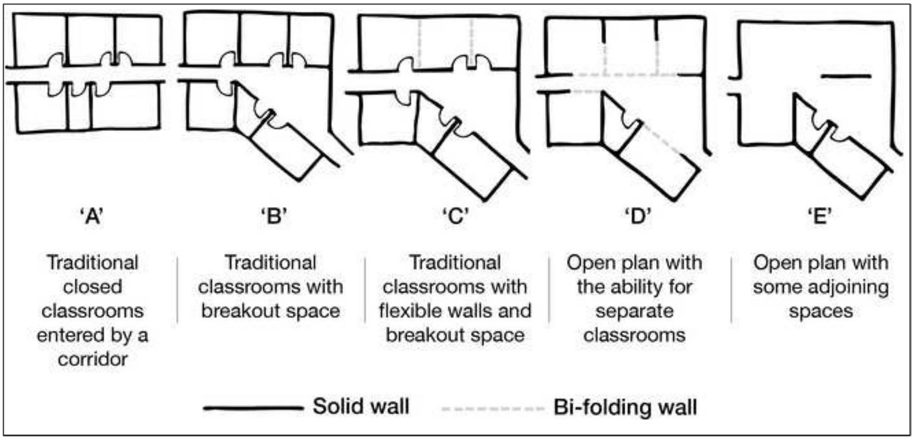

Fig. 2 Typology of learning spaces, from Imms et al. (2017). Reproduced with permission

In most Australian states, Year 11 is the level of schooling from which students' performance can contribute to their final qualifications. Prior research has found formal assessment with consequences attached associated with greater surface and less deep learning (Marton & Säljö, 1984; Selmes, 1986). To mitigate influence of high stakes assessment on the approach students adopt, the study was conducted among Year 10 students in Australia in and the corresponding Year 11 in New Zealand, where schooling runs from Year 1 to 13.

Initially, schools suitable for the study were identified from respondents to the School Design and Use Survey (SDU) conducted by the Innovative Learning Environments and Teacher Change Project at the University of Melbourne. This asked a principal or nominee in all schools within the project's partner jurisdictions[1] to ascribe the proportions of learning spaces present within their school according to the typology in Fig. 2 (Imms et al., 2017).

Secondary schools responding to the SDU survey comprised entirely or predominantly of either innovative type D and E spaces or traditional classrooms (types A-C) were approached to participate, yielding nine predominantly innovative and six predominantly traditional design schools agreeing to participate in the current study. Additional schools known to be comprised totally or predominantly of innovative or traditional spaces were approached, resulting in a final sample of 10 and 13, respectively, 16 in Australia and seven in New Zealand. These additional schools had a principal or nominee categorise their learning space composition as per Fig. 2. At least one class of students in the appropriate grade from each participating school taught in the school's predominant learning environment type was required to complete the Learning Approach Questionnaire (LAQ), gauging the degree to which they held deep and surface approaches towards their studies. Teachers of the students that took the LAQ were required to complete a survey gauging the degree to which their attitudes and approach to teaching align with Hattie's mind frames. Additional teachers, who had teaching contact with some or all of the students who completed the

[1] The government education systems in the Australian jurisdictions of New South Wales, Queensland and Australian Capital Territory, New Zealand Ministry of Education and Catholic Education—Diocese of Parramatta.

LAQ in the school's predominant learning space type, were requested to take this survey. The learning space composition of the participating schools, along with the numbers of students and teachers taking part in each is provided in Table 1.

Learning approach instrument

Most of the quantitative self-report instruments used to gauge student approaches to learning have been designed for and applied among tertiary students. Kember et al.'s (2004) Revised Two-Factor Learning Process Questionnaire (R-LPQ-2F) measures secondary students' adoption of deep and surface approaches and comprises 11-item surface and deep scales both composed of subscales gauging surface and deep learning motives and strategies. Students respond to items on a five-point Likert scale, ranging from (1) this item is never or only rarely true of me, to (5) this item is always or almost always true of me. All items are positively worded.

In a trial of the R-LPQ-2F among 162 New Zealand Year 11 students, surface motive subscale items loaded with deep scale items or not saliently at all, contributing to lower Cronbach's alpha for the surface scale (0.64) and unsatisfactory model fit. This is consistent

Table 1 Participants and learning space composition of schools

			School space type composition (%)				
School	N Students	N Teachers	A	B	C	D	E
Innovative design schools							
1	21	7	0	0	0	0	100
2	47	4	0	0	0	0	100
3	28	1	0	0	0	0	100
4	36	3	0	0	0	0	100
5	134	8	0	0	0	0	100
6	61	4	0	0	0	0	100
7	32	5	0	0	0	30	70
8	24	5	10	0	0	20	70
9	23	4	0	0	0	100	0
10	20	3	0	15	5	80	0
Traditional design schools							
1	28	4	80	10	10	0	0
2	26	3	85	5	0	10	0
3	17	–	85	15	0	0	0
4	23	8	100	0	0	0	0
5	20	5	100	0	0	0	0
6	18	2	100	0	0	0	0
7	18	3	100	0	0	0	0
8	26	4	100	0	0	0	0
9	32	4	100	0	0	0	0
10	20	6	35	5	60	0	0
11	21	5	70	5	10	10	5
12	21	4	90	0	0	10	0
13	19	1	10	0	90	0	0

with weaker reliability of the surface motive subscale in the initial validation trial (0.58, Kember et al., 2004) (attributed to multidimensionality within items and the subscale comprising only four items) and values as low as 0.42 in subsequent use (Phan & Deo, 2007). In response, we pursued a two factor learning approach questionnaire that dispensed with items gauging personal precursors of a surface motive (i.e. anxiety) or deep motive (intrinsic academic motivation). Removing poorly performing, mostly motive subscale, items from the R-LPQ-2F and sourcing two additional items from Biggs' (1987) original Learning Process Questionnaire and one from Entwistle et al.'s (2000) Approaches and Study Skills Inventory for Students, a 16-item Learning Approach Questionnaire (LAQ) was developed. Items do gauge motives of deep and surface learning but in terms directly relating to the study process, with the intention that the LAQ be used only to gauge distinct surface and deep learning approaches. The five-point Likert response scale was retained. Sample items for the deep and surface scales are provided in Table 2, and the complete16 item LAQ settled on is included as Appendix 1.

In a trial among 46 Australian year 11 students a clear two factor pattern was obtained using maximum likelihood extraction and promax rotation in SPSS 25, with all items loading as intended. Cronbach's alpha values were 0.77 for the deep approach scale and 0.75 for the surface. The factors were negatively correlated (− 0.28). These results were considered a satisfactory basis for employing the LAQ and results of confirmatory factor analysis (CFA), using the lavaan package in R, using data from the 715 students who took part in this study, were satisfactory: $X^2 = 368.50$, $df = 103$, $p < 0.0001$, RMSEA = 0.06 SRMR = 0.06 (Hu & Bentler, 1999).

Teacher mind frames instrument

Preliminary surveys were used to identify items measuring the degree to which teachers report adopting the eight mind frames Hattie (2012) identified in his initial outlining of the concept. This process drew on Hattie and Zierer's (2018) discussion of how particular teaching beliefs and practices identified in Hattie's (2008) synthesis support particular mind frames. Subsequently, an eight scale, 34 item survey was trialled on a sample of 282 teachers. The eight mind frames gauged (with sample items) are included as Table 3.

Responses were given on a six-point Likert scale, (Never = 1, Rarely = 2, Sometimes = 3, Often = 4, Very often = 5, Always = 6), the scale range allowing for the most detailed responses before, according to Simms et al. (2019), an 'asymptotic point of diminishing returns' (p. 564) to precision and psychometric properties is met. Three negatively worded items were reverse coded for the purposes of factor analysis and all subsequent analysis.

Table 2 Sample items, deep and surface scales of Learning Approach Questionnaire

	Sample item
Deep scale	I try to relate new material, as I am reading it, to what I already know on that topic
Surface scale	I see no point in learning material which is not likely to be in the examination

Table 3 Sample items, scales of teacher mind frames survey

	Sample item
I focus on learning and the language of learning	When I plan student learning I employ multiple ways to work out if they have made progress
I see assessment as informing my impact and next steps	I reflect on student data to inform my practice
I build relationships and trust	All students in my class feel respected by other students
I engage as much in dialogue as monologue	I encourage classroom discussion to complement my instruction
I am an evaluator of my impact	When I gather student data, I see it as a result of my teaching
I am a change agent	You can greatly change how intelligent you are
I collaborate with my peers	I actively share learning with my colleagues
I give and help students understand feedback	I integrate feedback into my lessons

The initial solution indicated eight factors with eigenvalues greater than one explaining 64 per cent of total variance using SPSS 25. An eight-factor maximum likelihood solution with promax rotation provided satisfactorily simple structure (Thurstone, 1947), with all items loading as intended and scale alpha values no lower than 0.72. Maximum likelihood CFA carried out using the lavaan package in R indicated satisfactory model fit: $X^2 = 909.4$ ($p < 0.001$, $df = 499$), RMSEA = 0.05, SRMR = 0.06. The factor correlation matrix indicated strong positive relationships among all factors except 'I am a change agent', suggesting a general higher order factor or factors. The initial solution obtained from maximum likelihood factoring the factor correlation matrix suggested a one or two factor solution explaining 45% and 59% of total variance, respectively. A one factor solution gave a simpler structure and explains almost half the variance among the eight mind frames, suggesting an overarching orientation towards effective teaching influences the adoption of the individual mind frames. Maximum likelihood CFA results for the higher order one factor solution were within accepted limits: $X^2 = 1021.87$ ($p < 0.001$, $df = 519$) RMSEA = 0.059 and SRMR = 0.071.

Results

This section discusses the results responding to the three aims of the study. Firstly, data analysis was used to gauge differences in students' adoption of deep and surface approaches to learning across innovative and traditional learning spaces. To do this, LAQ scale scores across learning space types were compared using responses aggregated at the school level. Learning approach scores were the aggregate responses to the eight items, with unitary weighting applied (Gorsuch, 1983). Deep learning approaches were significantly higher among students taught in innovative learning spaces, as detailed in Table 4. The effect size for innovative learning space on deep learning (Cohen's *d*) was 1.0. No significant difference was observed in surface approach scores, suggesting that engagement with studies at greater depth does not come at the expense of pragmatic approaches to studies where students deem it appropriate.

Table 4 Mean Learning Approach Questionnaire scale scores, students in innovative learning space and traditional classroom-predominant schools

	Mean (SD)	Mean difference (SE)	*t*	*p*	*d* (95% CI)
Deep learning					
Innovative	24.74 (1.98)	1.86 (.77)	2.40	0.03	1.0 (.12 to 1.88)
Traditional	22.89 (1.73)				
Surface learning					
Innovative	22.01 (1.52)	− 0.51 (.50)	− 1.02	0.32	− .43 (− 1.26 to .41)
Traditional	22.52 (.87)				

Secondly, analysis of data was used to compare teacher mind frames across traditional and innovative learning spaces. Teachers' adoption of Hattie's mind frames across differing working environments was compared using data at the individual level. Mean scores on the eight mind frames factors are contained in Table 5 along with results of ANOVA for all eight mind frames between subjects. The means are somewhat similar for seeing assessment as feedback to the teacher, building relations and trust and evaluating their impact, but the teachers in the innovative environments rated higher on focussing on learning, engaging in dialogue, seeing themselves as change agents and collaborating with their peers. Between-subjects effects were significant after Bonferroni correction for the dialogue and focus on learning mind frames. Multiple analysis of variance (MANOVA) conducted with the eight mind frame scale scores as correlated dependent variables indicated overall adoption of the mind frames varied significantly according to learning space type: $F(8, 84) = 2.62$, $p = 0.013$, Wilk's $\Lambda = 0.801$, partial $\eta^2 = 0.199$.

Finally, the data were analysed to investigate if teachers' adoption of the mind frames interacts with learning space type to influence students' learning approaches. Hierarchical linear modelling (HLM) was employed to estimate the effect of school design on adoption of deep learning approaches while accounting for sources of common variance among students of the same school and to investigate the possible moderating influence of teachers' adoption of the mind frames and levels of socio-educational advantage. Four schools from which less than three teacher mind frames surveys were returned were excluded. The 19 schools retained comprised 633 students (398 in innovative schools/235 traditional) and 89 teachers (43/46). In upper secondary school, students are taught by a variety of subject teachers, and it was not possible to assign students an individual level mind frames score based on the responses of a teacher they are taught by exclusively or even mostly. Accordingly, a mean school score mind frames score was employed.

Unconditional two and three level models revealed greater variation in deep learning approaches explained by differences between schools (intraclass correlation 0.10) than countries (0.07) with the former meeting accepted levels for conducting HLM (Spybrook & Raudenbush, 2009). A two level model was estimated with students clustered in classes, with their deep learning scores as the dependent variable and a categorical dummy variable for learning space type (traditional = 0/innovative = 1) as the only predictor. Estimated deep scale scores were 2.1 points higher among students in schools where innovative learning spaces (ILS) predominate and statistically significant at $\alpha = 0.05$ (see Table 6 model 1).

Prior research had indicated higher levels of parental education positively associated with adoption of deep approaches (Biggs, 1987). However, official measures of students' parental educational and occupational backgrounds employ different methodologies in Australia and New Zealand. In Australia, the index of community socio-educational

Table 5 Mean mind frames scales and general mind frames factor scores, results of between subjects ANOVA (individual mind frames) and independent samples *t*-test (general mind frames factor)

		Mean (SD)	Mean difference (SE)	*F*	*p*	*d* (95% CI)
I focus on learning, language of learning	Innov	18.93 (3.09)	1.87 (.59)	10.01	< .01	.66 (.24 to 1.10)
	Trad	17.06 (2.61)				
Assessment informs impact, next steps	Innov	21.39 (3.92)	.84 (.79)	1.10	.30	.22 (− .19 to .63)
	Trad	20.55 (3.76)				
I build relationships and trust	Innov	17.14 (2.63)	.38 (.59)	.421	.52	.14 (− .27 to .54)
	Trad	16.76 (2.30)				
I engage as much in dialogue as monologue	Innov	20.64 (2.71)	2.06 (.60)	12.02	< .01	.72 (.30 to 1.14)
	Trad	18.57 (3.00)				
I am an evaluator of my impact	Innov	16.05 (2.98)	− .18 (.65)	.076	.78	− .06 (− .46 to .35)
	Trad	16.22 (3.25)				
I am a change agent	Innov	19.05 (3.58)	1.70 (.81)	4.37	.04	.43 (.02 to .85)
	Trad	17.35 (4.19)				
I collaborate with my peers	Innov	19.23 (3.50)	1.31 (.64)	4.16	.04	.42 (.01 to .83)
	Trad	17.92 (2.67)				
I give and help students understand feedback	Innov	25.07 (3.59)	.80 (.70)	1.31	.26	.24 (− .17 to .65)
	Trad	24.27 (3.17)				
		Mean (SD)	Mean difference (SE)	*t*	*p*	*d* (95% CI)
General mind frames factor	Innov	138.43 (16.88)	7.08 (3.29)	2.16	.03	.45 (.03 to .86)
	Trad	131.35 (14.82)				

Table 6 Fixed effect estimates HLM, Australia and New Zealand

	Australian and New Zealand schools	
	Model 1	Model 2
Intercept	22.77* (.65)	22.96* (.76)
Innovative space	2.05* (.92)	1.68 (1.09)
Teacher mind frames		.05 (.09)
Innovative space*Teacher mind frames		− .01 (.11)
− 2 restricted log likelihood	4021.7	4027.7
	Australian schools only	
	Model 3	
Intercept	23.58* (.81)	
Innovative space	1.61 (1.11)	
ICSEA	.005 (.01)	
− 2 restricted log likelihood	3123.2	

Standard errors in parentheses. *$p < .05$

advantage (ICSEA) published by the Australian Curriculum and Reporting Authority (ACARA) is calculated at a school level based on every student's socio-educational advantage (SEA) index score, a composite based on their parents' occupation and educational level. A school's ICSEA score is their mean student SEA score adjusted for remoteness and percentage of indigenous students. (ACARA, 2013). ACARA does not release individual students' SEA scores, meaning school level means had to be employed. In New Zealand, schools are assigned SEA deciles by the Ministry of Education based on census income and parent education and occupation data for the community a school serves.

The effect of socio-educational advantage was modelled among the Australian sample (14 schools, 493 students) employing the official ICSEA measure, assigned at the school level. The estimate for the effect of school ICSEA (grand mean centred) on deep learning outcomes was negligible among these students (see Table 6, model 3). Modelling was not repeated among the smaller New Zealand subsample (5 schools, 140 students), in which the correlation between school deep learning scale means and SEA decile was 0.10. Combined, these results suggested it was not necessary to include SEA as a control variable and it was omitted from further modelling.

Teachers' mind frames were then introduced as a predictor variable using grand mean centred school average scores on the general mind frames factor. This would test the hypothesis supported by the 3P model that deep learning would be greater among students taught in innovative learning spaces by teachers reporting greater adoption of the mind frames. The equation for this model's estimation of the deep learning score for student i in school j can be written as

$$\text{deeplg}_{ij} = \beta_0 + \beta_1\left(\text{ILS}_{ij}\right) + \beta_2\left(\text{TMF}_{ij}\right) + \beta_3\left(\text{ILS}_{ij}\right)\left(\text{TMF}_{ij}\right) + u_{oj} + r_{ij}$$

where β_0 is a constant, β_1 the difference associated with being taught in innovative relative to traditional space for a student with the mean teacher mind frames score, β_2 the association coefficient for teacher' mind frames when $\beta_1= 0$ (i.e. in traditional space only) and β_3 the coefficient for the effect of teacher mind frames on deep learning for students taught in innovative learning spaces only. u_{oj} and r_{ij} represent residual error variance at the school and student level, respectively. As innovative space (ILS_{ij}) and teacher mind frames (TMF_{ij}) are school level variables, this model estimates the same deep learning score for all students within a given school.

Results for model 2 in Table 6 indicate no significant effect on deep learning due to teachers' adoption of the mind frames in either type of learning space. Although teacher mind frames and deep learning are higher within ILSs, there is no significant covariance between them. Of the variables specified, the model estimates almost all of the difference in deep learning to be due to differences in design of the space students learn in. This model, introducing teaching approach as a variable, albeit limited by employing school level mind frames scores, does not provide greater explanation for variation in students deep learning than model 1, indicated by the relative-2 restricted log likelihood values.

This study's comparison of students' adoption of learning approaches and teachers' adoption of Hattie's mind frames, across innovative and traditional learning spaces, and modelling of interaction between these found:

- Greater adoption of deep learning approaches among students being educated in innovative learning spaces
- Greater adoption of teaching approaches, or mind frames, identified by Hattie as more likely to have major positive impact on learning among teachers working in innovative learning spaces
- No significant effect on students' adoption of deep learning approaches resulting from interaction between innovative learning space and teachers' adoption of the mind frames.

Discussion

Deep approaches to learning were significantly greater among secondary school students taught in open and flexible learning spaces than those attending schools where traditional cellular classrooms predominate. Despite a link between innovative design and higher quality learning being advocated widely, this is one of the first studies investigating such a relationship. However, it is consistent with principals' perceptions of greater deep learning among students in Australian and New Zealand schools where innovative design predominates, reported by Mahat and Imms (2021).

Also noteworthy is the absence of any significant difference in surface learning approaches across space types. Most learning approach theory sees surface and deep learning existing in hierarchy (Biggs, 1996; Entwistle, 2018; Marton & Booth, 1997; Pask, 1976). Indications that surface learning is discouraged in innovative spaces may have led to speculation the deeper learning they support comes at the expense of pragmatic learning, is not built on adequate essential knowledge or is affected by what Pask (1976) termed globe-trotting, misunderstood or vacuous attempts to exhibit deep understanding.

Greater adoption of Hattie's mind frames among teachers working in less formal, more open educational settings suggests learning space design influences adoption of a range of pedagogical approaches associated with greater positive impact on learning. Some advocacy of innovative learning spaces, such as the suggestion by the OECD (2006) that these have an 'important role to play in facilitating innovative pedagogical methods' (p. 12) contain a degree of architectural determinism; that by changing the space in which teachers work, their practice will be transformed. This result lends some support to this contention. Teachers in innovative learning spaces report higher belief in, and use of, approaches widely considered part of effective contemporary teaching practice (Danielson, 2014; Darling-Hammond, 2012; Hattie & Zierer, 2018; Terhart, 2011), particularly greater use of dialogue and differentiation. This should be of interest to education authorities seeking to increase the use of these teaching approaches.

That learning context influences the approach a student adopts is endorsed by leading learning approach theorists (Biggs et al., 2001; Entwistle & Waterston, 1988; Marton & Säljö, 1976), and made explicit in Biggs' (1993) 3P model of learning. The results of the present study support this link between learning environment and students' adoption of a deep or surface approach. The absence of an effect of teacher mind frames, particularly in innovative learning spaces where they are more common, suggests at face value that the greater deep learning observed in these is not due to variation in the way teachers approach their work but other factors, contrary to expectations under the 3P model. Limitations in data availability, particularly not being able to link individual teachers' mind frame scores at the student level and limited teacher sample sizes available for some schools, should temper the implications drawn from this result. Also, measures of the degree to which individual teachers' practices align with the mind frames beyond the self-report instrument employed, such as rating by students or classroom observation, would have been optimal but were not available in this instance.

Other limitations of the study include that which attaches to all non-experimental research in the behavioural sciences: the possible influence of extraneous sources of variance. In particular, the influence of school and system cultures is not discounted. Innovative design schools often elevate the importance of twenty-first century skills and innovative teaching approaches in their policy and discourse. Over time, this is likely to attract teachers who share these objectives.

Conclusion

This study's headline finding of greater adoption of deep learning approaches among students in innovative learning spaces provides some empirical support for proponents who posit that open and flexible school design can help engender higher quality learning outcomes. Over the past two decades, a wide variety of educationalists, authorities and architects have endorsed a link between innovative school architecture and twenty-first century skills, including deep learning and critical thinking despite a lack of supporting research. Theoretical cases for why such a relationship might exist have also been largely absent from the literature. Still, as explicated here, learning approach theory emphasises the importance of context to the approach a student adopts towards study tasks. In view of this and the body of research establishing correlates of deep learning, the result here is not surprising. Teachers working in open and flexible learning spaces reporting greater belief in and application of effective pedagogical approaches encompassed by Hattie's mind frames should be of interest to education authorities seeking to encourage these.

The study's most useful contribution might be to point the way forward for future learning environment research. Greater understanding of which factors present in innovative learning spaces might covary with deep learning is needed. There is a view among scholars in the field that the alignment with certain pedagogical approaches will best realise the educational potential of innovative learning spaces to improve the quality of learning (Atkin, 2011; Mahat & Imms, 2021). Failure to find an interaction here between teacher mind frames, innovative design and deep learning suggest a broader range of possible explanatory factors that may vary across learning space types to influence learning need to be employed in future research, including environmental elements (light, noise, air quality), student background, school culture and students' affective response to their surrounds. However, given the limitations on teaching data used in this study, pedagogical approaches should still be operationalised, focussed on those that demonstrated the greatest variance across learning space types here: use of dialogue, differentiation and collaboration with peers. In all cases, data should be sought at the most granular level possible to enable effective modelling of effects on learning.

Modelling using large multivariate datasets as employed by Barrett et al., (2015) should be complemented by smaller scale studies allowing for random allocation of participants where possible. Such scale better facilitates use of objective measures of teaching and learning approaches through observation and assessment of student work samples (product under the 3P model), respectively, and can provide stronger grounds for claiming causation. With many education jurisdictions progressively upgrading school facilities, opportunities exist to research variation in learning outcomes and teaching approaches across systems where learning space design differs but curriculum, assessment and other aspects of policy are constant.

The educational imperative, which demands schooling be transformed to impart skills such as deep learning, critical thinking and collaboration that students will need to succeed in twenty-first century economies and societies, and which has driven the trend towards innovative learning spaces, is still being widely affirmed (Brookings Institution, 2022; Masters, 2022; UNESCO, 2021). Education authorities serious about supporting deeper and higher quality learning, particularly in secondary education when capacities for these are greater, need to consider the role innovative learning spaces can play in realising this goal.

Appendix 1: Learning Approach Questionnaire

Responses on five-point Likert scale:

1. Never or only rarely true of me
2. Sometimes true of me
3. True of me about half the time
4. Frequently true of me
5. Always or almost always true of me.

Deep approach	Surface Approach
I come to most classes with questions in mind that I want answering	As long as I feel I am doing enough to pass, I devote as little time to studying as I can. There are many more interesting things to do
I work hard at my studies because I find the material interesting	I like to be told precisely what to do in assignments**
When I read a textbook, I try to understand what the author means	I prefer subjects in which I have to learn just facts to ones which require a lot of reading and understanding material*
I like to do enough work on a topic so that I can form my own conclusions before I am satisfied	I see no point in learning material which is not likely to be in the examination
I try to relate what I have learned in one subject to what I learn in other subjects	I find it is not helpful to study topics in depth. You don't really need to know much in order to get by in most topics
I like constructing theories to fit odd things together	I think that teachers shouldn't expect secondary students to work on topics that are outside the set course*
I try to relate new material, as I am reading it, to what I already know on that topic	I find I can get by in most assessment by memorising key sections rather than trying to understand them
I feel that nearly any topic can be highly interesting once I get into it	I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra

Items from Kember et al. (2004) except *Biggs (1987) and **Entwistle et al. (2000)

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

Declaration

Conflict of interest All authors declare that they have no conflicts of interest in relation to this article.

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