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Workshop with 335 primary school children in The Netherlands: What is needed to improve the IEQ in their classrooms?

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ABSTRACT

To identify current problems in the classroom and to conceptualize design solutions by primary school children to solve these problems, 335 children from seven primary schools participated in a workshop held in the Experience room of the SenseLab, comprising of two parts. In part 1, the children were asked to think about their own classroom at school and to choose an IEQ-problem in their own classroom that they are bothered with. In part 2 of the workshop, the children were asked to imagine they are an inventor or scientist in 2040 with all resources available and to make a design for the future. The content analysis of the problems and solutions appearing in the drawings and the written text resulted in 5 themes (light, noise, temperature, air and other than IEQ) and 16 sub-themes (11 for the problems and 5 for the solutions). Noise-related problems were most frequently reported (58%), followed by temperature (53%), air (22%), and light (16%). Girls reported more problems than boys, which is possibly related to a better recollection of negative feelings towards those problems in their classrooms. 47% of the children proposed solutions related to more than one IEQ-problem. Solutions ranged from existing solutions, for example headphones to protect against noise to far-fetched solutions such as send noisy children away by means of a rocket. The outcome showed that children can be valuable contributors in co-designing 'new' or 'adapted' classroom environments.

1. Introduction

Studies all over the world have shown that the indoor environmental quality (IEQ) of classrooms affects the wellbeing and learning performance of school children [1]. Many studies all over the world have been performed to study indoor air, thermal, lighting and acoustical quality in relation to health, comfort and learnability of school children: European-wide studies (e.g. Refs. [2–5]), several studies in the United States (e.g. Refs. [6–8]), but also numerous national studies, for example in Denmark [9,10], Finland [11], Sweden [12,13], the Netherlands [14–16], the United Kingdom [17–21], Greece [22], Italy [23], Iran [24], Portugal [25], Japan [26,27], China [28], Taiwan [29], and Australia [30,31]. In those studies, health effects and comfort perceptions were assessed by using self-administered questionnaires (in a few also medical examinations, performance tests or absence ratings), combined with indoor environmental monitoring of several air pollutant concentrations, inspection of buildings with the use of a checklist and/or several physical measurements (e.g. temperature and relative humidity). The outcome comprised of a number of problems related to indoor environment in classrooms, that are likely to have an effect on comfort and health. Out of all the studies performed, most studies focused on relations with indoor air quality parameters, followed by thermal, acoustical and lighting aspects [1,32–34]. Only a few studied the school and its indoor environment in a holistic way (for example [16,21,35,36]) and even fewer studied the preferences and needs of children (e.g. Refs. [16,35]). While Barett et al. [21,36] studied the impact of the physical classroom features on the academic progress of children in classrooms based on observations, interviews with teachers and grades of children, Soccio [35] and Bluyssen et al. [16,37,38] consulted the children themselves about their preferences and needs with regard to the classroom environment, added with observations and monitoring of environmental parameters. The latter resulted in a list of classroom characteristics possibly related to the symptoms and problems reported by the children studied [16] and 6 profiles of children based on the rated importance of environmental factors in their classroom and their preferences for a number of individually controlled devices [37]. It was also concluded that teachers could not, or did not have the means to, improve children's comfort in the classroom [38].

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With all the knowledge gathered, it seems possible to present a list of IEQ-factors that have shown to have an effect on children's perceptions. But it is not easy to determine solutions for all of the problems identified that can improve the IEQ for each child in a classroom. Current guidelines for healthy indoor environments within schools [39,40] are still largely based on criteria that are originally set up for adults and focused on single factors, which do not consider interactions among them, and are set for an average person. Additionally, most of the time solutions are restricted due to limited resources [41]. Lab studies on the effect of different environmental factors on people, and preferences and needs of people, have been mainly performed with adults in office settings [1]. In few studies children have been directly asked about their perceptions and feelings and/or have been involved in the design process (that is to determine solutions) (e.g. Refs. [35,42–45]). Participatory research with children has been performed successfully before. For example, asking children to make drawings as a tool to evaluate environmental perceptions, performed by Barraza [46], in a study on environmental perceptions and major expectations and concerns for the future of English and Mexican school children (7–9 years old). Pelander et al. [47] studied the perceived quality of care that children receive in hospitals by analysing the content of drawings collected from children aged 4 to 11 during their stay in a university hospital in Finland. However, it seems that no studies so far have studied possible solutions for IEQ-problems in classrooms with children themselves.

Therefore, as part of a series of tests in a semi-laboratory environment the SenseLab [48], 335 children from the previously-studied schools were invited to take part in a workshop to identify IEQ-problems that children currently have in their own classrooms and to conceptualize design solutions for those IEQ-problems.

2. Methods

2.1. Study design

This study (a workshop) was part of a series of tests performed in the SenseLab, with children from previous studied schools [16]. From mid-February to the beginning of April 2018, 335 children visited the SenseLab on 10 different days in the Science Centre (a technical and scientific museum) on the premises of the TU Delft in Delft, The Netherlands. The recruitment of children was on a voluntary basis. For the selection, the 21 schools visited in the spring of 2017 [16] were approached directly.

A workshop consisting of two parts was held in which children were asked to identify problems in their own classroom (part 1) and to design solutions to control/fix these problems (part 2), by making drawings or writing their choices/solutions on a piece of paper with colouring pencils and pens.

2.2. Facilities

In these studies, the workshops were held in the Experience room of the SenseLab [48]. The SenseLab comprises of four test chambers (one for each IEQ factor: air, light, acoustics and thermal aspects) and the Experience room (a room for integral perception). The Experience room is a room of circa 6.5 m (l) x 4.2 m (w) x 2.6 m (h) for integrated perception of IEQ-factors in a semi-lab environment. In the Experience room, a classroom set-up was created with 16 school desks and chairs for the children, two chairs for the workshop moderators, and a smartboard. The table tops of the desks were of a light-wood laminate, the floor was covered with grey smooth flooring material, and the ceiling comprised of white acoustical panels, as this combination was the most common in the field study. For the workshop, pens, pencils and crayons were available for the children to draw and write down their thoughts.

2.3. General procedure

In each of the test chambers, a test was performed relating respectively to air (smell) [49], thermal [50], lighting [51] and acoustical quality [52]. In the Experience room besides the workshop, an *exposure study* [53] was performed to test the acceptability of light, sound, smell, temperature and draught (and their possible interactions) with different environmental configurations.

When the children arrived in the Science Centre, they were led to a room where they could leave their belongings. They were given an introduction on why they were there and a short explanation about the schedule and the experiments. Then they were divided into two or three groups with a maximum of 16 children per group, depending on the total number of children. Each child received a pen (they could keep), a binder with a number on it (their personal number for the day), and the first page for the binder (for collecting personal information). They were asked to fill that in. Then each staff member was introduced and walked his or her corresponding group to the first destination. Per day, the research team comprised of 7–8 members.

In the case of schools with more than 32 children, three groups were formed: group 1 started in the Experience room, group 2 in the test chambers, and group 3 could visit the remaining part of the Science Centre. After 35 min, group 1 went to the test chambers, group 2 to the Science Centre and group 3 to the Experience room. For the other days (schools with less than 32 children), two groups were formed: group 1 started in the Experience room and group 2 in the test chambers. After 35 min the groups switched. Both groups could visit the Science Centre when they finished both rounds.

2.4. Procedure experience room

When the children were seated in the Experience room, they first received an introduction using the smart board. It was explained what they were going to do in the next half hour or so. For the workshop it was explained that they would be asked open questions, in which they could write or draw what they believed was important. They were told that they are the experts of their own classrooms and that we needed them to give us information to design better classrooms in the future. The answers or information they gave could not be wrong, it was their opinion.

The workshop comprised of two parts. In part 1, the children were asked to think about their own classroom at school and to choose an IEQ-problem that they were bothered by. They were asked to close their eyes and imagine their classroom and think about which aspect bothered them the most. They could discuss this problem with the person next to them and were asked to write and/or draw it as detailed as possible. They were also asked to describe during which activity (reading, writing, listening) they were bothered the most by that problem and if there was a special moment during the day (e.g. morning, afternoon) or during the year (e.g. summer, winter). Then the moderator asked two or more children to tell the group which problem was bothering them the most and why.

In part 2 of the workshop, the children were asked to imagine they are an inventor or scientist in 2040 with all resources available and to make a design for the future. They were allowed to discuss this with their neighbour and help each other to think of a solution. Questions like 'What does your classroom look like in 2040? How does the solution work? Who can use it, the teacher, the student, or others? When can you use it?', were asked to help them think of a solution. They could again write it down in their booklet and/or make a drawing on what they thought could help to solve these problems. The moderator again asked two or more children to show their solution and tell the group about it.

2.5. Ethical aspects

After recruitment of the schools, the parents received an information letter and a consent letter via the school management, usually two weeks

before the visit. On the day of the visit, the research team collected the consent forms from the teachers accompanying the children. For the children without permission to join the experiments, the school management generally decided not to have them join the visit. The Ethics committee of the TU Delft gave approval for the study.

2.6. Data management and analysis

For the two parts of the workshop, the drawings and the written text were analysed using content analysis. Content analysis aims to explore both quantitative elements (e.g. counts and frequencies) as well as qualitative patterns (e.g., exploring themes) within both text and images [54]. The elements of analysis were the IEQ-problems (part 1) and the solutions (part 2) appearing in the drawings and the written text. A coding scheme was then developed for each question to capture the range of answers provided by the children.

All written information on the forms of the 335 children was manually typed in Excel. The information of the drawings was added with a written description. Since the written responses obtained from the workshop were in Dutch, they were translated into English. Then, four researchers (authors of this article) reviewed the written information and checked the meaning of the drawings, in several sessions. A list of themes and sub-themes expressed for both the problems and the solutions was determined, followed by defining categories for each of the themes. This was first performed by the researchers independently, and then compared with each other. After the categories were determined, the researchers looked for overlapping or similar categories. These categories were further refined and reduced in number by grouping them together.

To systematically evaluate the 335 responses comprising of written comments and drawings, from each part of the workshop, the response of each child was assigned a theme and a category within that theme, coded, transferred to IBM SPSS Statistics 24.0, and used for statistical analysis. If a child provided more than one problem, more than one code was assigned (the same was applied for the solutions). After each child was assigned and their problems were coded, the solutions given by each child were connected to the problems that they provided.

To study possible differences of reported problems at school level and at individual level (child level), several Chi-Square tests were performed. A comparative analysis was also performed to investigate whether the results from this study could be related to the findings from the earlier field study [16].

3. Results

3.1. Participants

In total 335 children (with an average age of 10.6 years) joined the experiments during 10 days divided into 24 groups of 11–16 children from 7 different schools, with 2 or 3 groups per day. Some personal characteristics of these children are presented in Appendix 1.

3.2. Content analysis

The content analysis resulted in 5 themes (light, noise, temperature, air and other than IEQ), 16 sub-themes (11 for the problems and 5 for the solutions) and 92 categories (46 for the problems and 46 for the solutions).

3.2.1. Part 1: problems

In total, 513 problems were reported (an average of 1.6 problems per child) by 318 children. Answers from 17 children were either not related to the question or impossible to interpret and were therefore excluded from the analysis. Table 1 summarises 46 categories of reported problems in classrooms by the 335 participating children in the first part of

Table 1
Reported problems by 318 children in part 1 of the workshop.

Themes of problems (%)	Sub-themes of problems (%)		Categories of problems	N (%)
Light (16)	Sunlight (14)		Sunlight bothers me	40 (13)
			Inappropriate use of solar shades	5 (2)
			Glare caused by sunlight	4 (1)
	Artificial light (2)		Low light level	2 (<1)
			Inconsistent light level throughout the day	2 (<1)
			Flickering light	1 (<1)
			Unhappy with artificial light	1 (<1)
Noise (58)	Noise inside classroom (38)	Classroom appliance and furniture (3)	Noise from air conditioning system	5 (2)
			Noise from copying machine	1 (<1)
			Noise from door/ chair/drawer	5 (2)
		Children (43)	Noise from children inside classroom	111 (35)
	Noise outside classroom (10)		Noise from children outside classroom	31 (10)
		Outside classroom (not from children) (1)	Noise from wind/ rain	2 (1)
			Noise from toilet (e.g. hand dryer)	2 (1)
	Unspecified (12)		Noise (source unclassified)	39 (12)
Temperature (53)	Temperature changes (9)	Unspecified (8)	Temperature changes during the day (reason unclassified)	25 (8)
		Misuse of window/ heating system (9)	Temperature changes during the day due to bad use of window/ heating system	5 (2)
	Either too warm or too cold (44)		Too warm due to misuse of window/ heating system	7 (2)
			Too cold due to misuse of window/ heating system	17 (5)
		Seating position (2)	Too warm (sit next to heating system)	2 (1)
			Too cold (sit next to window)	3 (1)
		Unspecified (18)	Too warm (reason unspecified)	41 (13)
			Too cold (reason unspecified)	16 (5)
		Seasonal effect (15)	Too warm in summer	17 (5)
			Too cold in winter	13 (4)
			Too warm in summer and too cold in winter	17 (5)
		Overcrowding (2)	Too warm due to overcrowding	3 (1)
Air (22)	Stuffy air (6)		Stuffy air due to overcrowding	3 (1)
		Seasonal effect (2)	Stuffy air in summer	4 (1)
			Stuffy air in winter	2 (1)
		Unspecified (9)	Stuffy air (reason unspecified)	14 (4)

(continued on next page)

Table 1 (*continued*)

Themes of problems (%)	Sub-themes of problems (%)		Categories of problems	N (%)
	Smell (16)		Smell (source uncspecified)	13 (4)
		Inside classroom (12)	Smell of food (e.g. kitchen or after lunch)	3 (1)
			Smell from children	31 (10)
			Smell in winter (window is always closed)	3 (1)
Other (7)	Personal problem (4)		Bad social interaction (with teacher or other children)	11 (3)
			Lack of exercise during the day	1 (<1)
			Unable to concentrate during lessons	1 (<1)
	Classroom furniture, layout, size and maintenance (3)		Unhappy with seating position (e.g. sitting next to door)	1 (<1)
			Teaching appliances	1 (<1)
			Lack of power socket	1 (<1)
			Uncomfortable chair	4 (1)
			Cleanliness of the classroom	2 (1)
			Bad interior design	1 (<1)
			Lack of personal storage	1 (<1)
			Classroom is too small	1 (<1)

Note. Some of the total percentages presented are lower than the addition of the percentages of individual problems, because children, on average, reported 1.5 problem.

the workshop. Fig. 1 (a 4-way Venn diagram) shows a graphical representation of the reported IEQ-problems.

93% of the participating children identified problems in their classrooms related to indoor environmental aspects, such as air, noise, temperature, and light. Noise-related problems were most frequently reported (58%), followed by temperature (53%), air (22%), and light (16%). In total, 39% of the children reported more than one IEQ-problem in their classroom. The most common combination was noise and temperature (24% of the children), which was followed by the combination of temperature and air (12% of the children) and the combination of temperature, noise and light (6% of the children). Approximately 7% of the children's problems were not related to IEQ. 3% of the children were concerned about their relationship with their teachers and/or their classmates. In this study we classified these responses as 'other than IEQ', of which more details can be found in Table 1 and Fig. 1.

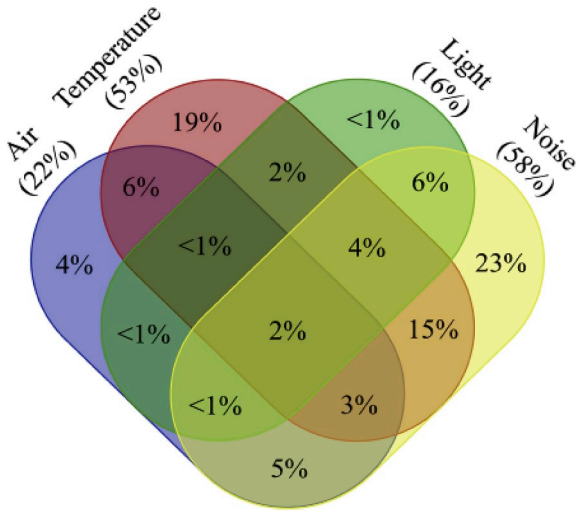

Fig. 1. A Venn diagram representing the components of classroom-related problems based on the responses of the 335 primary school children.

3.2.2. Part 2: solutions

In total, 335 children participated in part 2 of the workshop. The answers from 67 (20%) children were identified as either not related to the question or impossible to interpret. Therefore, the analysis of part 2 was based on responses of 268 (80%) children. These children proposed 446 solutions for their classroom problems (an average of 1.7 solution per person). 446 solutions were clustered into 46 categories, presented in Table 2.

12 types of solutions out of 46 categories were related to more than one IEQ-problem (an example is shown in Fig. 2), which accounts for 47% of the total number of solutions proposed by the children. For each of the solutions it was determined whether the type of solution was provided at school, classroom, local (desk + chair), individual, or at other level. 22% of the children proposed solutions (12 different types in total) for non-IEQ related problems, such as 'better' classroom furniture (e.g. chair with a cushion) (7%) or having a robot teacher (2%) (Fig. 3). Fig. 4 shows two solutions specifically proposed to solve one problem (i.e. smell (gasmask) and noise (headphone)).

3.2.3. Noise-related problems and solutions

35% of the children identified their classmates as the main source of noise in the classroom. The other sources of noise in the classroom identified included 'air conditioner', 'classroom furniture' and 'copying machine'. 38% complained about noise in the classroom. 10% of the children complained about noise outside the classroom. The most reported source of outdoor noise was playing school children, which was reported by 10% of the children. The other sources of noise in this category were outdoor weather such as rain and wind, and noise caused by a toilet dryer. Additionally, 12% identified noise as their main problem in the classroom, but they did not further specify the source of noise.

To improve the acoustical conditions in a classroom, 62% of the children came up with a total of 17 different types of solutions. The majority of their solutions were to reduce the noise level by controlling the sound when receiving, such as wearing a headphone (21%), replacing walls into noise-proof walls or windows (9%) and installing an acoustical panel on their desk (2%). Demanding more strict control of children by the teacher (6%), a mouth cover (4%), and removing noisy children (2%) were also suggested. 10% of the children suggested another approach to solve their noise problems: individual space within classroom (6%), learning via a PC (3%) and a smaller group of children per classroom (2%).

3.2.4. Thermal-related problems and solutions

44% of the children indicated that they felt either too warm or too cold in their classroom. More specifically, 27% of the children complained 'it was too warm', 15% 'too cold' and 5% 'too warm in summer and too cold in winter'. Some children were able to further describe the reasons for such problems in their classrooms. 'Seasonal effect' was pointed out by 15%, 'misuse of window/heating system' by 9%, and 'seating position next to window/heating system' by 2% of the children.

Table 2
Reported solutions for the problems in their classrooms by 268 children in part 2 of the workshop.

Themes of solutions (%)	Sub-themes of solutions (%)	Categories of solutions	N (%)
Light (13)	Local level (1)	Black coloured desk	1 (<1)
		Desk lamp	3 (1)
	Classroom level (5)	Moveable smart board	1 (<1)
		More curtains[a]	3 (1)
		Controllable light	2 (1)
		Soft (less intense) light	2 (1)
		More intense light	2 (1)
		Different colour of light	2 (1)
	School level (6)	Solar shades[a]	17 (6)
	Other (1)	Learning via a PC[a]	3 (1)
Noise (62)	Individual level (26)	Mouth cover on noisy children	12 (4)
		Remote control that mutes talking of children	1 (<1)
		Special shoes that do not make sound for running children	1 (<1)
		Headphone (or earbud)	56 (21)
	Local level (6)	Classroom furniture (e.g. chair with a cushion)[a]	3 (1)
		Individual space within classroom[a]	14 (5)
	Classroom level (10)	Send noisy children away from the classroom	4 (1)
		Turn off air conditioning	2 (1)
		Control of windows (e.g. automatic control)[a]	5 (2)
		Noise-absorbing device	5 (2)
		Acoustical panels	6 (2)
		Smaller group of children per classroom[a]	5 (2)
	School level (10)	Use hand towel instead of dryer	1 (<1)
		Noise-proof walls or windows	24 (9)
		Bigger school[a]	1 (<1)
	Other (9)	More strict control on noisy children by teacher	16 (6)
		Learning via a PC[a]	8 (3)
Temperature (47)	Individual level (3)	Smart clothes that control body temperature	3 (1)
		Warm (or more) clothes	5 (2)
	Local level (8)	Seating position (e.g. less children next to windows)	2 (1)
		Individual heating/cooling system at desk or chair	19 (7)
		Individual space within classroom[a]	1 (<1)
	Classroom level (19)	More curtains[a]	1 (<1)
		Heating system (incl. Control system)	27 (10)
		Ventilator[a]	6 (2)
		Control of windows (e.g. automatic control)[a]	15 (6)
		Imaginary animal or superhero that removes heat	3 (1)
	School level (16)	Solar shades[a]	4 (1)
		Air conditioning[a]	41 (15)
	Other (1)	Robot teacher (who responds to all kind of requests)[a]	1 (<1)
Air (22)	Individual level (2)	Gas mask	3 (1)
		Tape on children's butt	2 (1)
	Local level (7)	Individual ventilator at desk	15 (6)
		Individual space within classroom[a]	3 (1)
	Classroom level (13)	Air conditioner[a]	5 (2)
		Ventilator[a]	16 (6)
		Smell-absorbing device	5 (2)
		Control of windows (e.g. automatic control)[a]	6 (2)
		Plants in classroom[a]	3 (1)
		Bigger school[a]	1 (<1)
Other (22)	Individual level (1)	Background music (on headset)	3 (1)
	Local level (7)	More storage in each desk	1 (<1)
		Classroom furniture (e.g. chair with a cushion)[a]	18 (7)
	Classroom level (5)	Different layout of classroom	3 (1)
		Plants in classroom[a]	2 (1)
		Dog in classroom	2 (1)
		Smaller number of children per classroom[a]	4 (2)
		Better hygiene in classroom	1 (<1)
	School level (2)	Bigger school[a]	5 (2)
	Other (7)	Robot teacher (who responds to all kinds of requests)[a]	6 (2)
		More exercise during school	2 (1)
		Learning via a PC[a]	12 (4)

[a] An asterisk indicates solutions that were reported for more than one theme of problems.

Fig. 2. Drawing tackling many problems.

Additionally, 9% of the children reported 'too much variation in temperature within a day' as their main problem in the classroom.

47% of the children proposed 13 different solutions for thermal discomfort, of which 36% work at classroom level. An air conditioning system (15%), a better heating system (10%) and a better control of windows were proposed most. A different seating position (2%) and a robot teacher, who can respond to all kinds of requests (<1%), were also

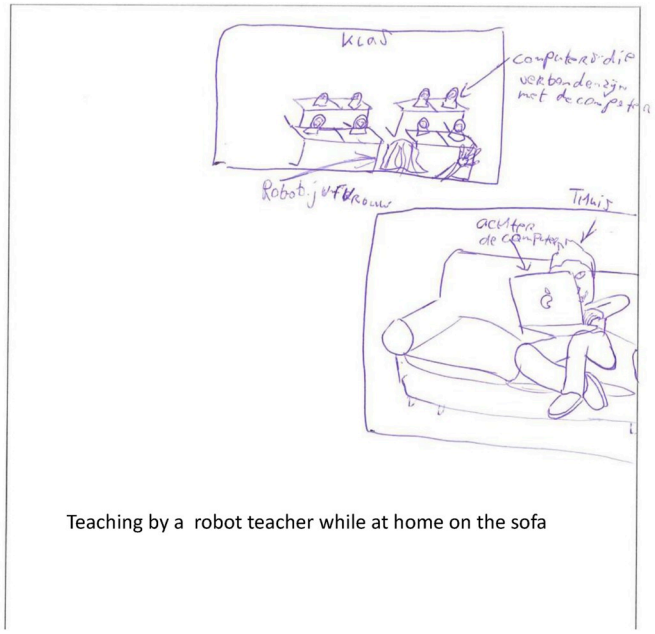

Fig. 3. Solution for a problem not related to IEQ.

suggested. Few children (3%) suggested solutions at individual level, such as wearing more clothes (2%) or smart clothes that automatically regulate their body temperature (1%). 7% suggested an individual heating/cooling system at their desk.

3.2.5. Air-related problems and solutions

22% of the children were bothered by air-related problems, comprising of children who complained about 'smell' (16%) and children who complained about 'stuffy air' (6%). With respect to smell quality, 10% of the children pointed out their classmates as the source of smell in the classroom. Only few children (less than 1%) identified the smell of food (either from kitchen or after lunch) as the problem.

22% of the children proposed 10 different types of the solutions for air-related problems in their classrooms. The use of a ventilator (6%) or an individual desk ventilator (6%) at each desk was proposed most. Other solutions were to have better control of the windows (2%), a smell-absorbing device (2%), an air conditioner (2%), having more plants in the room (1%) and a gas mask (1%).

3.2.6. Light-related problems and solutions

16% of the children were bothered mainly by light-related problems. Most of their problems (14% of the children) were associated with incoming sunlight. Slightly less than 2% of the children complained about the quality of artificial light in their classroom, such as inappropriate light level and flickering light.

10 different types of solutions were suggested by 13% of the children to improve light conditions in their classrooms. Most of the children (6%) suggested to make use of or improve the use of solar shades (6%). A desk lamp (1%), controllable light (1%) and a different colour of light (1%) were also suggested. 1% of the children suggested to change classroom furniture (e.g. black coloured desk and moveable smart board), to solve problems such as glare.

3.3. Detailed analysis

Chi-square tests (with Bonferroni correction) were performed to investigate the differences of the problems between the seven participating schools (see Table 3), differences in self-reported problems between gender and age group (see Table 4) and the effect of age on self-reported problems (see Table 4). The results show that girls in general complained more about noise ($p = 0.036$), temperature ($p = 0.001$) and air ($p = 0.028$) than boys. The results of the analysis of the two different age groups (8–10 years old and 11–13 years old) show that the younger group was more sensitive to noise inside the classroom ($p = 0.006$) than the older group. None of the other elements such as temperature, air and light were found to be related to age.

3.4. Comparative analysis

254 children (mean age: 10.8 years; 123 girls and 121 boys) out of

Fig. 4. Solutions focused on one problem: smell (gasmask) and noise (headphone).

Table 3
Percentage of children of each of the seven participating schools who reported noise, temperature, air and light being a problem in their classroom and their relationships.

	S1 (N = 82)	S2 (N = 46)	S3 (N = 58)	S4 (N = 26)	S5 (N = 44)	S6 (N = 43)	S7 (N = 36)	Adj. P^a
Noise (overall)	62.2	60.9	77.6	19.0	47.7	44.2	41.7	< **0.001**
- Noise inside classroom	31.7	41.3	39.7	15.4	43.2	39.5	33.3	0.998
- Noise outside classroom	25.6	13	5.2	0	2.3	2.3	2.8	< **0.001**
Temperature (overall)	48.8	65.2	62.1	42.3	31.8	39.5	55.6	0.216
- Either too cold or too warm	40.2	52.2	53.4	30.8	31.8	30.2	41.7	0.875
- Temperature changes	8.5	13	8.6	11.5	0	9.3	13.9	1
Air (overall)	13.4	19.6	37.9	19.2	9.1	32.6	2.8	**0.002**
- Smell	11	19.6	31.0	3.8	2.3	25.6	2.8	< **0.001**
- Stuffy air	2.4	8.7	6.9	15.4	6.8	7	0	0.981
Light (overall)	7.3	6.5	29.3	42.3	0.0	11.6	22.2	< **0.001**
- Sunlight	6.1	4.3	22.4	42.3	0	11.6	22.2	< **0.001**
- Artificial light	1.2	2.2	6.9	0	0	0	0	0.801

[a] Adj. *P*-values in bold refer to significant relationships at 5% level.

Table 4
Percentage of children who reported noise, temperature, air and light being a problem in their classrooms and their relationships for gender and age.

	Gender			Age		
	Boy (N = 166)	Girl (N = 166)	P^a	8-10 (N = 149)	11-13 (N = 177)	P^a
Noise (overall)	49.4	60.8	0.036	65.1	47.4	0.007
- Noise inside classroom	29.5	42.7	**0.012**	46.3	28.2	**0.006**
- Noise outside classroom	9.6	10.2	0.854	8.1	10.7	0.823
Temperature (overall)	41.6	58.4	**0.001**	51.7	49.7	0.352
- Either too cold or too warm	36.7	45.2	0.118	44.3	39.5	0.190
- Temperature changes	4.8	13.3	**0.007**	7.4	10.2	0.525
Air (overall)	15.1	24.7	**0.028**	16.8	23.2	0.078
- Smell	10.8	19.3	**0.032**	14.8	15.8	0.346
- Stuffy air	5.4	6.6	0.645	4.7	7.3	0.571
Light (overall)	13.9	15.7	0.643	14.1	16.4	0.427
- Sunlight	12	13.9	0.624	12.1	14.7	0.222
- Artificial light	1.8	1.8	1	2	1.7	0.329
Number of problems						
- A single IEQ factor	54.2	44.6	0.079	47.0	51.4	0.719
- More than one IEQ factor	28.3	49.4	< **0.001**	43.0	36.7	0.583

[a] *P*-values in bold refer to significant relationships at 5% level.

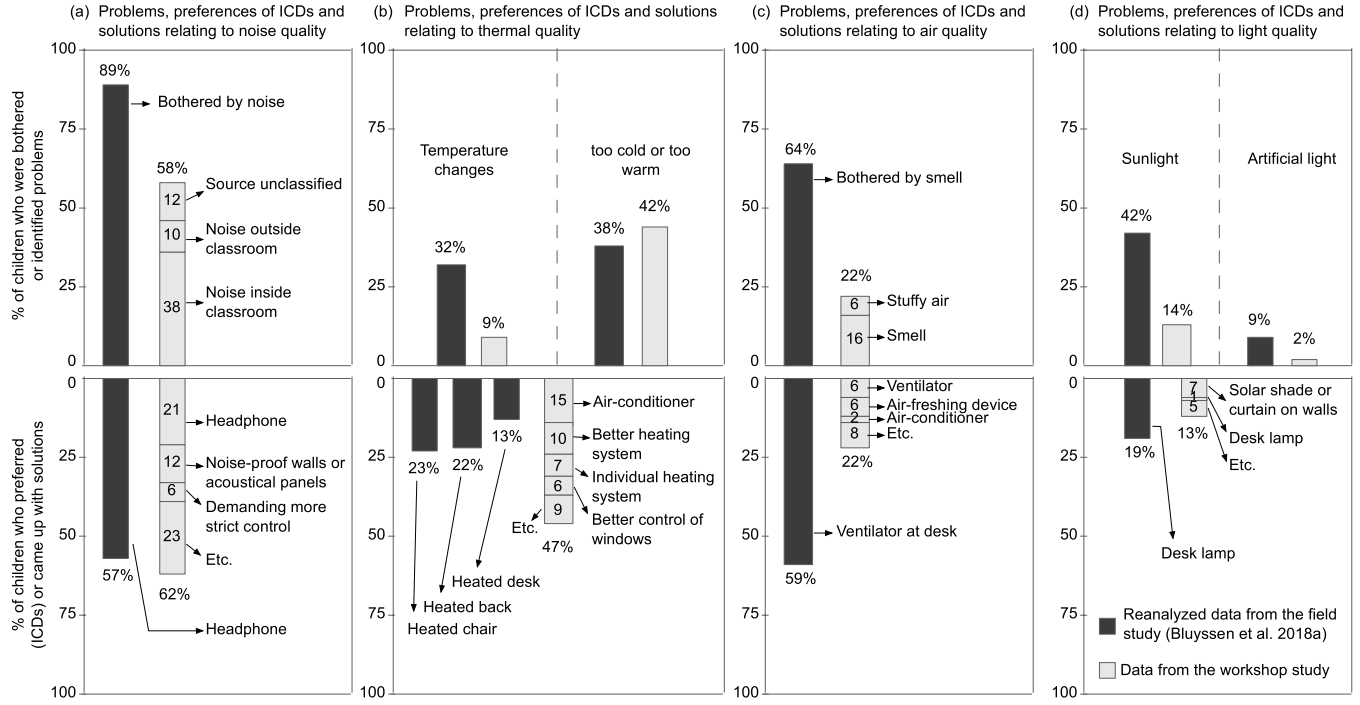

Fig. 5. Reported problems, preferences of ICDs and solutions suggested by 254 children who participated both in the field study and in the workshop.

335 children were also involved in the previous field study in 21 schools [16]. In the field study, children were given a questionnaire to assess their health and comfort related problems in a classroom and give their preference for six individually controllable devices (ICDs), including a 'headphone', 'heated chair', 'heated back', 'heated desk', 'ventilator at desk' and 'desk lamp, to improve the indoor environment in their classroom [32]. A comparative analysis was performed to study the possible differences between the problems and preferences of ICDs reported via a questionnaire with pre-defined items in a real classroom and the problems and solutions via an open-ended questionnaire in the current workshop study. Fig. 5 shows the comparisons for the 254 children that participated in both the field study and this study (part 1 and part 2 of the workshop).

3.4.1. Noise

The field study showed first of all an urgent need for acoustical measures. Most classrooms have acoustical ceiling tiles, but this is not enough to create the acoustical environment the children need to feel well. In both studies, it is seen that the highest percentages of problems were found for noise: 89% in the field study and 58% in the workshop study. This outcome suggests that regardless of the research method, the children are bothered the most by noise in their classroom. To improve the acoustical quality in their classrooms, 57% preferred a headphone in the field study, while in this study 62% suggested various solutions, among 21% headphones.

3.4.2. Temperature

In the field study, 32% of the children reported being bothered by changes in temperature and 38% reported the temperature to be either too cold or too warm. In the workshop, the majority of the identified thermal problems were related to being too cold or being too warm (42%) and only 9% described problems related to changes in temperature. To improve the thermal quality, ICDs such as a heated chair, a heated back and a heated desk were preferred by 23%, 22% and 13% respectively in the field study. In the workshop 17% of the children suggested an improved heating system (including individually controlled heating system), 15% suggested the use of an air conditioner in the classroom, and 6% suggested improving the control of the windows in the classroom.

3.4.3. Air

Concerning air quality, the field study revealed that 64% of the children were bothered by smell, whereas in this study only 16% of the children described smell as their main problem in the classroom. In the field study, 59% preferred a ventilator at the desk, which comes close to the 64% that were bothered by smell. 22% of the children in the workshop suggested solutions to improve air quality in a classroom, which matches the 22% that described the problems related to air conditioning.

3.4.4. Light

Compared to the field study, 42% of the children were bothered by sunlight, a lot less children identified light as their main problem in this study. Nevertheless, the children were able to suggest their own specific needs for their preferred light conditions very well: such as use of a different colour of light and less reflecting desk surface materials. While, in the field study 19% of the children reported their preference for a desk lamp, in this study only 1% did.

4. Discussion

4.1. Study design

In this study, a first attempt was made to involve children as co-designers to improve the IEQ of their classrooms using generative tools [54] revealing both visual and verbal components (drawings and/or written text). In the first part of the workshop, the context was to set the problems they experience in their classroom related to IEQ. The school children were very capable of pointing out what their main problem was and were in general able to describe those problems very well with text and/or drawings. Also, the reported problems confirm earlier findings suggesting that children have different annoyances with and preferences to their classroom environments [16,32]. The study design enabled to collect more detailled information about the children's problems, compared to a questionnaire, e.g. "too cold due to misuse of window/heating system" or "noise from wind/rain". The second part of the workshop then focused on solutions for these identified problems. The solutions ranged from existing solutions, for example a headphone to protect against noise (Fig. 4), to far-fetched solutions such as send noisy children away by means of a rocket. Although, the combination of text and drawing provided in general more detailed information than a drawing without text or text without drawing, revealing visual and verbal information appeared to be effective in expressing solutions closely related to IEQ-problems.

In Appendix 2, a dendrogram is presented of the IEQ and non IEQ-related problems in classrooms and reported solutions. It shows that although children identified a certain problem or problems, they did not always provide solutions to those problems and provided often solutions to other problems. The study design could be the reason for this: the children were asked to discuss the problems with each other, and some of them presented their problems to the group. This process could have led to choosing another problem or problems for the second part of the workshop in which a solution for their problems was the aim.

4.2. Problems

4.2.1. Comparision with field study

In the previous field study, of the 1145 participating children (average 10 years old), 87% was bothered by noise (mainly produced by themselves), 63% by smells (mainly produced by themselves), 42% by sunlight when shining, 35% didn't like the temperature in the classroom (too cold or too warm), 34% experienced temperature changes and only 7% were bothered by draught [16]. In this study, for all IEQ-aspects, except for temperature, the percentage of children that identified a certain aspect as a problem was lower than the percentage of children that were bothered by that aspect. This could be related to the method applied. Complaints encountered in the field study were gathered based on a questionnaire with scales, while in the workshop problems were expressed in writing and drawings by the children in the Experience room based on open questions. In the workshop they could give more details as compared to the field study. For children that are able to describe or draw their problems as well as their solutions this works very well. From the 268 children responses that were useable (complete), 254 children were also part of the field study. All of those 254 reported problems related to IEQ. This might indicate that they all were already familiar with the aspects of IEQ and the questions that we asked them. It must also be mentioned that the 254 children that participated before, were a year older than in the field study, and probably their classroom at school was different from the year before as well as their seating position and outdoor weather conditions at the time of the field study compared to the current study, one year later.

4.2.2. Differences at school level

In the detailed analysis, problems related to smell and sunlight were found to be related to the schools, indicating that some building and

classroom characteristics might be responsible for this statistical difference. In the field study the ventilation type (mechanical assisted vs. natural) was found to be associated with the number of complaints [16]: a child in a classroom with mechanical assisted ventilation (mechanical exhaust) had fewer complaints than a child in a classroom with natural ventilation only. Also, the presence of a solar shading device that hampers ventilation/opening windows increased the number of complaints in the field study. These findings indicated inefficient ventilation when needed. The latter finding (solar shading device hampers natural ventilation) could also have led to pointing out sunlight as a problem. Other possible reasons identified in the field study were: lack of solar shades, reflection on the desk, or feeling too warm, while in this study children pointed out sunlight, inappropriate use of solar shades, glare caused by sunlight and misuse of window as problems related to the sun. Unfortunately, the actual characteristics of the classrooms of the children participating were not recorded, so it is therefore difficult to confirm the actual differences between the schools.

Noise from outside the classroom was also found to be related to the schools, whereas noise caused inside the classroom was not. Considering the fact that most of the noise inside the classroom was reported to be caused by the children themselves, the results suggest that children are bothered by noise caused by their classmates regardless of which school they are in.

4.2.3. Differences between boys and girls

There was no difference in gender ratio for the seven participating schools, and could therefore not be the reason for the differences found between girls and boys. Girls identified noise inside the classroom and smell more as a problem than boys, while there was no statistical difference in the percentages of problems related to noise outside the classroom, stuffy air or light. Although a different target group, no gender difference in light perception was found in a study on student perceptions of higher education classrooms [55].

Concerning temperature, girls noted temperature changes more often as a problem, while problems related to the temperature (too cold or too warm) did not differ significantly. This is in line with a study performed by de Giuli et al. [56] in seven schools with children aged 9–11 years old, in which no statistically significant differences were found between boys and girls with regards to dissatisfaction with temperature, glare or noise. Temperature changes were not studied. For adults, however, gender differences in thermal comfort and temperature preference have been shown in several studies (e.g. Ref. [57]): females feel both uncomfortably cold and uncomfortably hot more often than males.

It was also found that girls also reported more problems related to more than one IEQ-aspect than boys. In a review study performed by Kensinger [58], it was shown, both by behavioural and neuroimaging evidence, that people in general memorize bad things better than good things. In the field study, the girls in general were more bothered by comfort-related problems than boys, while boys reported more symptoms than the girls [16]. Because the workshop in the Experience room concerned mainly comfort-related complaints, the better recollection of negative feelings towards them by the girls, could explain that girls reported more problems related to comfort aspects than boys.

4.3. Solutions

The main aim of this study was to conceptualize solutions from identified problems in the classroom by primary school children. Most studies that have involved children as co-designers tend to focus on the methodology (e.g. Refs. [59–61]) and the process rather than on the final products conceptualized with their involvement. While many other studies tend to focus on design for children with special needs (deaf, autism, disabilities) (e.g. Refs. [62–64]. An exception perhaps, was the study performed by Soccio [35], in which children were asked to answer the question 'How could your existing classroom be redesigned for improved comfort?' by using a scale model of their classroom and pre-cut doors, windows, lighting, heating and cooling etc. Furthermore, most studies in which children participate in the design process, tend to be for the development of technologies for children [65], but not necessarily for solutions for future classrooms or for the improvement of the indoor comfort of the children (e.g. Refs. [66,67]). In such studies, which tend to use a technique called 'cooperative inquiry' comparable to the one used in the present study, it has been concluded that for technology, children want 'control', 'social experiences', and 'expressive tools' [68]. In this study, 22% of the children proposed solutions for non-IEQ related problems, indicating a need for 'control' and 'social experiences' as well.

While in the study performed by Bartlett et al. [36], lighting had the largest impact on the performance of children, the outcome of this study showed that the majority of the children identified sound (noise) as a major problem. They blamed their classmates being noisy and their solutions were mainly related to those noisy children. This is similar to findings by McAllister et al. [69] based on interviews with preschool children. While a conventional air conditioning system was identified the most as the solution for being too warm or too cold, the second most important problem, for getting rid of smell (caused by classmates), considerably less of a problem in this workshop than in the field study [16], several interesting solutions were provided (e.g. gas mask, smell-adsorbing device, tape on children's butt). For lighting, the solar shades were pointed out the most often as the solution for incoming sunlight.

5. Conclusions

As part of a series of tests with children from 7 primary schools, 335 children participated in a workshop to create solutions for improving the identified IEQ-problems of their classrooms through drawings and/or written text. The outcome suggests that children are very capable to express their perception of IEQ in their classroom, and that most children are conscious and knowledgeable about existing solutions and creating new ideas to control IEQ in classrooms. Children can be valuable contributors in co-designing 'new' or 'adapted' classroom environments.

The previous field study of 21 schools (1145 children in 54 classrooms) and this study, although different in research methodology, both suggest that noise especially caused by children themselves is the biggest problem in classrooms. Girls reported more problems than boys, which is possibly related to a better recollection of negative feelings towards those problems in their classrooms (girls were more bothered by comfort-related aspects than boys).

In future studies it is recommended to include an inspection of the classrooms of the children in the same period of time as the workshop is held, in order to be able to better identify the reasons for the reported problems.

Declaration of competing interest

The authors 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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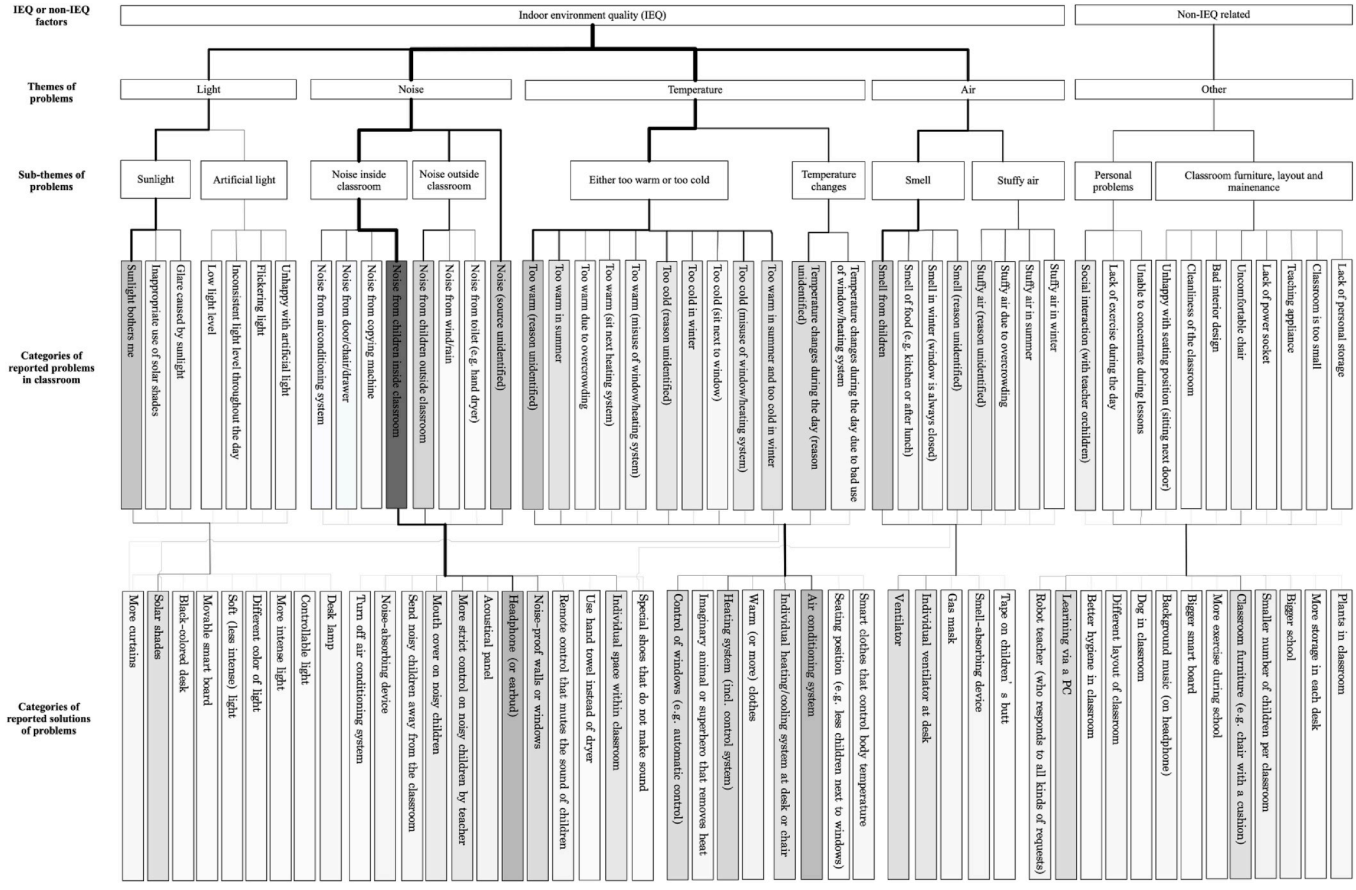
Appendix

Appendix 1Personal information of the 335 children that joined the workshop at the experimental days

Date	No. Of children	Girls n (%)	Mean Age	Feel good n (%)	Allergy n (%)	glasses/lenses n (%)	Colour blind n (%)	Hearing problem n (%)	Having a cold n (%)
Feb 13	15	6 (40)	10.1	14 (93)	4 (27)	3 (20)	0	0	8 (53)
	12	5 (42)	10.3	10 (83)	3 (25)	3 (25)	0	1 (8)	7 (58)
Feb 15	15	8 (53)	11.4	12 (80)	6 (40)	2 (13)	0	0	9 (60)
	14	6 (43)	11.4	12 (86)	4 (29)	2 (14)	0	0	6 (43)
Feb 20	15	10 (67)	9.3	13 (87)	5 (33)	2 (13)	0	2 (13)	5 (36)
	11	5 (45)	9.4	11 (100)	10 (91)	1 (9)	0	0	1 (13)
Feb 22	12	5 (42)	10.1	9 (75)	2 (17)	1 (8)	0	0	6 (50)
	12	2 (18)	10	12 (100)	4 (33)	0	1 (8)	0	4 (33)
	12	9 (75)	10.3	12 (100)	4 (36)	1 (8)	0	0	8 (73)
March 8[a]	15	7 (47)	10.6	14 (93)	5 (33)	3 (20)	0	0	7 (47)
	15	6 (46)	11.7	13 (93)	5 (33)	4 (27)	1 (7)	1 (7)	2 (13)
	14	6 (43)	11.7	9 (64)	4 (29)	1 (7)	0	0	5 (36)
March	14	6 (43)	11.3	14 (100)	4 (29)	1 (7)	0	0	2 (14)
15	12	8 (67)	11.1	10 (91)	4 (33)	2 (17)	1 (8)	1 (8)	5 (42)
March	14	11 (79)	10.3	13 (100)	5 (36)	2 (14)	1 (7)	0	11 (79)
20	14	6 (43)	10.5	14 (100)	1 (7)	0	0	0	7 (50)
March	15	12 (80)	11.5	15 (100)	8 (53)	3 (20)	0	3 (20)	4 (27)
27	15	5 (33)	11	14 (93)	2 (14)	2 (13)	0	0	7 (47)
April 3[b]	16	7 (44)	9.5	16 (100)	5 (31)	2 (13)	0	2 (13)	4 (25)
	16	6 (38)	9.6	13 (81)	2 (13)	1 (6)	0	0	10 (63)
	14	7 (50)	9.3	10 (71)	5 (39)	2 (14)	0	2 (14)	4 (29)
April 5	16	7 (44)	10.6	14 (88)	4 (25)	4 (25)	0	1 (6)	8 (50)
	16	12 (75)	11.6	11 (69)	5 (31)	4 (25)	0	0	9 (56)
	11	4 (36)	10.9	9 (82)	3 (27)	2 (18)	0	1 (9)	7 (64)
Total	335	166 (50)	10.6	294 (88)	94 (28)	48 (14)	4 (1)	14 (4)	146 (44)

[a]: school from city in province North-Holland (North of the Netherlands).
[b]: school from village in province Brabant (South of the Netherlands).



Appendix 2. A graphical representation (dendrogram) of the reported problems in classrooms and reported solutions by the 335 participating children. The lines are thicker when there are more children reporting a certain solution for a certain problem.

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