Evaluation of indoor environmental quality and pupils' satisfaction in Flemish primary schools

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Abstract. Children spend much of their time in classrooms, which often have an unsatisfactory indoor environmental quality (IEQ). Unsatisfactory IEQ conditions could hamper pupils' learning performance. Therefore, it is important to provide IEQ conditions which meet the pupils' needs. This study evaluates the IEQ and pupils' satisfaction in 7 primary school classrooms. 6-week long data collection campaigns were performed during heating season and within the frame of a citizens' science project. Data collection consisted of both IEQ monitoring and satisfaction assessments. The following IEQ parameters were monitored: CO_2-concentration, air temperature, relative humidity, sound pressure level and lighting level. Pupils' satisfaction and knowledge on nature of science (NoS) was assessed using both right-here-right-now and retrospective surveys. The collected data was used to (1) evaluate the classrooms' IEQ, (2) asses pupils' satisfaction with IEQ, and (3) validate a recent developed questionnaire to determine pupils' NoS. Results show that the classrooms' IEQ often violates guideline values, especially too low room temperatures were found. Furthermore, the satisfaction assessments indicate frequent dissatisfaction with the acoustic (18.4%), IAQ (16.5%) and thermal (11.7%) conditions in the classroom. Lastly, the validation of the NoS questionnaire showed insufficient internal consistency in the subscales of the questionnaire.

Keywords. Indoor environmental quality, Occupant satisfaction, Classrooms, Nature of Science

1 Introduction

The indoor environmental quality (IEQ) of classrooms is often perceived as unsatisfactory by pupils and teachers (Carton et al., 2022; Onderzoek Centrum voor Gezonde Scholen, 2013). In addition, the IEQ conditions strongly affect the performance of teachers and pupils (Wargocki et al., 2019, 2020). Therefore, an optimal classroom IEQ should be provided in order to minimize learning losses. In order to guarantee a proper IEQ, governments have adopted guideline values that public buildings should comply with (Vlaamse Overheid, 2018). As a results of the COVID pandemic, attention on IEQ conditions increased which resulted in the definition of practical guidelines to maintain an acceptable indoor air quality (IAQ) in classrooms (Mampaey et al., 2021).

This study analysed the IEQ conditions and pupils' satisfaction with the IEQ in seven primary school classrooms. Data collection campaigns were performed consisting of IEQ monitoring and occupant satisfaction assessment via regular right-here-right-now (RHRN) surveys. The collected data was used to assess the IEQ conditions and occupants' satisfaction with that IEQ in Flemish primary schools during heating season. The data collection campaigns were performed in the frame of the citizens' science project: 'BurgerSTEM'. This project investigated the integration of citizens' science in primary schools, and its effect on pupils' scientific literacy. Within this study, a recently developed questionnaire to assess pupils' nature of science (NoS) or understanding of science was partly validated. The NoS survey could help to determine the impact of pupils' participation in a scientific project on their NoS.

2 Methods

2.1 Case study classrooms

Seven classrooms from four different primary schools in Flanders (Belgium) were monitored for six weeks from October until December 2021. Each of these classrooms was occupied by the same group of pupils

and teachers. Three of the classrooms (i.e. A, B and C) were identical and located in the same school. More detailed information on the classrooms are shown in **Table 1**.

Table 1

Case study classrooms description

Classroom	Volume	Operable window area + orientation	Ventilation
A	182m^3	1m^2 East	Mechanical extraction
B	182m^3	1m^2 East	Mechanical extraction
C	182m^3	1m^2 East	Mechanical extraction
D	216m^3	11.77m^2 North-West	Natural
E	380m^3	4m^2 South-East	Natural
F	/	1m^2 West	Balanced mechanical
G	165m^3	1.76m^2 South-East	Natural

2.2 Monitoring set-up

A monitoring campaign was set-up in the seven classrooms from 21/10/2021 until 14/12/2021. The monitoring period corresponded to heating season conditions. Data collection was paused from 01/11/2021 until 07/11/2021 due to a school holiday. The classroom IEQ conditions were monitored using a HOBO-MX, HOBO U12-012 and Netatmo smart weather station. The three measurement devices were placed at opposite sides of each classroom and at different heights ranging from 0.8 to 1.5m. The sampling frequency was set to 5 minutes. **Table 2** gives an overview of the measured IEQ parameters with the measurement accuracy per monitoring device.

Figure 1

Example of the CO_2 monitoring device (Selectron, 2021)

During the monitoring period, all classrooms were equipped with an additional CO_2-monitoring device to inform the pupils and teachers about the IAQ condition in the classroom. The monitoring device was cased as a bird in order to make it interesting for pupils (Figure 1). The monitoring device had two functions, i.e., changing eye colours and whistling. The eye colour changed from green to blue and from blue to red at a CO_2-level of 800 ppm and 1200ppm respectively. The device was set to whistle at 1000ppm. The whistling function was only activated from the fourth week of the monitoring campaigns.

Table 2

Overview measured IEQ parameters with accuracy

Device	Variable	Accuracy
Netatmo smart weather station (indoor module)	Air temperature [°C]	± 0.3 °C
	Relative humidity [%]	± 3%
	CO_2-concentration [ppm]	±50 ppm (<1000 ppm) 5% (>1000 ppm)
	Air pressure [hPa]	± 1mbar
	Sound level [dB]	/
Onset HOBO MX	Air temperature [°C]	± 0.21 °C
	Relative humidity [%]	± 2% (20% - 80%) ± 6% (< 20% & > 80%)
	CO_2-concentration [ppm]	±50 ppm
Onset HOBO U12-012	Air temperature [°C]	± 0.35 °C
	Relative humidity [%]	± 2.5 % (10% - 90%) ± 5 % (< 10% & > 90%)
	Light intensity [Lx]	/

2.3 Survey content and distribution

The assessment of the occupants' satisfaction with the classroom IEQ, and the evaluation of pupils' knowledge of science was done using online surveys. The online surveys were designed and distributed using the software Qualtrics (Qualtrics, 2005). Two types of surveys were used in this study, i.e., a retrospective survey and a RHRN survey. For both survey types both a pupil- and teacher-version was prepared. All surveys were in Dutch, which was the native language of the pupils and teachers. This paper will only focus on the surveys distributed among the pupils.

2.3.1 Retrospective survey

The retrospective survey was completed at the start and at the end of the monitoring campaign. The retrospective survey assessed pupils' perception and satisfaction with IEQ for the past weeks and was based upon the survey defined in a previous study (Carton

et al., 2021). Furthermore, pupils' NoS was assessed using the survey developed by Boven et al. (2021). The survey is an adaptation of the survey of Chen et al. (2013), and is suitable for Flemish pupils from 10 to 12 years old. The assessment of NoS was done by asking pupils' opinion on 20 statements, regarding their views on science, and on a five-point Likert scale (1= Strongly disagree, 2= Disagree, 3= neither agree nor disagree, 4= Agree, 5= Strongly agree). Pupils had the option to indicate 'I don't understand the question' in case the statement was unclear to them. The 20 statements could be categorised into four subscales, i.e., tentativeness, creativity, coherence and objectivity, and theory-ladenness (=scientific observations are shaped by a scientist's previous experiences). The four subscales were in line with four of the seven constructs of NoS (Chen et al., 2013)

2.3.2 RHRN survey

The RHRN assessed pupils' and teachers' perception and satisfaction with the classroom IEQ at the moment of completing the survey. The survey started by asking pupils' id number, which was pseudonymised afterwards, in order to track their responses throughout the monitoring campaign. The RHRN survey continued with gathering contextual information, such as, the moment of the day, activities done by the pupils before completing the survey, their location in the classroom, and number of windows and doors opened in the classroom. Afterwards, pupils' satisfaction with the separate IEQ domains (i.e., indoor air quality (IAQ), thermal, acoustic and visual comfort) and the IEQ as a whole were assessed on a 5-point scale in the form of stars (1 star = Very dissatisfied, 2 stars = Dissatisfied, 3 stars = Ok (Just satisfied), 4 = Satisfied, 5 = Very dissatisfied). In case that pupils have given a satisfaction score lower than three stars, a follow-up question appeared asking about the cause of their dissatisfaction. In case the RHRN survey was completed at the end of the day, additional questions on pupils' motivation on completing the surveys were posed.

A survey completion schedule was designed and sent to the participating schools. The participating classes were asked to complete the RHRN surveys five times a day for two days a week (i.e., Monday or Tuesday and Thursday or Friday). Of the five completion moments for the RHRN survey, three assessed the satisfaction upon entering the classroom (i.e., start of the day, after the morning break, after afternoon break), and two assessed the satisfaction when pupils and teachers were in the classroom for some time (i.e., before the morning break, end of the day). The two survey completion moments, i.e., upon entering and before leaving the classroom, were used in order to assess pupils' satisfaction before and after adapting to the indoor environment.

Furthermore, pupils' motivation for filling in the survey and their interest in the study were assessed at the end of a school day. From the fourth week of the monitoring campaign, the RHRN survey was extended with two questions. One question asked about the whistling of the CO_2-monitoring device. In a second question, the pupils could indicate which actions he/she or the teacher took to improve the IAQ in the classroom.

2.4 Data analysis

2.4.1 IEQ evaluation

The classroom IEQ conditions were evaluated based on national (Vlaamse Overheid, 2018) and international guidelines (EN 12464-1). A subset of the monitoring data was used, which consisted of measurements during which the classroom was occupied by the pupils. Firstly, only measurement data during school hours were retained, i.e., Mondays, Tuesdays, Thursdays and Fridays from 8:30 until 16:00, and Wednesdays from 8:30 until 12:30. Secondly, datapoints in which the CO_2-concentration in the classroom was lower than 500 ppm were discarded.

No high differences were found between the three measurement devices placed in the classroom. As a result, only the measurements of the Netatmo smart weather station (indoor temperature, relative humidity, CO_2, sound level) and HOBO U12-012 (lighting level) were used for the IEQ evaluation.

The measured IEQ conditions in the classrooms were assessed using the guideline values mentioned in the Flemish decree on IEQ (Vlaamse Overheid, 2018), standard EN 12464-1. **Table 3** gives an overview of the guideline values. The violation time, i.e., the percentage of time that the IEQ variable did not meet the guideline value during occupancy of the classroom, was calculated per IEQ variable. No guideline value was determined for the measured sound level. WHO recommends a background noise of maximum 35 dB. In this study we only measured the

Table 3

Guideline values for IEQ variables based on national and international guidelines

IEQ variable	Guideline value	Source
Indoor temperature	20°C – 24°C	Flemish decree on IEQ
Relative humidity	40% - 60%	Flemish decree on IEQ
CO_2-concentration	< 900ppm (< 500ppm above outside CO_2-concentration)	Flemish decree on IEQ
Lighting level	>300 Lx	EN 12464-1

indoor noise level and we could thus not differentiate the background sound level. Furthermore, a comfortable sound level in classrooms depends on the activity the pupils are performing, e.g., lecture, group work, taking a test,… These activities were not monitored continuously.

2.4.2 Pupils' satisfaction evaluation

Pupils' satisfaction with the classroom IEQ was assessed in the RHRN surveys on a 5-point rating scale. The pupils' satisfaction was evaluated per classroom and per assessed IEQ domain by calculating the dissatisfaction rate. The dissatisfaction rate was the percentage of the total number of assessments, which scored lower than three on the 5-point scale. For the assessment of the thermal environment and IAQ only survey responses were used that were completed by the students upon leaving and entering the classroom, respectively. For the assessment of pupils' satisfaction with the acoustic and visual conditions, all survey responses were used.

2.4.3 Nature of science questionnaire validation

Pupils' NoS was evaluated at the start and end of the monitoring campaigns. A partial validation of the NoS survey was done using the collected data. Firstly, the number of times that the statements were indicated as incomprehensible by the pupils was determined in order to evaluate the questionnaire's level of intelligibility. Secondly, the internal consistency among the statements of each subscale (i.e., tentativeness, creativity, coherence and objectivity, and theory-ladenness) was determined. The Cronbach's α (Tavakol & Dennick, 2011) was used to check if there is sufficient internal consistency among the NoS-statements in each of the subscales. A Cronbach's α of at least 0.7 indicates sufficient internal consistency. Values lower than 0.7 indicate that the statements were insufficiently related, which could make an aggregation of the results per subscale unreliable.

3 Results & discussion

3.1 Descriptive statistics

In total, 4841 responses on the RHRN survey were collected from 126 pupils. **Table 4** gives an overview participating pupils' demographics and the number of responses per classroom. The amount of survey responses is divided into responses given upon entering (start) or before leaving the classroom (end).

A low number of survey responses was collected in classroom G. The monitoring campaign in classroom G only lasted for one week due to practical issues in the classroom. Therefore, the results of classroom G should be interpreted with care.

Table 4

Pupils' demographics and survey responses per classroom

Classroom	Gender (M/F/U)	Average age	Responses (start/ end)
A	10/12/ 1	9.6	679/342
B	9/9/1	9.9	610/265
C	8/12/2	10	594/188
D	4/12/2	10.8	498/303
E	3/6/6	11	398/181
F	10/9/0	10.8	426/278
G	6 / 2 / 3	10.4	47/ 32

3.2 Evaluation of the classroom IEQ

The mean values with standard deviation are shown in **Table 5**. The mean values for indoor temperature and lighting level are for multiple classrooms outside the guideline requirements. In contrary, the mean values for relative humidity and CO_2-concentration are in the range of the guideline values for all classrooms.

Table 5

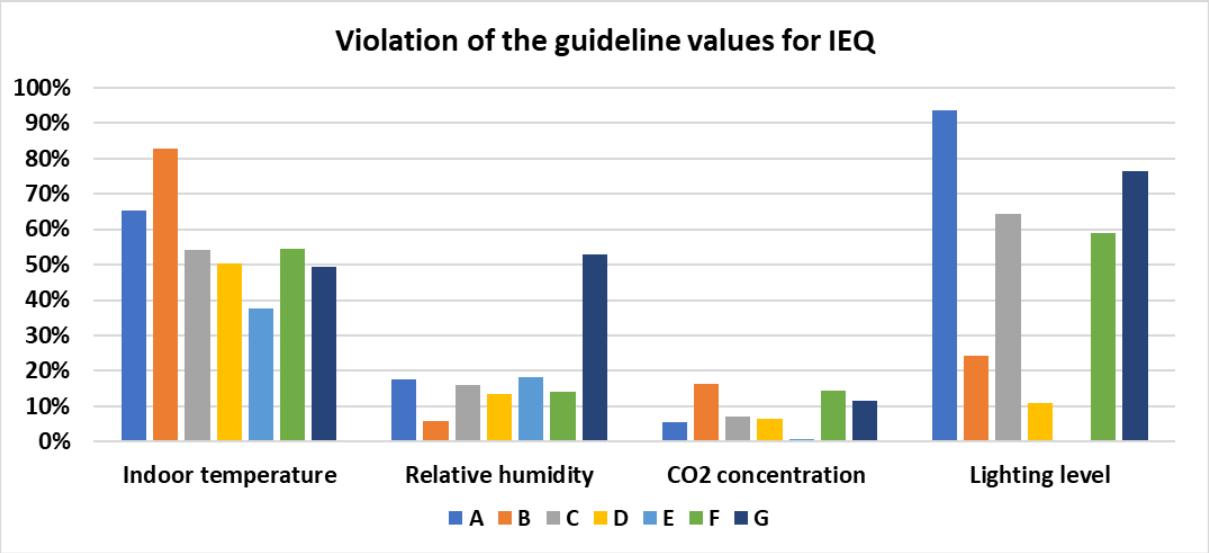
Mean values and standard deviation of the measured IEQ variables during occupied periods

	T [°C]	RH [%]	CO_2 [ppm]	Noise [dB]	Lighting [Lx]
A	19 ± 2	51.1 ± 6.9	640 ± 127	57.2 ± 6.4	178.2 ± 91.2
B	18.6 ± 1.3	48.8 ± 5.1	735 ± 167	53.6 ± 6.3	487.9 ± 246.4
C	19.7 ± 1.4	53.4 ± 5	678 ± 126	53.4 ± 7.1	265.4 ± 140.4
D	19.7 ± 1.5	44.9 ± 4.8	668 ± 140	61.2 ± 8.2	555.5 ± 277.1
E	20.3 ± 0.9	45.5 ± 5.1	622 ± 83	60.5 ± 8.6	/
F	20 ± 1.7	45.7 ± 4.8	711 ± 175	52.1 ± 7.1	316.5 ± 239.9
G	19 ± 3.8	49.6 ± 12.1	706 ± 199	44.2 ± 11.3	257.7 ± 383.1

More detailed results are shown in **Figure 2**, which visualises the violation times for each IEQ variable and classroom. The violation times for the indoor temperature ranges from 37.6% to 82.7%. In these cases, the indoor temperature fails to reach the minimum value of 20°C. Furthermore, lighting levels in the classrooms were often lower than the recommended minimum value of 300 lx. Violation times for the lighting level ranges from 10.9% to 93.5%. It should be mentioned that the lighting levels were measured in only one location in the classroom. More measurement points are necessary to assess the lighting conditions in the classrooms more accurately and to determine local effects of shading by e.g. blocking of light by objects or persons. No lighting

Figure 2

Percentage of time IEQ variables violating the guideline values during occupancy



levels were measured in classroom E due to practical errors during the monitoring campaign.

Relative humidity mostly met the guideline values in all classrooms with violation times ranging from 5.9% to 18.1%. One classroom (G) reaches a violation time of 52.8% for relative humidity, however, this result only comprises of one week of measurements. The CO_2-concentrations in the classrooms rarely violated the required concentration of 900ppm. Violation times for CO_2-concentration range from 0.8% to 16.4%. However, it is important to mention, that the requirement of the CO_2-concentration was mostly met by intensive natural ventilation (opening windows). This resulted in the classrooms mostly failing to meet the guideline values for indoor temperature. The results show that in most cases a compromise between the thermal and IAQ conditions in the classroom had to be made. Since data collection was performed during the COVID pandemic, the window opening behaviour mostly benefited the IAQ conditions.

3.3 Pupils' satisfaction with IEQ

A total of 4841 satisfaction assessments are gathered during the monitoring campaigns. **Figure 3** shows the dissatisfaction rates for each IEQ domain per monitored classroom. The dissatisfaction rate is the percentage of satisfaction assessments scored lower than 3 on the 5-point rating scale. **Figure 3** indicates that the pupils were mostly dissatisfied with the acoustic (mean: 18.4%), IAQ (mean: 16.5%) and thermal conditions (mean: 11.7%) in their classroom. The pupils were least dissatisfied with the visual conditions in their classroom (mean: 9.2%) with only two classrooms exceeding a dissatisfaction rate of 10%. This is in line with previous studies (Bluyssen et al., 2018, 2020) showing that pupils tend to be most dissatisfied with the acoustical conditions in their classroom.

The results show clear differences between the monitored classrooms. The pupils in classrooms G and D were the most frequently dissatisfied with the IEQ. In both classrooms, the dissatisfaction rate exceeded 10% for all assessed domains. However, the number of collected survey responses in classroom G is low due to a short monitoring period, which could bias the results when comparing to the other classrooms.

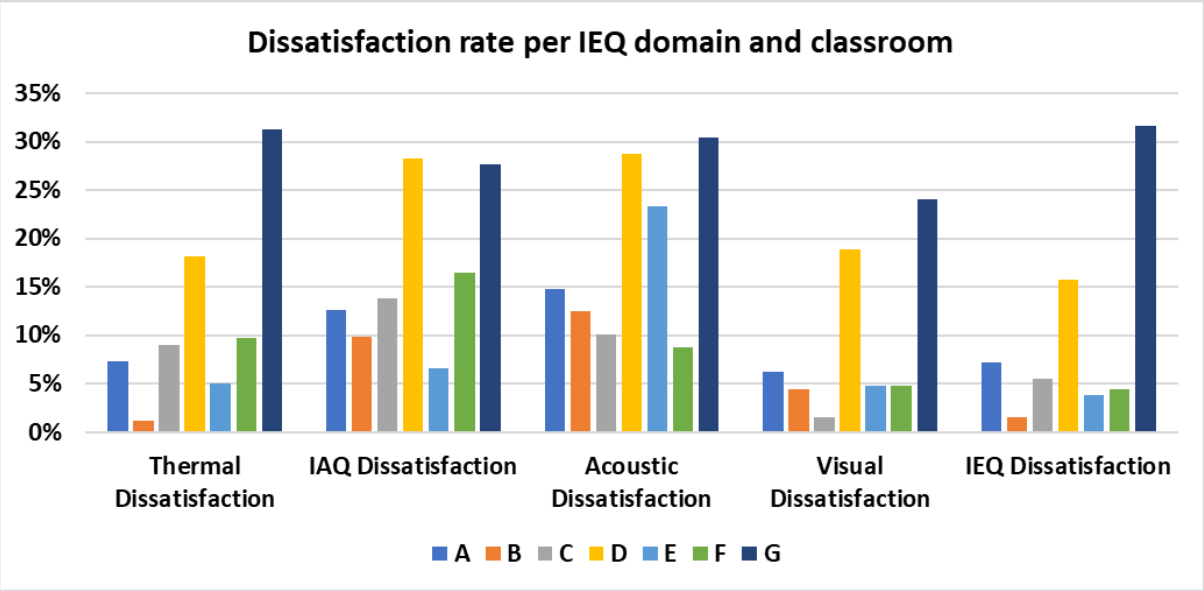
Remarkably classroom B shows the lowest dissatisfaction rate for thermal comfort, while the results in **Figure 2** show that the indoor temperature is the most violated in classroom B. This indicates that violating the guideline values does not necessary lead to pupil dissatisfaction. Likewise, the pupils in all classrooms frequently assess the IAQ condition in their classroom as unsatisfactory while the CO_2-threshold remained mostly under the 900ppm threshold during the monitoring campaigns. Due to the COVID measures in place during the study, students were required to wear a face mask from the second monitoring week onwards. Therefore, the wearing of a face mask was added as a potential cause of dissatisfaction. The wearing of a face mask was often shown as a reason for dissatisfaction with IAQ, with percentages ranging from 1.2% up to 36.7%.

3.4 Validation of NoS questionnaire

A total of 232 completed NoS questionnaires were gathered, of which 118 and 114 were gathered at the start and end of the monitoring campaign, respectively. The pupils frequently indicated that they did not understand the statements, on average 12.8% times per statement. The frequency of not understanding the statement ranges from 5.2%

Figure 3

Overview of the dissatisfaction rates for each IEQ domain in all monitored classrooms



(statement 7, see **Table A 1**) up till 25.4% (statement 13, see **Table A 1**). These results show that an additional effort could be necessary to make the survey comprehensible for children aged 10 – 12 years old.

Table 6 shows the Cronbach's α values for each subscale and all 20 statements combined. Low Cronbach's α values are determined for the subscales 'Creativity' and 'Coherence and objectivity'. Both subscales are the only subscales consisting of negative items, i.e., wrong statements instead of correct ones. The subscales 'Tentativeness' and 'Theory-ladenness' obtain higher Cronbach's α values which are just below the required value of 0.7. When combining all 20 statements, the Cronbach's α achieves the required value of 0.7. The results show that there is insufficient internal consistency between the statements in the subscales. As a result, the aggregation of the statements into subscales is unreliable. However, combining all 20 statements does lead to sufficient internal consistency.

Table 6

Cronbach's α calculated per subscale and all 20 statements combined

Subscale	Cronbach's α
Creativity	0.42
Tentativeness	0.69
Theory-ladenness	0.63
Coherence and objectivity	0.35
All statements	0.75

The presented validation is an initial step into validating the NoS questionnaire. More survey responses would be needed to more accurately validate the NoS questionnaire. Furthermore, other techniques such as principal component analysis are necessary to gain more detailed insights.

4 Conclusion

The guideline values set by the Flemish government or by standards were often violated in the investigated classrooms. Especially with respect to indoor temperature (mean violation time: 52.3%) and lighting levels (mean violation time: 54.7%). A more detailed monitoring set-up consisting of multiple measurement points for lighting intensity would be needed to assess the lighting conditions in the classroom more correct. A majority of the classrooms were able to meet the requirements for relative humidity (mean violation time: 19.7%) and CO_2-concentration (mean violation time: 8.9%) more frequently.

The satisfaction assessments showed that the pupils were mostly dissatisfied with acoustic conditions (mean dissatisfaction rate: 18.4%). Furthermore, the pupils frequently perceived the IAQ as unsatisfactory (mean dissatisfaction rate: 16.5%), although the CO_2-concentraction was mostly kept below the guideline values of 900ppm. The next step consists of statistical analyses to determine the influencing effects on pupils' satisfaction.

The responses on the NoS questionnaire show that the statements are often unclear to the pupils with statements being assessed as incomprehensible in, on average, 12.8% of the times. Furthermore, results show insufficient consistency among the subscales of the survey, which indicates that an analysis of the

survey results per subscale could be unreliable. Especially the subscales 'creativity' (α = 0.42) and 'coherence and objectivity' (α = 0.35) show low internal consistency. Both subscales consisted of negative items, while the subscales 'tentativeness' (α = 0.69) and 'theory-ladenness' (α = 0.63) did not consist of negative items. However, the internal consistency among all 20 statements is acceptable (α = 0.75). More data is necessary to further validate the NoS questionnaire.

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7 Appendix

Table A 1

The questionnaire used to assess pupils' views on NoS. Statements are shown per subscale both in Dutch and translated in English. The table shows if the statement is a positive (+) or negative (-) item

Subscale	Statements	+ / -
Creativity	[1] Wetenschappers moeten vindingrijk zijn (ideeën hebben) om onderzoek te doen *(Scientists need to be inventive (have ideas) to conduct research)*	+
	[7] Om dingen uit te vinden moeten wetenschappers creatief zijn *(To invent things, scientists have to be creative)*	+
	[12] Als je creatief bent kan je geen wetenschapper worden *(If you are creative you cannot become a scientist)*	-
	[17] Wetenschappers moeten verbeelding hebben om hun onderzoek te verklaren *(Scientists need imagination to explain their research explanation)*	+
	[20] Wetenschappers hebben, net zoals kunstenaars, fantasie nodig *(Scientists, like artists, need imagination)*	+
Tentativeness	[2] Nieuwe gebeurtenissen (bv. de uitbraak van het Corona virus) zorgen ervoor dat wetenschappers andere dingen gaan onderzoeken *(New events (e.g. the Corona virus outbreak) cause scientists to investigate different things)*	+
	[4] Wat wetenschappers nu weten kan later veranderen *(What scientists know now may change later)*	+
	[5] De wetenschap kan veranderen door nieuwe uitvindingen *(Science can change through new inventions)*	+
	[11] Wat we vandaag leren op school kan later (bijvoorbeeld binnen 2 jaar of 50 jaar) veranderen *(What we learn at school today may change later (e.g. within 2 years or 50 years)*	+
	[18] Wat wetenschappers onderzoeken kan veranderen door nieuwe resultaten *(What scientists study may change with new results)*	+
Theory-ladenness	[3] Er zijn veel manieren om onderzoek te doen *(There are many ways to conduct research)*	+
	[19] Wat wetenschappers weten, beïnvloedt de manier waarop ze hun onderzoek uitleggen *(What scientists know affects how they explain their research)*	+
	[8] Wat wetenschappers meemaken (ervaringen, gevoelens, …) heeft invloed op de manier waarop ze hun onderzoek verklaren *(What scientists go through (experiences, feelings, ...) affects the way they explain their research)*	+
	[10] Voordat wetenschappers onderzoek doen weten ze al hoe ze het gaan aanpakken *(Before scientists conduct research they already know how they are going to do it)*	+
	[13] Wat de wetenschapper geleerd heeft, beïnvloedt hoe hij/zij het onderzoek verklaart *(What the scientist learned influences how he/she explains the research)*	+
Coherence and objectivity	[16] Cultuur (afkomst, kunst, religie, …) heeft een invloed op hoe de wetenschappers onderzoeken *(Culture (origins, art, religion, ...) affects how scientists investigate)*	+
	[6] Als twee wetenschappers hetzelfde onderzoek doen en de resultaten anders uitleggen dan moet één van de twee fout zijn *(If two scientists do the same research and explain the results differently then one of them must be wrong)*	-
	[9] Twee wetenschappers die hetzelfde onderzoek doen, zullen wat ze zien steeds op dezelfde manier uitleggen *(If two scientists do the same research and explain the results differently then someone must be wrong)*	-
	[14] Alle wetenschappers denken hetzelfde over onderzoek *(All scientists think alike on research)*	-
	[15] Wetenschappers kunnen een andere mening hebben over hetzelfde onderzoek *(Scientists may have different opinions on the same research)*	+