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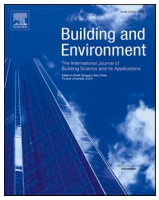

Comparison of open, flexible, and enclosed learning spaces – teaching staff's experiences and activity sound exposure

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ABSTRACT

Learning spaces can be categorized into open, flexible, and enclosed spaces. Enclosed space enables teaching one 20–30 students' group while open space enables teaching several groups in the space simultaneously. Flexible spaces offer a possibility for closing and opening the space. This study examined whether teaching staff's experience and sound exposure differ in learning space types. The questionnaire responses from primary schools' teaching staff working in enclosed space (enclosed environment group, $N = 267$) were compared with teaching staff working in flexible or open spaces (innovative environment group, $N = 94$) (total $N = 361$). Additionally, the activity sound pressure levels (SPLs) were measured in 20 schools' four learning spaces for five workdays. The innovative environment group was less satisfied with sound environment, amount of space, functionality of transit routes and more disturbed by environmental factors than the enclosed environment group. Almost a third (29 %) of the innovative environment group perceived that their learning space did not support the pedagogical methods they wanted to use, while this was 15 % in the enclosed environment group. The learning environment groups did not differ in noise annoyance related to different places in school, nor the prevalence of vocal symptoms. The activity SPLs in the open learning spaces were lower or similar than in the enclosed learning spaces but did not differ between enclosed and flexible learning spaces. Negative experience in innovative learning environments is not related to higher noise levels, but to environmental distractions, therefore, open learning spaces' design should always consider cognitive ergonomics along with action possibilities.

1. Introduction

Many new schools have new innovative learning environments, which are designed to enable a larger range of pedagogies than traditional enclosed learning environments [1]. These innovative learning environments enable student-centered pedagogies with flexible use of space, adaptability and spatial flow from one practice to another [2]. **Innovative learning environments** here mean **open or flexible learning spaces.** These learning spaces offer possibilities for teaching different groups sizes or numbers of groups at a time (see, e.g., [2] for types of learning spaces). Here o**pen learning spaces** are defined to have open floor plans without partition walls, which enable teaching at least two groups of 20–30 students at the same time and which cannot be closed into 25 student spaces (see Fig. 1c for an example). Spaces that enable opening and closing the space with solutions such as sliding walls are called **flexible learning spaces** (see Fig. 1b for an example). Flexible learning spaces enable teaching multiple or large groups at the same time as well as dividing the space for a smaller group only. Innovative learning environments are designed to enable student-centered pedagogies, which enclosed learning spaces are thought to constrain [2]. **Enclosed learning space** is here a space for one 20–30 student group, which is separated with walls and doors (and ceiling), as traditional classrooms are (see Fig. 1a for an example). They are related to traditional teacher-centered pedagogies, which open-plan learning spaces are thought to constrain [2]. Person-environment fit theory states that when the needs of a person and opportunities for their achievement create a match, fit is high, and stress is low [3]. A possibility to use a larger set of pedagogies could mean that teachers experience more often fit with their environments in innovative than in enclosed learning spaces (Hypothesis 1 (H1)).

Enclosed learning spaces are criticized for their inadaptability. On the other hand, open learning spaces are criticized for noise

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disturbances, especially intrusive noise from adjacent groups, reduced speech intelligibility and privacy, which cause distraction and dissatisfaction to both students and teachers [4] (H2). Experiences related to open, flexible, and enclosed learning spaces have been mostly examined from students' point of view [5,6], with qualitative approach [6]. There is a lack of studies quantitatively comparing teachers' experiences of their environments in different learning space types. Teachers' experiences might differ from students' experiences, as, for example, teachers are more disturbed and distracted by noise than students are [7].

From a room acoustic perspective the learning spaces are either open or enclosed spaces. Flexible spaces' categorization depends on their use mode. In open learning spaces, the adjacent groups' activity might influence the learning spaces' sound pressure levels (SPLs) [8]. Average activity SPLs reported from schools' general learning spaces range from 64 to 72 dB L_{Aeq} [9–12]. L_{Aeq} denotes the A-weighted equivalent continuous SPL. No difference was found in the average lesson SPLs measured in open learning spaces (40 lessons' average 63.2 dB L_{Aeq}) compared to enclosed learning spaces (234 lessons' average 64.4 dB L_{Aeq}) [10]. However, the speech-to-noise ratio estimated with the difference between L_{Aeq} and L_{A90} in a condition, when one person was speaking, was lower in open learning spaces (9.9 dB) than in enclosed learning spaces (13.9 dB) [10]. L_{A90} is the A-weighted SPL that is exceeded 90 % of the measurement period and here it describes the SPL of ambient background sounds. The intrusive noise coming from adjacent groups' work with movement can be 10 dB L_{Aeq} higher than intrusive noise from activity where one person is speaking at a time [8]. Even though the average activity SPLs can be expected to be similar in open and enclosed learning spaces [10] (H3), the situation might be different with different activity types.

In general, activity sounds are important in schools. In areas without a high environmental noise burden, outside noise was related to classroom sound level only during the quiet activity [9]. Therefore, the primary sound source in an enclosed learning space is the learning group working there. The most annoying sound sources in schools also come from students' activity with the most annoying being students' speech or chatter [7,13]. The influence of activity type on the average SPL of the learning space ranges from 5 dB L_{Aeq} in secondary schools to 20 dB L_{Aeq} in primary schools [9,10,13]. Activity-based learning with several people talking and moving at the same time showed the highest SPLs [9, 13]. Innovative learning environments are supposed to support student-centered learning, where activity-based learning is commonly used. Therefore, it is important to examine the SPLs during different activity types in different learning space types. Sounds of activity-based work from adjacent groups can raise the SPLs of the open learning areas [8], so open learning spaces were expected to have higher SPLs during calm activity than enclosed learning spaces (H4).

From a teachers' perspective, noise is a risk for health and well-being. School teachers' noise exposure in general classrooms posed no risk of noise induced hearing impairment but it was associated with vocal load, development of vocal symptoms, and cognitive fatigue [12]. Teachers' higher self-rated noise exposure has been related to lower job satisfaction, lack of energy after work, and an interest in leaving their job [14]. The high number and young age of children in the class, and low teacher seniority were positively associated with teachers' self-reported noise exposure [15]. Open learning spaces can fit more students than enclosed learning spaces. Additionally in open learning spaces, the adjacent groups' activity might also influence the SPLs [8]. Therefore, noise annoyance and self-reported noise exposure could be higher in innovative than enclosed learning spaces (H5).

Additionally, noise in schools is a risk factor for teachers' voice [16] as activity SPLs in learning spaces are so high that they cause a risk for occupational voice disorders [11]. A recent scoping review on the effects of acoustics on teachers' well-being showed that vocal health is the most common symptom studied [17]. Every fifth teaching professional reported suffering from voice problems [18]. Voice problems are also a factor related to teachers' absenteeism [19]. Most studies examining teachers' vocal health and acoustic conditions showed either no effect or a negative relation, meaning worse acoustic conditions caused more vocal symptoms [17]. However, activity SPLs are not necessarily directly related to vocal symptoms, as pedagogical activities might also influence vocal strain. During the day, teachers in louder ambient noise raised their voice level, whereas teachers in louder activity noise changed less their voice level [16]. Here ambient noise refers to noise from sources other than the current classroom activity, such as noise from equipment, appliances, adjacent groups, and outside the building. Therefore, the prevalence of voice problems needs to be compared in innovative and enclosed learning environments. As the background SPL during activity is assumed to be higher in the innovative than in enclosed learning environments due to the intrusive sounds from other groups activity [10], the vocal symptoms were assumed to be more prevalent in the teaching staff of innovative than enclosed learning spaces (H6).

Our aim was to examine whether teaching staff's experience and activity sound exposure differ in learning space types. We did this using quantitative methods as previous research on teachers' experience has concentrated on qualitative methods [6]. Our research questions were:

1. Do teaching staff working in innovative learning environments differ in the experience of their working environment from teaching staff working in enclosed learning environments?
   - H1: Teaching staff feels more often fit with their environment in innovative than in enclosed learning spaces.
   - H2: Dissatisfaction is higher in innovative than enclosed learning spaces.
2. Do teaching staff working in open or flexible learning spaces differ in sound exposure from teaching staff working in enclosed learning spaces?
   - H3: Average activity SPLs do not differ in open and enclosed spaces.
   - H4: Open spaces have higher SPLs during calm activity than enclosed spaces.

a) Enclosed learning space b) Flexible learning space c) Open learning space

Fig. 1. Examples of a) enclosed, b) flexible, and c) open learning spaces. Please, notice that these are just examples, and they do not represent the whole variety of these learning space types.

3. Do teaching staff working in innovative learning environments differ in the prevalence of noise related health effects from teaching staff working in enclosed learning environments?
   - H5: Noise annoyance and self-reported noise exposure are higher in teaching staff of innovative than enclosed learning spaces.
   - H6: Vocal symptoms are more prevalent in the teaching staff of innovative than enclosed learning spaces.

2. Methods

2.1. Design

The study involved examining 21 primary schools. Their floor plans were reviewed, principals were interviewed, and learning spaces were assessed through guided tours. Questionnaires were distributed to all teaching staff, which included both teachers and teaching assistants as these are the professionals working directly with students in learning spaces. In 20 schools, the activity SPLs were measured for five working days in four learning spaces. During the measurements, the teachers in these learning spaces maintained an activity log.

As the schools had many different types of learning spaces and specific people commonly used just a few of them, the respondents were divided into **environment groups** based on their questionnaire responses describing the learning space type they used the most (see Chapter 2.4.1 for more details). As very few respondents reported mostly teaching in other types of spaces than a space for one teacher and one group, we formed two learning environment groups: enclosed and innovative. In this way, the innovative group describes spaces with additional action possibilities.

For activity SPL measurements, we had precise information on the learning spaces. Therefore, the innovative environments could be classified into flexible and open space types. This more precise classification was applied because from the room acoustic perspective flexible spaces in their closed mode are enclosed spaces. However, as different flexible solutions might not be as sound insulating as normal walls, we wanted to examine the SPLs of enclosed and flexible learning spaces separately. Furthermore, to our knowledge the activity SPLs of flexible learning spaces have not been studied previously. Therefore, the **space type** was classified to **enclosed, flexible, and open** for SPL measurements (see Chapter 2.5.2 for more details). Table 1 presents a description of environment groups and learning space types.

2.2. Ethical considerations

The Human Sciences Research Ethics Committee of Turku University of Applied Sciences approved the study (LP09_2022, 3.10.2022). A formal approval was also obtained from the municipalities or towns organizing the teaching as well as from the schools participating in the study.

Table 1
Description of the environment groups and the space types.

Environment group [1]	Space type[2]	Description
Enclosed	Enclosed	Space for one 20–30 students' group separated with walls and doors.
Innovative	Flexible	Spaces enabling opening the space and closing the space with different solutions as sliding walls but used in a closed mode.
Innovative	Open	Spaces that could contain more than one 20–30 students' group at a time.

[1] The environment groups were defined using the questionnaire responses (see Chapter 2.4.1) and used in the examination of the questionnaire results. These describe additional action possibilities.

[2] The space types were used in the examination of activity SPLs (see Chapter 2.5.2). Flexible spaces in their closed mode are flexible spaces and in their open mode open spaces. These describe the acoustic properties of the environment.

2.3. School selection procedure

The objective was to study schools with predominantly enclosed learning spaces and those with multiple innovative learning spaces. The aim was to have an equal number of schools with several innovative learning spaces and those with mainly enclosed learning spaces. Additionally, the schools were also supposed to be quite new or recently renovated to avoid the influence of different age and condition of learning spaces. They were also required to be Finnish speaking and located in Southern Finland for logistical reasons.

Finding such schools was demanding as the information about schools' floor plans was not publicly available. We approached our collaborators as well as school facility managers in certain large towns to get information on potential study schools. The criteria presented to them were: elementary schools engaged in the education of students from grades 3–6 (9–12-year-old students), no other large indoor environmental problems than possible noise complaints (e.g., problems with air quality), reasonably new or recently renovated buildings fulfilling current building regulations. In this way, we could get 31 potential schools to contact.

Next, we contacted 27 school principals to inquire about their willingness to participate in the study. We also interviewed them to verify that their school met the criteria. For schools agreeing to participate, we also obtained permissions from the municipalities organizing teaching.

We conducted separate interviews with all principals before the measurements and the questionnaires. In the interviews, we discussed the spatial solutions and the use of school premises using the school floor plans provided by the principals. We also covered the practical aspects of the study, such as the locations of the activity SPL measurements, informing students, parents and school staff, and scheduling the visits and measurements.

The school principals distributed the questionnaire to the teaching staff (including teachers and teaching assistants) and reported the total number of teaching staff members to calculate the response rate. Each school got feedback from the study results concerning their school.

The socio-economic status of the schools was estimated by asking the principals whether the schools received positive discrimination money, which is additional funding distributed to those schools that reside in socially challenging areas. The schools receiving this extra support are reported in Table 2.

The number of schools was based on a power calculation. For a medium effect size ($d = 0.4$), a power of 80 % and a significance level of $p < 0.05$, the number of respondents for the examination of two independent groups needed to be at least 200 [20]. We estimated that schools would have at least 20 potential respondents from which half would respond. Therefore, the final number of schools selected was 20.

To ensure that we had enough different types of schools, we aimed to have half the schools with flexible or open learning spaces and half with mostly traditional enclosed learning spaces. We classified schools according to Dovey and Fisher [2] classification. Their classification from A to E goes from traditional learning spaces to open learning spaces: A – Traditional classroom clusters; B – Traditional classroom clusters + streetspace; C – Convertible classrooms; D – Convertible streetspace; and E – Dedicated commons. They defined streetspace as an open learning area with major through traffic as the primary access space to other learning spaces. Commons was defined as an open learning area that is protected from major through traffic.

We dichotomized the school type into traditional schools (Types A and B) and flexible schools (Types C, D, and E). Eleven schools were classified as traditional and ten as flexible. The schools are described in Table 2. However, as most schools have many types of learning spaces, the most common learning space type of the respondent was inquired about by the questionnaire (See Chapter 2.4.1) and the environment group was used as the independent variable. This was necessary, since

Table 2
Description of the study schools.

School ID	School classification [1]	School type	Construction year	Renovation year	Description of school layout	Grades[2]	Number of Teachers + Teaching assistants[3]	Response rate [%][4]	Positive discrimination money
1	A	Traditional	1924	2018	Corridor school	1–6	26+8	24	
2	A	Traditional	1956	2020	Corridor school, few flexible classes with transfer walls.	1–6	36+4	40	
3	A	Traditional	2011		Corridor school	1–6	12+3	53	
4*	A	Traditional	1950	2022	Corridor school	7–9	42+1	40	
5	A	Traditional	1970	2016	Corridor school	1–6	53+0	53	+
6	A	Traditional	1970	2016	Corridor school	1–9	45+7	33	+
7	A	Traditional	1967	2016	Corridor school	1–6	31+4	34	+
8	B	Traditional	1974	2020	Mainly enclosed spaces. Connecting doors between some.	1–6	27+7	65	+
9	B	Traditional	1985 & 2000		Mainly enclosed spaces. Connecting doors between some.	1–6	31+9	53	
10	B	Traditional	2004		Enclosed spaces with group work space in front of the classroom.	1–9	65+6	38	+
11	B	Traditional	2003&2009		Enclosed spaces with group work space in front of the classroom.	1–9	59+10	45	
12	C	Flexible	2020		Flexible space, which can be divided by folding walls.	1–9	60+6	26	+
13	C	Flexible	2014		Enclosed spaces with the possibility of cooperation between class pairs.	1–6	25+8	45	
14*	C	Flexible	1950	2022	Flexible connectable spaces and enclosed spaces.	3–6	24+9	27	
15	C	Flexible	1976	2018, 2023, 2006	Enclosed spaces, but also teaching halls and co-teaching classes with transfer walls.	1–6	32+15	34	+
16	D	Flexible	2018		Learning cells with flexible spaces.	1–9	49+3	23	
17	E	Flexible	1950	2016	Open-plan learning cells.	1–9	23+5	25	
18	E	Flexible	2020		Open learning spaces, flexible learning spaces and enclosed learning spaces.	1–9	50+10	57	+
19	E	Flexible	2020		Cells with large open space and flexible spaces.	1–6	29+3	59	
20	E	Flexible	2017		Cells with large open space and flexible spaces.	1–6	27+5	41	
21	E	Flexible	2018		Cells with large open space and enclosed spaces.	1–9	52+4	20	

* These two schools were administratively different but working partly at the same premises. The upper school used mainly the older traditional, but completely renovated side for teaching, whereas lower school used mostly, but not completely the new side. The sound level measurements were performed in the grades 3–6, but they represent the learning spaces of both schools.
[1] The school classification was based on Dovey and Fisher [2] classification.
[2] Elementary school grades are from 1 to 9 with 7–15-year-old students.
[3] The number of teachers and teaching assistants describes the number who received the invitation to respond to the survey.
[4] The response rate is the proportion of invited that responded.

we conducted the questionnaire for the whole teaching staff of the schools, not only among the staff that worked in the learning spaces where the SPL measurements were conducted.

2.4. Questionnaire

2.4.1. Environment group

The teaching staff was asked to think about their most used learning space and respond to the questions while thinking about that one specific space. The flexibility of the learning space was inquired with the question "What is the most common space you use for teaching?" The response options were: A) A space with one class/group and a teacher simultaneously B) A space with several classes/groups and teachers simultaneously C) A flexible learning space (an enclosed learning space with e.g., an aquarium, hall or corridor outside, where the learning space can be expanded to), D) Other. The respondents were classified into environment group "enclosed", if they worked mainly in a space used by one teacher and one teaching group simultaneously (option A). As all other options received only a few answers ($N = 94$), these were classified into environment group "innovative".

2.4.2. Perceived fit

As innovative and enclosed learning environments are suggested to constrain different types of pedagogical methods [2], we wanted to examine how teaching staff experience the support from the space to use their preferred learning methods. We call this support perceived fit, which examines the fit between the person and the environment [3]. To estimate *Perceived fit* between the learning space (supply) and preferred

pedagogical methods (need) the respondents chose the most appropriate option: 1 – My learning space supports well the methods I use in my teaching. 2 – My learning space supports quite well the methods I use in my teaching. 3 – My learning space slightly restricts the methods I use in my teaching. 4 – My learning space noticeably restricts the methods I use in my teaching. 5 – Because of my learning space, I must continuously use methods I would not otherwise use in my teaching. The variable was dichotomized into "fit", which means the learning space supports or restricts a little (options 1, 2, and 3) and "no fit", which means the learning space restricts it at least noticeably (options 4, and 5).

2.4.3. Subjective noise exposure

Subjective noise exposure was assessed as self-rated noise exposure in the study [15]. The question was: "Are you exposed to noise that disturbs you when you are teaching in your learning space." The response scale was: 1 – Never; 2 – Very rarely or very little; 3 – Approximately ¼ of the time; 4 – Approximately half of the time; 5 – Approximately ¾ of the time; 6 – Almost all the time. The responses were further classified into categories: never/rare (1 and 2), quarter to half of the worktime (3 and 4), and more than half of the time (5 and 6).

2.4.4. Environmental satisfaction

General *environmental satisfaction* with the learning space was assessed with: "How satisfied are you with your learning space in general?". The 7-point bipolar response scale was verbally labeled in three items: −3 – Very dissatisfied, −2; −1; 0 – Neutral; 1; 2; 3 – Very satisfied.

2.4.5. Satisfaction with indoor environmental quality and acoustic factors

The question was "How satisfied are you with the following factors in your learning space?" The following indoor environmental quality (IEQ) factors were evaluated: temperature, air freshness, sound environment, amount of light, amount of dust or dirt, furniture, teaching equipment, IT-solutions, amount of working space, amount of storage space, functionality of transit routes, undisturbedness of space. In addition, a similar estimation was given for the following acoustic factors: acoustics for talking, sound insulation to neighboring learning spaces, sound insulation to corridor, sound insulation to outside. The response scale was the same as in 2.4.4 (−3 – Very dissatisfied, −2; −1; 0 – Neutral; 1; 2; 3 – Very satisfied).

2.4.6. Places of noise annoyance

The question was modified from the standard ISO/TS 15,666 [21]: "How much has the sound environment in school bothered, disturbed, or annoyed you during the last month in the following spaces?" The places assessed were my learning space. other learning space, school canteen, corridor, lobby, gymnastics hall, school yard, and teachers' lounge. The response scale was: 1 – Not at all; 2 – Slightly; 3 – Moderately; 4 –Very; 5 – Extremely.

2.4.7. Annoying sound sources

The list of annoying sound sources was modified from several articles on school noise [7,13,22]. The question formulation was: "How much do the following sounds annoy you in your learning space? If you have not heard the sound in this space, respond I cannot hear the sound." The sound sources were students' speech, corridor, neighboring classes, furniture, echo, air conditioning, school yard devices, and traffic. The response scale was: A) I cannot hear the sound. B) I hear the sound, but it does not annoy. C) Sound annoys a little. D) Sound annoys a lot. The proportion of highly annoyed (category D) was examined.

2.4.8. Voice symptoms

Voice symptoms were modified from a previous report on school noise [22]. The question was "How often have you experienced following symptoms?" with the following symptoms listed: Voice gets tired easily; Hoarseness without a cold; Sore throat; Difficulty making a voice heard; Voice breaks off; Lose of voice without a cold. The response scale was: 1 - Daily, 2 - Weekly, 3 - Monthly, 4 - Few times a year, and 5 - No symptoms. The responses were dichotomized so that categories 1 and 2 (reporting symptoms at least weekly) were classified to show repeatedly occurring symptoms.

2.5. Activity SPL monitoring

2.5.1. Learning space selection

The activity SPL was monitored in four learning spaces in 20 schools. For activity SPL measurements, a learning space was defined to be a space for one group of 20–30 students. This means that in open learning spaces, it was possible to have more than one point for monitoring as there was space for more than one group. The learning spaces were selected together with the school principals in the interviews before the visits to the schools. The principals were asked to select learning spaces for activity SPL monitoring with the following criteria: spaces represent most of the school's learning spaces; are used most of the school day and for teaching 3–6 grade (9–12-year old) students; are not small, special learning spaces, for art and craft learning only, nor for special classes; and the teacher mostly using the learning space might be willing to fill in an activity log for five working days. Small space was defined to fit only a group smaller than 20 students. The representativity of the learning spaces was further verified with an instructed tour around all schools' learning spaces, while deploying the sound level meters to the school. In 20 research schools, the sound level meters were installed to four spaces. One school included in the study was administratively separate and had students only from grades 7–9, but it shared the premises with another school with grades 3–6, therefore, the measurements were performed only at the school with grades 3–6, but the teachers at both administratively separate schools responded the questionnaire.

2.5.2. Space type

The space types are described in Table 1. What should be noted is that the flexible spaces were divided into two depending on their use mode, which the teachers' reported in their activity logs (see 2.5.4): the flexible learning spaces used in the closed mode accommodating only one group were defined as flexible spaces, whereas flexible learning spaces used in an open mode with a possibility to accommodate more than one group were defined as open spaces. The distinction between flexible and enclosed spaces was used as in many cases the sliding walls or other solutions used to divide learning spaces did not have as good sound insulation as normal walls would offer.

2.5.3. Activity SPL measurement

The sound level meters (NTI Audio XL2 with M2230 microphone) were placed near the teachers' most common place in the space to get an estimate of teachers' sound exposure. This was most often near teachers' desks, but not all spaces had obvious teachers' desks, or the desks were not located in the places where teachers were during teaching. The place was chosen also so that it would not interfere with teaching. Most commonly, the microphone was attached to a stand on the height of 1.55 m (variation between 1.5 – 2.7 m) and close to a wall so that it would not be in the way. The meters were calibrated before taking them to each school and their time setting was checked. The meters were left to the space for at least five working days when the devices were constantly recording the sound pressure levels each minute.

2.5.4. Teachers' activity logs

During these five days, the teachers working in these spaces marked to the activity log the times of teaching, the number of people in the learning space, and the most common activity or activities of the lesson. The times used for teaching are here called learning periods. The teachers marked the activities of the learning periods using four activity categories (Table 3), which were adapted from Radun et al. [13]. As many learning periods had many activities, we further classified the activity categories into two *activity types.* The learning periods classified

Table 3
Description of the activity types.

Activity type	Activity categories
Calm activity	A1: Quiet working, A2: One person talking (teacher lead teaching/learning conversation/independent work etc.),
Lively activity	A3: Pair or group work (activity, where multiple people are talking at the same time), A4: Activity-based working (multiple people talking and moving in the learning space at the same time).

into two activity types contained only activity categories from one *activity type*, but not the other (Table 3). If the space was flexible with a possibility to open or close the space, this was also reported in the activity log for each learning period. The teachers could also write comments on the activity log.

2.5.5. Learning periods

The learning period is the time the teacher marked teaching in the measured space. Some teachers marked several learning periods for one lesson as the activity category changed and some marked the duration of the whole lesson with several activity categories. The sound level meters were taken to 80 learning spaces (4 spaces in 20 schools), but in one case the device had a technical failure and in other four cases the teachers had not filled in the activity logs. Therefore, we got successful measurements from 75 different learning spaces. However, the flexible spaces were divided into two depending on their use mode, in other words as flexible in enclosed mode and as open in open mode (see 2.5.2). Therefore, the after considering also the space type, we got learning periods from 83 different types of spaces. Table S1 in the Supplementary material describes the learning spaces per schools.

To remove the noise of transitions and to capture the SPLs during that specific learning activity, 5 min from the beginning and 5 min from the end of the lessons were excluded. From these 1514 learning periods those learning periods were chosen that were 10 min or longer and had 10 people or more in the space. When the number of people was missing, it was assumed that the group size was above 10 people featuring the whole group normally studying in the learning space. In total, we had 1356 learning periods (see Table 4 for details). Table S1 in the Supplementary material reports the number of learning periods per school.

2.5.6. Activity sound pressure level (SPL) variables

The average A-weighted equivalent SPL (L_{Aeq}) per space for the time of the learning periods during the five days was determined from the 1-minute measurements received from the sound level meters (LAeq_dt) (see Supplementary material for the equation). These were calculated using Matlab (MATLAB R2022b, The MathWorks Inc., Natick, Massachusetts, USA). The quietest learning period ($L_{Aeq,min}$) and the loudest learning period ($L_{Aeq,max}$) were examined in each space. The period lengths ranged from 10 to 95 min (Table 4). Depending on the space, the number of defined learning periods varied from 3 to 30 with mean being 16. Similarly, the average SPL for calm ($L_{Aeq,calm}$) and lively ($L_{Aeq,lively}$) activity types were determined per space.

2.6. Statistical analysis

The statistical analyses were performed with RStudio 2024.04.0 + 735 for windows (Posit Software, PBC). The categorical variables were examined with Pearson Chi-squared test with Yates continuity correction and the effect size was estimated with $phi=(x^2/n)^{1/2}$, where x^2 is the value of the chi-squared test and n is the number of observations. The categorical variables in the questionnaire were background variables in Table 5, perceived fit, subjective noise exposure, annoyance of sound sources, and the prevalence of voice symptoms. All background variables were not marked as obligatory in the questionnaire; therefore, some respondents left some of them unanswered. However, as these respondents answered most other questions, they were included in further examination.

For continuous variables, the Linear Mixed Effects analysis from libraries lme4 and LmerTest were used with the environment group as the fixed effect and the school as a random effect. Linear Mixed Effects analysis was used because not all variables fulfilled the requirements of analysis of variance, and due to differences between the schools, we wanted the school to be the random effect. As we were interested in evaluating the significance of fixed effects of the models, we used models

Table 5
The description of respondents per environment group.

	Environment group		Total		
	Enclosed	Innovative	Number of respondents	Proportion [%]	*p*-value [1]
Respondents	267	94	**361**		
School type					<0.001
Traditional	179	29	208	58	
Flexible	88	65	153	42	
Gender					0.830
Woman	214	77	291	81	
Age					0.089
less than 34 years	76	24	100	28	
35–44 years	59	33	92	25	
45–54 years	73	22	95	26	
55 years or more	59	15	74	20	
Group size*					<0.001
15 or less	75	21	96	27	
16–20	73	24	97	27	
21–30	114	33	147	41	
More than 30	1	11	12	3	
Grades**					
1–2	71	22	93	26	0.661
3–6	147	50	197	55	0.848
7–9	66	27	93	26	0.531
Experience*					0.240
0–4 years	84	30	114	32	
5–9 years	43	20	63	17	
10–14 years	29	15	44	12	
15 years or over	108	29	137	38	

[1] The *p*-values denote whether the environment groups differed statistically from each other in these background characteristics.
[*] The total number of respondents differs from 361 due to missing responses.
[**] Some respondents were teaching several groups and grades.

Table 4
Description of the learning periods.

Space type		Number of persons in the space			Length of the measurement period		
	Count [1]	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Enclosed	810	20	10	60	35	10	95
Flexible	221	20	10	47	33	10	80
Open	325	31	10	67	31	10	81

[1] Count describes the number of learning periods. The total number of learning periods was 1356 in studied 20 schools.

fitted with restricted maximum likelihood (REML) with Satterthwaite's approximations as suggested by Luke [23]. The effect size for linear mixed models was marginal R^2 (R^2m) calculated with MuMIn package with r.squaredGLMM command as recommended by Brysbaert & Debeer [24]. It tells, how much variance is explained by the fixed effect in Linear Mixed Effects analysis and the interpretation equals to the interpretation of eta-squared [24]. The continuous variables in the questionnaire were satisfaction ratings, and annoyance ratings related to different places in schools.

For activity SPL measurements, different SPL measures were first determined for each learning space and then the statistical difference between the space types was tested using the Linear Mixed Effects analysis as described above with the space type as the fixed effect and the school as the random effect.

3. Results

3.1. Description of respondents and environment groups

Altogether 361 members of teaching staff responded to the questionnaire. The respondents were teaching staff working in learning spaces with the students, i.e., mostly teachers and teaching assistants. Most of the respondents were teachers (332 respondents; 92 %). Table 2 presents the number of teachers and teaching assistants in each school and the response rates of the school. The response rates from schools ranged from 20 to 65 % (see Table 2). The total response rate was 39 %.

Table 5 shows the description of respondents according to their environment groups. The environment groups differed from each other in school types ($X^2(1)=35.8$, $p < 0.001$, $phi=0.315$) with 69 % of respondents in innovative environment group working in flexible schools and 67 % of respondents in enclosed environment group working in traditional schools. In addition, the typical group sizes in the innovative environment group were larger than in the enclosed environment group ($X^2(3)=29.2$, $p < 0.001$, $phi=0.285$) (Figure S1 in the Supplementary material). The learning environment groups did not differ in other descriptive background characteristics ($p > 0.05$).

3.2. Subjective experiences of environment groups

3.2.1. General estimations of learning environments

The environment groups differed in perceived fit ($X^2(1)=7.3$, $p = 0.007$, $phi=0.142$). In the innovative environment group, 29 % of respondents considered learning space as no fit which means that learning space restricted their teaching methods at least noticeably or they must use methods they otherwise would not. In the enclosed environment group, 15 % of the respondents reported no fit.

Subjective noise exposure described the proportion of working time teaching staff thought they were exposed to disturbing noise. Only 23 % of teaching staff estimated being exposed to disturbing noise rarely or never, while 22 % estimated being exposed ¾ of their working time or more. The subjective noise exposure estimation did not differ between the environment groups ($X^2(2)=5.8$, $p = 0.056$, $phi=0.126$) (Figure S2 in the Supplementary material).

3.2.2. Satisfaction with environment

The enclosed environment group was more satisfied with their environment (mean=0.6, standard deviation (sd)=1.6) than the innovative environment group (mean=−0.1, sd=1.5) (Figure S3 in the Supplementary material, $F(1, 355)=7.4$, $p = 0.007$, $R^2m=0.020$).

The satisfaction with different indoor environmental quality factors in their learning space was higher in the enclosed than in the innovative environment group or did not significantly differ between the environment groups (Fig. 2). The respondents were the most satisfied with the amount of light, teaching equipment, IT-solutions, as well as temperature, which showed no differences between the environment groups ($p > 0.05$). The enclosed environment group was more satisfied with sound environment ($F(1, 353)=15.1$, $p < 0.001$, $R^2m=0.041$), functionality of transit routes ($F(1, 355)=12.3$, $p < 0.001$, $R^2m=0.034$), amount of storage space ($F(1, 359)=6.8$, $p = 0.010$, $R^2m=0.018$), undisturbedness of space ($F(1, 353)=3.1$, $p = 0.002$, $R^2m=0.026$), amount of working space ($F(1, 358)=5.9$, $p < 0.016$, $R^2m=0.016$), and air freshness ($F(1, 359)=4.4$, $p = 0.036$, $R^2m=0.011$) than the innovative environment group.

3.2.3. Satisfaction with acoustic factors

The satisfaction with acoustic factors was examined more closely (Fig. 3). The respondents were in general the most satisfied with sound insulation to outside. However, the enclosed environment group was more satisfied with it than the innovative environment group ($F(1, 359)=18.9$, $p = 0.003$, $R^2m=0.024$). The enclosed environment group was also more satisfied with other acoustic factors than the innovative environment group (acoustics for talking: $F(1, 358)=9.5$, $p = 0.002$, $R^2m=0.026$; sound insulation to neighboring learning spaces: $F(1, 358)=9.5$, $p = 0.002$, $R^2m=0.026$; and sound insulation to corridor: $F(1, 356)=12.0$, $p < 0.001$, $R^2m=0.033$).

3.2.4. Places of noise annoyance

Noise annoyance was estimated for different places in schools. Noise was the most annoying in school canteens, corridors and lobbies and the least annoying in school yards, and teachers' lounges (Fig. 4). The environment groups did not differ in noise annoyance in different places of the schools ($p > 0.05$), not even regarding their own learning space (F

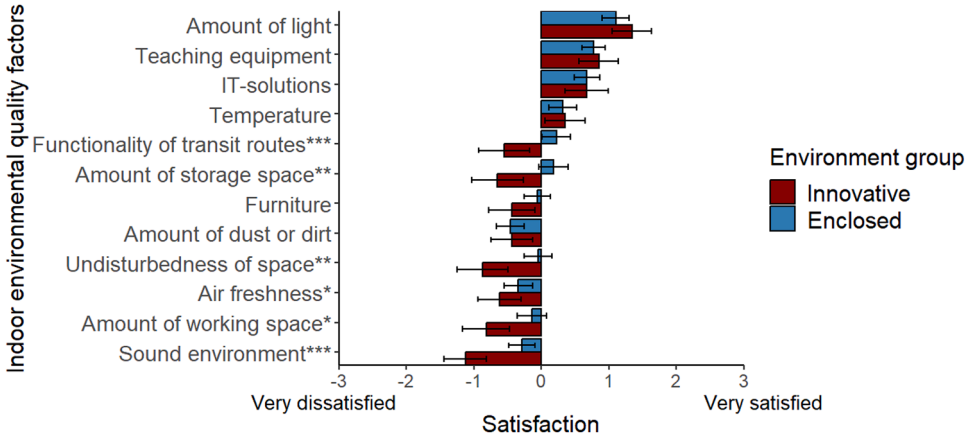

Fig. 2. The mean satisfaction with indoor environmental quality factors in the environment groups. The error bars denote the 95 % confidence intervals. The asterisks denote the significant differences between the environment groups: * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

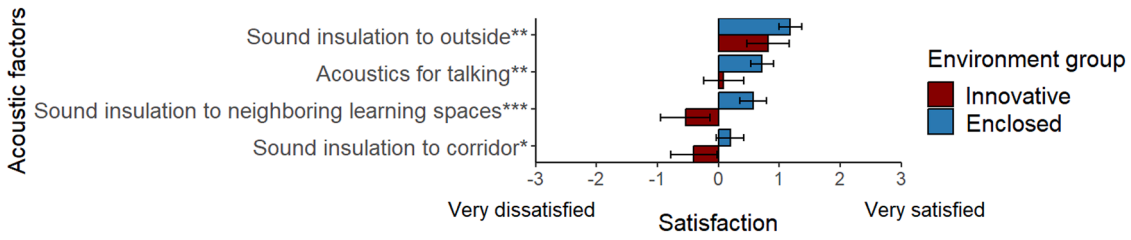

Fig. 3. The mean satisfaction with acoustic factors in the environment groups. The error bars denote the 95 % confidence intervals. The asterisks denote the significant differences between the environment groups: * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

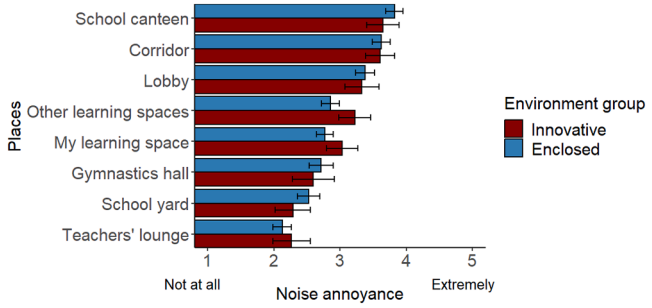

Fig. 4. The mean noise annoyance in different places of school presented for the environment groups. The error bars denote the 95 % confidence intervals.

(1, 345)=3.4, $p = 0.065$, R^2m=0.010).

3.2.5. Annoying sound sources

In general, the annoying sound sources were inside the schools (Fig. 5). The most annoying sound source was students' speech, with 23 % of highly annoyed respondents in both environment groups. The environment groups differed in the proportion of highly annoyed respondents by the noises from the neighboring classes: 6 % of the enclosed environment group was highly annoyed, while this was 16 % in the innovative environment group (X^2(1)=7.6, $p = 0.006$, *phi*=0.145). In addition, the innovative environment group was more annoyed by echo, which highly annoyed 10 % of the innovative environment group compared to 2 % in the enclosed environment group (X^2(1)=9.1, $p = 0.003$, *phi*=0.159).

3.2.6. Vocal symptoms

27 % of respondents reported suffering from two or more vocal symptoms at least weekly. The most common vocal symptom was that voice gets tired easily, which affected at least weekly 31 % of the enclosed environment group and 35 % of the innovative environment group (Fig. 6). The environment groups did not differ in the prevalence of any vocal symptoms ($p > 0.05$).

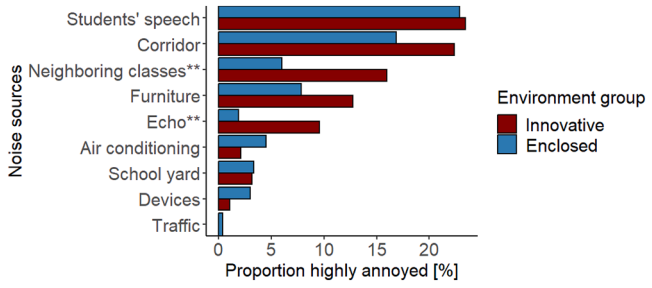

Fig. 5. The proportion of respondents reporting high annoyance in their learning space for different noise sources in the environment groups. The asterisks denote the significant differences between the environment groups: * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

3.3. Activity SPL measurements

3.3.1. Activity SPLs in different learning space types

In the following analysis, the enclosed space type was taken as a reference, and flexible and open space types were compared with it. Here, the flexible learning spaces in their enclosed modes are called flexible spaces, and in their open modes, they are classified as open spaces. Our results contain measurements from 75 different learning spaces, but in eight learning spaces the space type diffed according to the use of flexible learning spaces. This means that these eight learning spaces were recorded in both flexible and open modes, while most of the flexible learning spaces were used in one mode throughout the measurement period. Finally, we have measurements from 43 enclosed, 18 flexible, and 22 open spaces (see Table S1).

Altogether, we obtained 1356 learning periods from different learning spaces. The distribution of the number of people in the learning spaces as well as the lengths of the learning periods are reported in the Figure S4 in the Supplementary material. The number of people in the learning space was higher in open spaces (mean 31 persons) than in enclosed (mean 20 persons) or flexible (mean 22 persons) spaces (F(1, 1063)=131.0, $p < 0.001$, R^2m=0.165) (Figure S5a in the Supplementary material). The learning period length did not differ between the space types (F(1, 543)= 0.7, $p = 0.396$, R^2m=0.001) (Figure S5b in the Supplementary material).

The frequency distributions of the average activity SPLs are presented in Figure S6, and the average activity SPLs of learning space types are presented in Table 6 and in Figure S7. The average SPL of all lessons during the five days of recordings ranged from 57 dB to 73 dB L_{Aeq}. The average SPL depended on the space type (F(2, 73)=4.6, $p = 0.013$, R^2m=0.123). The average activity SPL was 2 dB higher in enclosed spaces (65 dB L_{Aeq}) than in the open spaces (63 dB LAeq) (t(80)=−2.9, $p = 0.005$), but there was no difference between the enclosed and the flexible spaces (t(77)=−0.6, $p = 0.532$).

The quietest lessons in the space during the five days of recording ranged from 38 to 68 dB $L_{Aeq,min}$ and depended on the space type (F(2, 72)=8.4, $p < 0.001$, R^2m=0.162). These lessons were quieter in the open spaces (mean = 50 dB) than in the enclosed spaces (mean = 56 dB) (t(76)=−3.6, $p < 0.001$), but no difference was observed between the enclosed and the flexible space (t(80)=−0.2, $p = 0.859$).

The loudest lessons of the space during the five days of recording ranged from 63 to 77 dB $L_{Aeq,max}$ and did not depend on the space types (F(2, 71)=2.2, $p = 0.119$, R^2m=0.087). The mean loudest lessons' SPL was 70 dB.

3.3.2. Activity sound levels during different activity types

The teachers marked to the activity logs the main activity or activities of the lesson. The histograms of SPLs recordings for different activities from each space type are presented in the Supplementary material Figure S8.

The SPLs during calm activity ranged from 53 dB to 73 dB $L_{Aeq,calm}$ and did not depend on the learning space type (F(2, 72)=3.0, $p = 0.056$, R^2m=0.068) (Table 6; Figure S9a). The mean calm activity SPL was 63 dB.

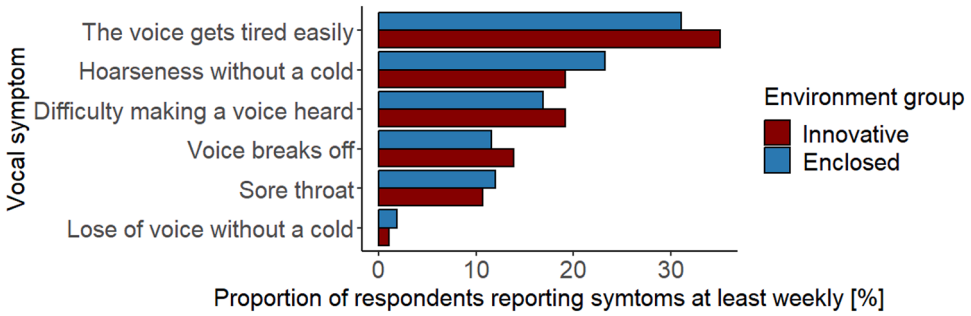

Fig. 6. The proportion of respondents reporting vocal symptoms at least weekly in the environment groups.

Table 6
The activity sound pressure levels in different space types.

Activity sound measure	Space type[1]												*p*-value[2]
	Enclosed ($N = 43$)				Flexible ($N = 18$)				Open ($N = 22$)				
	mean	sd	min	max	mean	sd	min	max	mean	sd	min	max	
L_{Aeq} [dB]	65.4	2.4	60.3	70.9	65.1	2.3	61.0	72.9	62.6	3.1	56.8	69.9	0.013
$L_{Aeq,min}$ [dB]	55.8	6.0	40.6	68.3	56.4	6.2	44.3	68.4	49.6	6.7	37.6	66.0	0.001
$L_{Aeq,max}$ [dB]	70.4	2.4	65.1	76.5	69.7	3.1	65.4	75.3	68.5	3.0	62.6	73.3	0.119
During activity types													
$L_{Aeq,calm}$ [dB]	63.8	3.1	55.6	71.0	63.4	3.9	59.0	72.8	60.8	4.1	52.8	72.7	0.056
$L_{Aeq,lively}$ [dB]	66.7	2.8	58.7	71.2	66.0	3.3	60.1	73.1	62.9	3.4	56.0	68.2	0.001

[1] The means, standard deviations (sd), minimum (min), and maximum (max) of the learning periods are presented.
[2] *P*-value denotes whether the difference between the space types was statistically significant ($p < 0.05$).

The SPLs during lively activity depended on the learning space type ($F(2, 72)=7.6$, $p = 0.001$, $R^2m=0.158$) (Table 6; Figure S9b). The range was from 56 to 73 dB $L_{Aeq,lively}$. The SPLs in the enclosed learning spaces were higher than in the open spaces ($t(77)=-3.8$, $p < 0.001$) and there was no difference in the SPLs between the enclosed and the flexible spaces ($t(79)=-0.8$, $p = 0.407$).

4. Discussion

We compared the teaching staff's experience and the activity SPLs in different learning space types. The teaching staff working in flexible or open spaces (innovative environment group) was less satisfied with their environment than the group working mainly in enclosed spaces (enclosed environment group). Almost one third of the respondent in the innovative environment group (29 %) reported no fit compared to 15 % in the enclosed environment group. "No fit" means that the respondents estimated their learning space to restrict their teaching methods at least noticeably or that they had to use teaching methods they otherwise would not use. The innovative environment group was less satisfied with sound environment, functionality of transit routes, amount of working and storage space, undisturbedness of space, and air freshness than the enclosed environment group. The innovative environment group was less satisfied with acoustic factors than the enclosed environment group. The higher proportion of the innovative environment group was highly annoyed by neighboring classes and echo than the enclosed environment group. The learning environment groups did not differ in noise annoyance related to different places in schools, nor the prevalence of vocal symptoms. Therefore, the innovative environment group experienced the environment clearly more negatively than the enclosed environment group. However, the activity SPLs were slightly higher in the enclosed spaces than in the open spaces regarding the average SPLs, the quietest learning periods, as well as during lively activity. The SPLs did not differ between learning space types in the loudest learning periods or during calm activity.

Our results showed that a larger proportion of teaching staff in the innovative environment group perceived no fit regarding the learning space than in the enclosed environment group. This was opposite to our expectations that the innovative environment group would show higher perceived fit than the enclosed environment group (H1), as innovative learning spaces should afford a larger range of pedagogies than traditional enclosed classrooms [1]. Our results show that person's needs and learning spaces' supply often do not meet. Person-environment theory states that low need-supply fit would lead to higher strain that in the long-term can result in illness [3]. However, a deeper analysis of person's needs is required as, from another view. enclosed and flexible learning spaces constrain different types of pedagogies: enclosed learning spaces constrain student-centered pedagogies and flexible learning spaces constrain teacher-centered pedagogies [2]. We do not know the preferred pedagogies of the participants. Therefore, the fit between usage and space should be more carefully examined. In the interviews with the principals, one could observe that the general policy of the schools regarding, for example, co-teaching varied. In the future, the fit between the pedagogical use of the space and environmental affordance [1] should be further examined in schools with different environmental solutions.

Besides the fit between the pedagogical approach and space, there is another possible explanation for the teaching staff's negative estimations of innovative learning environments: the lack of cognitive ergonomics. The SPLs were lower in open than in enclosed learning space, but the innovative environment group was less satisfied with the sound environment, the undisturbedness of space, as well as in general with their learning space than the enclosed environment group. This result is in line with our assumption (H2), and with a review that criticized open learning spaces for noise, especially from the adjacent groups [4]. In line with this, the satisfaction with acoustic factors was lower in the innovative environment group than in the enclosed environment group, especially concerning the sound insulation to the neighboring classroom and corridor. The innovative environment group was also less satisfied with the amount of working and storage space, as well as the functionality of transit routes than the enclosed environment group. This might reflect the fact that the space efficiency is often higher in new school buildings than in old ones. This might also be reflected in the

transit routes, which can go through open learning spaces, as the concept of streetspace described in the classification of school spaces from Dovey and Fisher [2]. These transit routes may produce additional distractions, which do not exist in enclosed spaces.

The second most common health effect of environmental noise is annoyance [25], therefore, it is an important factor to examine. General noise annoyance in different places of the schools did not differ between the environment groups, nor was there a difference in the self-reported noise exposure. However, a higher proportion of the innovative environment group (16 %) reported being highly annoyed by neighboring classes compared to the enclosed environment group (6 %). Therefore, our hypothesis (H5) was partly supported. The most common places in schools where noise was annoying were places where students are freely together or in transition, such as school canteens, corridors, and lobbies. More attention should be given to the acoustic treatments of these school premises. The largest proportion of respondents reported being highly annoyed by students' speech (23 %), which is in accordance with earlier studies [7,13]. In general, sounds related to school activity, like sounds from the corridor, neighboring classes, and furniture, caused the most annoyance. The subjective noise exposure, however, did not differ between the environment groups. This was surprising as the higher number of people in the space have been related to higher subjective noise exposure in enclosed classrooms [10,15] and in our data larger groups sizes were reported in the innovative than in the enclosed environment group.

Activity SPLs in learning spaces can cause a risk for teachers' occupational voice disorders [11], which is why we examined vocal symptoms that were reported at least weekly. The environment groups did not differ in the prevalence of any vocal symptoms; therefore, our hypothesis (H6) was not supported. However, more than 30 % of teaching staff reported that their voice gets tired easily, and every fifth respondent reported hoarseness without a cold and difficulty making their voice heard. In addition, 27 % of respondents reported having two or more symptoms at least weekly. A public health survey performed in Stockholm reported that 19 % of teaching professionals suffer from voice problems to a small or great extent [18], which is a very similar proportion to ours. We assumed that the background sound pressure level during activity would be higher in the open learning spaces due to intrusive noise from other learning groups [10], which could cause more vocal strain. However, it is possible that pedagogical activity might influence vocal strain, as teachers teaching in louder activity noise changed their voice SPL less during the day than the teachers teaching in loud ambient noise [16]. If the innovative learning environments afford student-centered learning pedagogies [2], raising the voice might not be necessary. On the other hand, slightly lower activity SPLs in innovative learning environments may be caused by their larger room volume: the SPL caused by constant voice effort increases with decreasing room volume since the same energy is distributed to a smaller volume.

The activity SPLs were lower in open than in enclosed spaces with regards to the average SPL, the quietest learning periods in the space and during lively activity. During the loudest learning periods as well as during calm activity the SPLs did not differ between the space types. This result was somewhat opposite to our expectation (H3), and previous results showing no difference in SPLs in flexible and enclosed learning spaces [10]. The reason for lower SPLs can be physical: open spaces are significantly larger: the sound power of speech is distributed to larger room volume leading to lower energy (SPL) in the room. Another reason might be behavioral: people in open spaces know that their sounds can disturb other groups working in the same space, so they keep their activity quieter. This may further be reflected to lower support for different activities. Previous studies have reported sounds from adjacent groups to create the intrusive sounds in open spaces [10]. We expected intrusive sounds to raise the SPLs during the calm activity in open learning spaces (H4). However, the SPLs during the calm activity did not differ in open than in enclosed spaces. Nonetheless, as the mean SPLs were slightly lower in open than in enclosed learning spaces, this lack of difference between the space types may reflect the intrusive noise from adjacent groups.

4.1. Strengths and limitations

Our study quantitatively examined teaching staff's experiences of their learning environments in different environment types. Previous studies have concentrated on students' experiences [5,6], used qualitative methods [6], or are from the previous century (see e.g., most studies in review [4]), which might mean that new student-centered learning methods were used less than today. In this respect, our study provides a novel systematic contribution to this changing research field, where many different types of spaces are compared [6].

Another strength is the large number of schools, which the researchers knew well because all learning spaces of these schools were visited. This procedure guaranteed that the school fits to our research design and the learning spaces where the activity SPL was monitored represent the school well. In addition to the activity SPLs, the room acoustic conditions of the classrooms involving SPL monitoring were measured, but they are reported separately [26].

Unfortunately, the response rate was under 30 % in six schools. Even though the study protocol in all schools was similar, the principals had different amount of interest in the study, and they might have motivated the teaching staff to respond with varying degrees of enthusiasm.

Our study may also be affected by response bias. Both school principals and teaching staff knew that the purpose of our research was school's acoustics and noise. It is possible that staff responded more actively in schools with noise problems (response bias).

The SPL measurements might be influenced by the fact that we had just one sound level meter in each space, which was positioned in a place where the teacher would most likely be. However, especially, during student-centered learning, the teachers might move quite freely in the space, which means that our measurements do not accurately measure the teachers' noise exposure. We assumed that this may have impacted the SPLs of calm activity types. During active activity types, the sound should be distributed to the entire learning space and the uncertainty is probably smaller.

The age of the school might influence the results. We tried to control for this by having renovated schools if the schools were older. The fact that there was no difference in the satisfaction with teaching equipment, IT-solutions and furniture between the environment groups shows that schools were up to date. We did not examine furniture layout, circulation plans, material design, nor the sound insulation between different learning spaces. These also might explain functional and unfunctional flexible learning space solutions. What should be noted is that usually new school furniture is easy to move to increase flexibility of the learning space. Therefore, it is common for teachers to change the furniture layout quite often to accommodate their needs. Furthermore, we consider that the large number of schools enables the general comparison of the environment groups and space types in our study.

5. Conclusions

The aim of this study was to examine whether teaching staff's experience and activity sound exposure differ in learning space types. In general, teaching staff working in innovative learning environments (open or flexible) were less satisfied and more disturbed by environmental factors than teaching staff working in enclosed learning environments. Almost one third of staff working in innovative learning environments perceived that the space does not support the pedagogical methods they wanted to use, which might indicate low need-supply fit. This implies that currently innovative learning environments in Finnish schools fail to offer larger range of pedagogies teachers would like to use. However, the SPLs in the open spaces were the same or slightly lower than in the enclosed spaces: probably due to larger room volume and/or different behavior. We propose that the problem with open and

flexible learning spaces is not the sound exposure, but rather the distractions and lack of cognitive ergonomics, which might lead to a less pleasant experience. Special focus should be put on reducing distractions in schools via architectural, acoustical, as well as behavioral solutions. Schools should be designed to have separated clear transit routes that do not cross learning spaces. Open learning spaces should be designed with the possibility to split the group into separate or flexible enclosed learning spaces. School schedules should be planned so that neighboring groups do not disturb others. Groups working in the same space should be able to coordinate their activities so that the space would have simultaneously only one type of activity. The interaction between space and its usage should be further researched. When examining the functionality of innovative environments, cognitive ergonomics should always be included as one aspect. For school design, considering only possibilities for different actions is not enough; cognitive ergonomics must also be considered.

CRediT authorship contribution statement

Jenni Radun: Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Jukka Keränen:** Writing – review & editing, Validation, Supervision, Software, Methodology. **Sanna Rantanen:** Writing – review & editing, Methodology, Conceptualization. **Marjaana Veermans:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Conceptualization. **Valtteri Hongisto:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Jenni Radun reports financial support was provided by The Finnish Work Environment Fund. Jenni Radun reports financial support was provided by Saint-Gobain Finland Ltd, Ecophon Finland. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.buildenv.2025.113125.

Data availability

Data will be made available on request.

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