CITIZEN SCIENCE:
THEORY AND PRACTICE

Co-Designing an Air Quality Web App with School Pupils and Staff: The SAMHE Web App

METHOD

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ABSTRACT

This methods paper describes a new UK-wide citizen science project, the Schools' Air Quality Monitoring for Health and Education (SAMHE) project, which is exploring indoor air quality (IAQ) in schools. Central to the project is a Web App, where school teachers and pupils can see air quality and environmental data from their classroom, learn about the significance of the data that their monitor collects, enter important contextual information to support data analysis by researchers, and are supported to do their own experiments related to air quality. School use of the SAMHE Web App is essential to the project's aims to 1) improve understanding of air quality in schools; 2) empower teachers and pupils to make informed decisions about management of their classroom environment, including ventilation; and 3) support the UK's next generation to think differently about air quality. Therefore, it is critical that the SAMHE Web App was co-designed with schools, to maximise its acceptability within schools, and to ensure that teachers and pupils engage with it. This paper describes the co-design process used within SAMHE, how co-design has helped shape the web app (including overall theme, visualisation of data, and supporting materials), and some lessons learned from the process that will be useful for future software development and citizen science projects with schools.

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INTRODUCTION

WHAT AIR QUALITY IS

Air quality is the term used to describe the levels of pollution in the air that we breathe. The World Health Organization (WHO) recognises air pollution, both outdoors and indoors, as the biggest environmental threat to human health due to its contribution to both morbidity and mortality (WHO 2021). For this reason, WHO established guideline levels initially for 28 pollutants (WHO 1987) applicable to both indoor and outdoor environments. In response to strengthening evidence, revised air quality guidelines were published in the year 2000 for a total of 35 air pollutants, and updates for "classical" pollutants (particulate matter [PM], ozone [O_3], nitrogen dioxide [NO_2], sulphur dioxide [SO_2] and carbon monoxide [CO]) in 2005. Further updates in 2010 for nine pollutants and in 2021 for classical pollutants were published with a particular focus on indoor environments. Additionally, specific to indoor air quality (IAQ), WHO has dedicated guidelines for damp and mould since 2009 (WHO 2009). Another metric typically used to measure air quality indoors is carbon dioxide (CO_2). Although CO_2 is not itself dangerous to health at low levels, it is used as an indicator of how well a room is ventilated.

One of the barriers to public awareness on the links between air quality and health is that air pollution is often imperceptible (Semenza et al. 2008). It is for this reason that providing real-time localised air quality data in a manner that is easily understandable by the general public is crucial to make air quality visible (Carro et al. 2022).

WHY GOOD AIR QUALITY IN SCHOOLS IS IMPORTANT

Accumulating evidence indicates that healthy learning environments can reduce pupil absences, improve concentration (and therefore test scores), and enhance learning and productivity of both pupils and teachers (see Sadrizadeh et al. 2022 for a recent review). A combination of interventions in and around schools (Rawat and Kumar 2023) may work effectively to reduce particulate matter (PM) and gaseous pollutants. Air quality measurements can provide the necessary evidence to evaluate such interventions. Low-cost sensors equipped with a bespoke app, such as those used in this project, enable both scientists and pupils to gather data to assess the impact of classroom interventions. Such low-cost sensors typically measure CO_2, temperature, and relative humidity, and less often CO, VOCs, and $PM_{2.5}$ (Ródenas García et al. 2022).

Thermal conditions in classrooms are also important for learning and satisfaction. While the range of preferred temperatures can vary in different parts of the world and across seasons, studies have suggested that children prefer slightly "cooler-than-neutral" sensations compared with adults (Kim and de Dear 2018) in schools. A systematic review of the literature over the past 50 years found that children in Europe (with many studies conducted in the UK) are satisfied at an indoor temperature of about 22°C, while dissatisfaction increases with temperatures over 27°C (Sadrizadeh et al. 2022, Singh 2019).

Geographical location plays a role in school air quality as emissions from outdoor sources such as road traffic, construction, and industrial activities can penetrate into classrooms. Classrooms that are located close to busy roads or child drop-off/pick-up areas are more susceptible to increased particulate matter concentrations. For instance, Kumar et al. (2020) reported an increase of two times higher $PM_{2.5}$ concentrations during drop-off hours in a nearby classroom compared with off-peak periods due to ingress of outdoor pollutants from drop-off vehicles. Interventions that address this issue are crucial as there is strong evidence that long-term exposure to air pollution, including high $PM_{2.5}$, is associated with suppressed lung function growth and new-onset asthma in children, and in adulthood, this long-term exposure has been linked to cardiovascular disease and lung cancer (Royal College of Physicians 2016).

WHAT WE KNOW FROM AIR QUALITY MONITORING IN UK SCHOOLS

Classrooms are densely occupied for relatively long periods. As such, exposure to any air pollution within them is of long duration, with potentially numerous negative impacts. This includes the inhalation of rebreathed air (air already exhaled by someone else) offering potential for the spread of infections. Classroom ventilation, i.e., the supply of air from outdoors, is a primary mechanism to dilute the build-up of pollutants from indoor sources, but it does risk introducing pollutants from outdoors. To robustly assess classroom air quality, measurements of a number of metrics/species are required. However, the presence of carbon dioxide (CO_2)–rich exhaled breath in classrooms provides a useful indicator of air quality (Lowther et al. 2021) and is used to infer ventilation within the UK Government Department for Education's (DfE) guidance (DfE 2018).

Within UK classrooms, neither environmental nor air quality data are routinely recorded. Subject to certain caveats, the DfE does require that the design and construction of new school premises, or the refurbishment of existing schools, enables temperature and CO_2 within classrooms to be routinely recorded via the iSERV/K^{2}n platform (DfE 2022). The data recorded is made available to the school, to local authorities responsible for education, and/or to the educational trust, but is not openly available, and to date, has proved unavailable for research purposes.

In response to the COVID-19 pandemic, the DfE issued more than 300,000 CO_2 monitors in English schools during the winter of 2021–2022 (DfE no date), with a similar-scale provision repeated during wintertime 2022–2023; broadly equivalent provisions were also made in each of the UK devolved nations. However, these monitors were predominantly intended to help classroom staff manage the ventilation supply when opening/closing their windows. The air quality data measured by the monitors provided are not centrally recorded. As a result, current knowledge on the air quality in schools originates from a limited number of relatively small-scale research studies. For example, Chatzidiakou, Mumovic, and Summerfield (2012) reported (from 14 different studies containing data from 53 classrooms) that in 30% of classrooms, the median CO_2 levels exceeded the thresholds within the DfE guidance on school air quality and ventilation (DfE 2018). More recently, Vouriot et al. (2021) and Burridge et al. (2023) reported varying CO_2 levels in classrooms within the same schools, inferring that ventilation rates varied widely between classrooms and noting that the ventilation rates during wintertime were broadly half those during warmer seasons. All of these findings have implications for classroom air quality, and highlight that more data is required.

CITIZEN SCIENCE AND AIR QUALITY IN SCHOOLS

This methods paper describes the co-design elements of the Schools' Air Quality Monitoring for Health and Education (SAMHE) project. SAMHE began in January 2022 in the UK and aims to increase knowledge about air quality in schools, which could strengthen the evidence base to reduce school exposure, whilst supporting the UK's next generation to think differently about air quality. SAMHE is developing and testing new methods of collecting an unprecedented volume of environmental and IAQ data in classrooms using low-cost sensor technologies and a co-designed web app, the SAMHE Web App. Data will be used to help design behavioural interventions to help reduce school communities' exposure to poor indoor air quality, for example, targeting pollutants of particular concern or times of day, and these interventions will be offered to participating schools via the SAMHE Web App.

SAMHE uses a collaborative citizen science approach, as participants are involved in stages of the scientific process beyond just collecting data (Shirk et al. 2012). For example, participants helped to design the data collection platform (a web app, which is the focus of this paper), and they participate in analysing their data. A citizen science approach was chosen because it allows us to collect data over a wide geographic area, by placing air quality monitors in spaces researchers cannot easily access themselves (schools), whilst educating pupils, teachers, and other school staff about the importance of good indoor air and what can be done to improve it. The selected monitor (Air Gradient One) has multiple sensors.

Importantly, air pollution researchers need to have contextual information about monitor location and relevant indoor activity in order to be able to interpret their readings. The SAMHE Web App is central to answering the project's research questions, which are:

- What CO_2 levels and ventilation rates are typical in UK school classrooms?
- How does IAQ in schools vary with ventilation patterns, seasonality, school building characteristics, and school location?
- What is the between-school and within-school variation of indoor air pollution?
- Can taking part in SAMHE improve people's understanding of air quality?
- Can taking part in SAMHE help schools improve their IAQ?

Other projects have also used a citizen science approach to explore air quality in and around schools. For example, the Breathe London Wearables Study gave primary school children sensors incorporated into backpacks to wear on their daily school commute, and presented findings from the project to schools, with a majority of children showing good understanding of the effects of traffic-related pollution after the project (Varaden et al. 2021). Other projects have used paper and petroleum jelly to trap dust and visually show this form of pollution (Castell et al. 2021). Grossberndt et al. (2021) describe how pupils in three Norwegian schools designed their own air quality monitoring projects, gained knowledge about air pollution, and developed skills, including how to build sensors and to conduct data analysis. The team had hoped that behavioural changes would follow from knowledge acquisition, but this was not the case, and the authors suggested teachers should facilitate space for group discussion to support this (Grossberndt et al. 2021).

Mobile or web-based apps have been previously used to provide indoor and/or outdoor air quality data, and suggest behaviours that could reduce harmful exposure during poor air quality episodes (Kim and Sohanchyk 2022; Kim et al. 2021; Delmas and Kohli 2020; Campbell et al. 2020). Delmas and Kohli (2020) developed an outdoor air quality mobile app, AirForU, which provided users with historical, live, and forecasted air quality data in their area, as well as health recommendations. They found that intrinsic motivations, such as pre-existing respiratory or heart conditions, were the main drivers of engagement with the app and of reported behavioural changes. However, 90% of the initial engagement dropped by the 12th week after downloading the app. A similar pattern was observed by Kim and Sohanchyk (2022), who developed a mobile app for children aged 6–7 years, inAirKids. This app displayed air quality in and outside their home. Children involved in the study reported losing interest after several weeks. Lack of interactivity independent of IAQ changes was identified as one of the reasons for disengagement. The SAMHE Web App addresses the risk of disengagement by providing hands-on activities and adopting a "gamification" approach (game design elements in a non-game context [Deterding et al. 2011]).

The SAMHE Web App

SAMHE has co-designed a web app that provides both a place where schools can see data from their monitor, getting real-time information about air quality in their school, and a tool to help them develop their own knowledge and understanding of air quality by reading/watching educational resources; designing and conducting experiments; and gathering, analysing, interpreting, and recording their findings. This is what Blumenfeld et al. (2000) describe as project-based science—where students engage in long-term enquiry to help develop skills and knowledge. The web app is also designed to be fun, using gamification to increase engagement.

We worked with school teachers, pupils, and other school stakeholders to co-design the SAMHE Web App, to ensure that it meets their needs and the needs of the research team. Participants were recruited through social media (primarily Twitter but also LinkedIn and Facebook), via emails and newsletters from other organisations working with schools, and through direct emails to schools known to the team.

METHODS

WHAT CO-DESIGN IS AND WHY WE USED IT

Blumenfeld et al. (2000) noted that innovations in schools are more likely to succeed if they are less challenging to the users' (in our case, teachers and pupils) existing capabilities, organisational culture, and policy/management structures (which includes factors such as number of computers/tablets available to pupils, lesson length, etc.). By working closely with schools over a series of discussion sessions, we sought to understand their capabilities, classroom practices, and how the SAMHE project can fit into their daily structures, thereby maximising the chances of the monitor and web app being used by schools.

Co-design is a loose term, allied to co-creation, and arising from participatory design as part of a broader turn towards more participatory practices in many fields (Smith, Bossen, and Kanstrup 2017). Here, we follow the lead of Sanders and Stappers (2008) and use co-design to mean the collective creativity of designers and non-designers, although in our case, the designers include software developers. Researchers and other support staff play a role in the design process by facilitating sessions and platforms where ideas and concepts can be generated. There are several steps in the design process. The first step is the front end, or pre-design stage, the purpose of which is to inform what it is that is going to be designed. After this stage, the traditional design process of development of concepts, prototypes, and product is followed (Sanders and Stappers 2008). Like other participatory approaches, including citizen science, there are different degrees to which participants get involved, and where the balance of power lies in the process, for example, who ultimately makes the decisions about what gets included in the prototype(s) and product(s).

A recent systematic review of participatory design studies (Tuhkala 2021) found that teachers are not often involved in co-designing technologies that they use in their teaching. Co-design can be very intensive, involving a small group of teachers. For example, Hundal, Levin, and Keselman (2014) worked with four teachers on a weekly basis for 10 months. The majority of the 72 studies reviewed by (Tuhkala 2021) were with small numbers of teachers. A smaller number of lengthier (e.g., a half or full day) workshops is also an option (see for example Paracha et al. 2019). An alternative approach, which we took, is to work less intensively with a larger number of teachers and pupils, so that the burden of participation on busy teachers is spread out, while the opinions voiced might be more diverse.

Both pupils and teachers participated in our co-design activities (see Figure 1). The involvement of teachers was important as previous studies (e.g., Varaden et al. 2021) have found that without their input, pupils can develop misconceptions about air quality if materials are not pitched at the correct level. In SAMHE co-design activities, pupils participated with a teacher, either as a class group or as a lunchtime or after-school extra-curricular group such as a science club, school council or eco-group. A group of older students, Arkwright Scholars, aged 16+, participated without teachers. Teachers participated mainly in small group discussions, although, because of dropouts and other factors, some sessions were conducted with a single teacher and the SAMHE team. Teachers were also able to input asynchronously via a series of Padlet boards so that they were free to input at times that suited them.

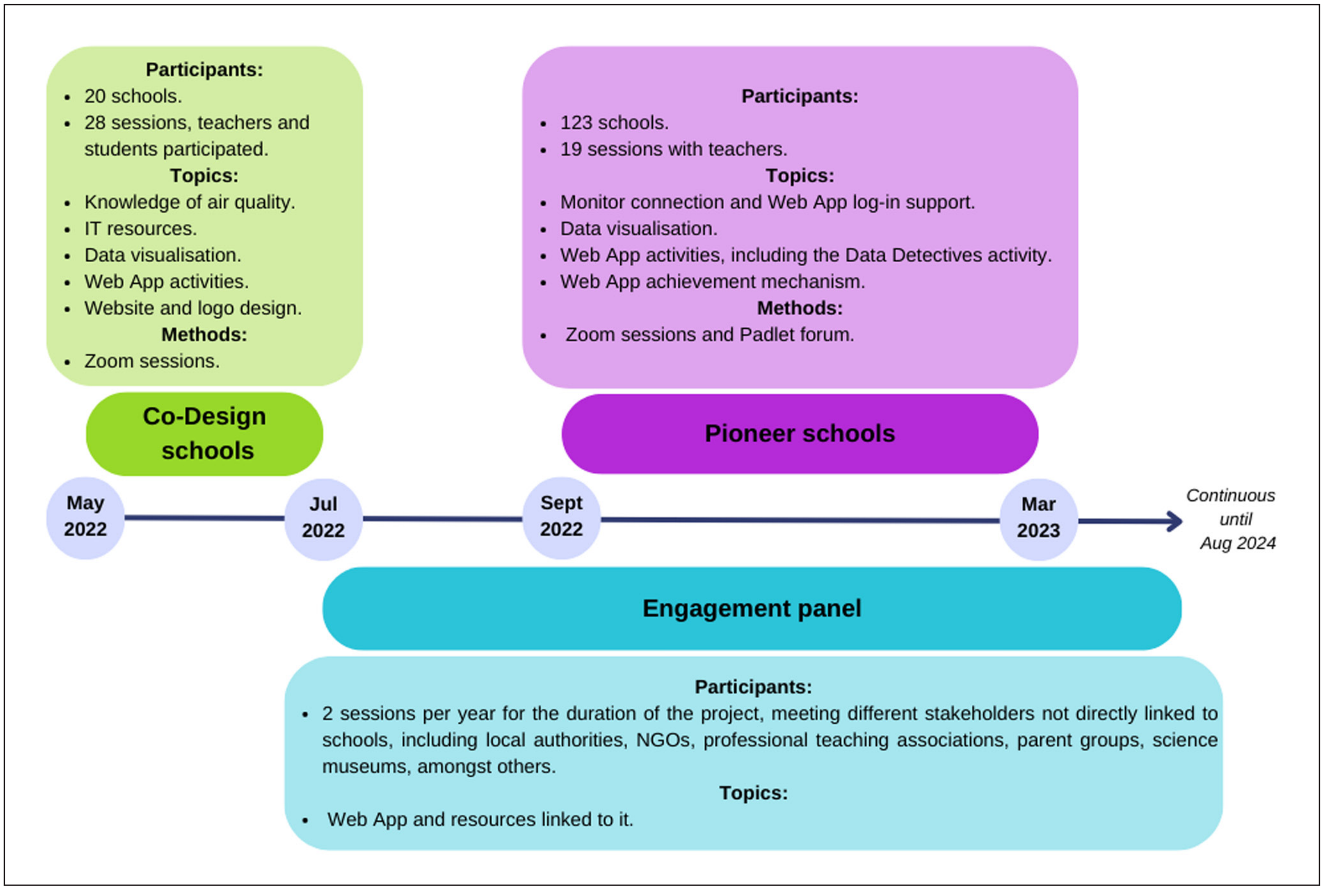

Figure 1 The stages of co-design, showing when activities took place with Co-Design schools, Pioneer schools, and the engagement panel.

ETHICS

To ensure that citizen science is used ethically through SAMHE, the European Citizen Science Association's (ECSA's) Ten Principles of citizen science (ECSA 2015) were used as a framework. Table 1 shows how SAMHE has considered these principles, and gives details on the nature of schools' involvement. Although not widely discussed in the literature pertaining to citizen science, the SAMHE team also considered the legacy of the project as an element of the ethical soundness of the project. To ensure that teachers and pupils would be able to continue exploring the air quality of their classrooms post-funding, SAMHE will:

- Develop a teacher resource pack to be hosted on external teacher-facing websites.
- Facilitate and support external partners' engagement with SAMHE schools to build local school air quality networks.
- Build teacher and pupil capacity to make changes to the environment, as well as encourage engagement with policy makers through SAMHE Web App activities.
- Produce a data sharing agreement that ensures all future published research that uses SAMHE data is translated into school-appropriate outputs.

Ethical approval for the co-design work was granted by the University of York's Environment and Geography Department multidisciplinary Ethics Committee in March 2022, with a subsequent application for additional work with schools approved in July 2022. Key considerations covered by this application included means of ensuring that the views of all participants were, as far as possible, given equal representation, e.g., engaging with different groups (teachers and pupils, and pupils of different ages) separately, targeting small group sizes to allow each participant sufficient time to talk, using a trusted mediator/intermediary (a teacher) to encourage contributions from less confident pupils, and implementing measures to create an environment in which participants felt comfortable expressing their honest, unfiltered opinions. For example, we chose not to record any of the sessions or to produce transcripts to mitigate against any perceived pressures to express thoughts eloquently. Equally, all feedback gathered was anonymous at source rather than attributed to any individuals, which we reminded participants of at the beginning of all sessions. Our ethics applications also addressed online security issues including protecting our participants against the risk of unwanted interference from third parties, such as Zoom bombing, by using waiting

CITIZEN SCIENCE PRINCIPLE	SAMHE APPROACH
1. Citizen science projects actively involve citizens in scientific endeavours that generates new knowledge or understanding.	• By using the SAMHE monitors, schools are providing real-time IAQ data about their classroom to produce a large indoor air quality data set across the UK. • Through the SAMHE Web App, teachers and pupils provide contextual data to support the monitor data for scientists to investigate.
2. Citizen science projects have a genuine science outcome.	• The data collected through the SAMHE air quality monitors in schools, and the contextual data provided through web app activities will produce an unparalleled dataset, helping to improve understanding of IAQ in schools, which could influence future research projects and policies.
3. Both the professional scientists and the citizen scientists benefit from taking part.	• Professional scientists benefit by having access to the valuable contextual data collected through SAMHE Web App activities, behavioural data collected through surveys, IAQ data collected through the SAMHE air quality monitors, and they gain insight into schools' understanding of IAQ and ventilation behaviour. • Schools receive access to resources providing pupils with the opportunity to practise various skills. Data from the monitors / web app also enables schools to make informed decisions about managing classroom environments.
4. Citizen scientists may, if they wish, participate in multiple stages of the scientific process.	• Schools have been a part of method design. • Schools are part of data collection. • Schools are analysing their own data, and can disseminate as they wish.
5. Citizen scientists receive feedback from the project.	• Project updates are published on the SAMHE website, in a newsletter for SAMHE schools, and through social media.
6. Citizen science is considered a research approach like any other, with limitations and biases that should be considered and controlled for	• Ethics approval has been sought for school-facing activities. • Participation methods have been co-designed. • Limitations and biases are continually reviewed through regular meetings with the full SAMHE team.
7. Citizen science project data and metadata are made publicly available and where possible, results are published in an open-access format.	• All authors of published research that uses SAMHE data agree to a data sharing agreement that includes guidance on open-access publishing, as well as public- and school-appropriate accessible outputs based on the findings. • Lay person abstracts for teachers and pupils.
8. Citizen scientists are acknowledged in project results and publications.	• All publications that use any SAMHE data or discuss the project should acknowledge SAMHE schools.
9. Citizen science programmes are evaluated for their scientific output, data quality, participant experience, and wider societal or policy impact.	• Monitoring of scientific outputs and policy impact is taking place throughout the project. Focus groups with schools will provide detailed insight into the experiences of participants. • Surveys, as well as feedback questions at the end of each web app activity, will be used to evaluate participant experience. • Quiz activities on the SAMHE Web App test pupils' knowledge and understanding of SAMHE and indoor air quality and will be used as an indicator of data quality.
10. The leaders of citizen science projects take into consideration legal and ethical issues surrounding copyright, intellectual property, data-sharing agreements, confidentiality, attribution, and the environmental impact of any activities.	• Attribution has been considered through ethics reviews. • Environmental and health impacts were considered as part of method design. • Data ownership and implications for Freedom of Information requests have been explored.

Table 1 Shows the ECSA's Ten Principles of citizen science (ECSA 2015) and how SAMHE is planning to meet them.

rooms and meeting passcodes, and preventing screen sharing for users other than the host.

STAGES OF CO-DESIGN

We had two phases of co-design, one with a smaller number of schools (n = 20), which we termed Co-Design schools, followed by a second phase in which we engaged what we termed Pioneer schools. Eight of the Co-Design schools also participated as Pioneer schools, plus an additional 115 new Pioneer schools. Although this may seem like a large number of schools, our approach was designed so that schools could engage as much or as little as they liked, as we know many teachers are very time poor. All of our sessions with schools took place via Zoom video conferencing software. This approach was chosen because of time constraints (both for the SAMHE team and teachers), budget, and environmental impact. It also allowed us to use live messaging so those not able to hear could still participate. Figure 1 shows the stages of co-design.

Co-Design schools

Our work with Co-Design schools began in May 2022 and ran until the end of the English summer term, July 2022. During this time, we ran 28 sessions, all on Zoom, with individual teachers and groups of students attending up to 4 sessions (see Table 2). The sessions were run by two of the authors (LW and SW) with a developer (SB) attending some of sessions 2 and 3. Our project communications lead (VB) also attended some sessions, such that they could hear schools' feedback firsthand and incorporate learnings from their insights into project messaging directly. Each week, the wider project team, including the developers, met to discuss summarised feedback from the sessions so that ideas could be incorporated into the web app's design. Early sessions covered preliminary topics such as what websites pupils like to use at school and why, what access to IT hardware they have (e.g., computers, tablets, phones), when do they use these devices, and with what level of supervision (see Supplemental File 1: Topic Guide for session 1). Later sessions focused on preliminary design ideas for the web app, including its content, structure, and style. Sessions lasted between 30 and 40 minutes, and contained a mix of polls (via physical hand raising in pupil sessions) and open discussion using a topic guide. Due to rolling recruitment of schools, some sessions were merged so that they covered multiple sessions' content.

Session 1 ran 15 times. For both teachers and pupils, it covered preliminary topics including their ability to recognise a CO_2 monitor; their understanding of air pollution; whether they had a science or eco club; and their access to computers. Teacher session 1 then went on to discuss where air pollution is covered in the curriculum, if at all; whether SAMHE activities needed to be linked to the curriculum; their motivations for participating in the project; whether awards or certificates would be motivating (either for the school or for pupils); and the level of in-school IT support available for monitor set up. Pupil sessions covered whether they like using computers at school, the types of websites they like using in and outside of school and why.

While we often incorporated voting into sessions to help with the decision-making process, we used vote tallies as a guide rather than definitive direction. This is because through the sessions and Padlet interactions, we had rich comments providing insight into the preferences of our test users that needed to be given appropriate weight. Throughout the co-design process, we were aware we were dealing with very engaged teachers whose views (as they often recognised themselves) would not necessarily be representative of their colleagues, who may need more convincing in order to participate. We used tallies and comments to guide our approach, but sometimes deviated from this, as we needed to balance these with what was feasible from a development perspective, and the data our researchers needed.

Session 2 was run nine times. Schools were presented with a series of line graphs showing indoor air quality data from a previous project and were asked for their feedback. We also asked them which ways of viewing data are familiar to them, which data they would be most interested in seeing from the monitors, and how they planned to use monitor data. Next, we showed them two options for how a homepage could be laid out and asked for their preference, and we asked what theme they'd like for the web app, if any. We also showed them 6 logo designs and straplines and asked which they liked and disliked and why. For pupil sessions, we then asked about other websites they use that show data and what they liked or disliked about them. In addition, for the Arkwright scholars, we asked how they prefer to navigate through content on websites.

Session 3 was run six times. Schools were shown a list of the types of activities we could include within the SAMHE Web App and were asked to give positive and negative feedback and suggest ideas for other activities. Teachers were also asked what information they would need before starting activities. In earlier sessions, many pupils and teachers had mentioned that they like videos, so in this session we asked teachers about appropriate video length.

We ran two final sessions (session 4), one with teachers and one with Arkwright scholars, in which we showed logos and straplines that had been revised based on earlier feedback, got final thoughts from them about the design, and showed them an early version of the project

SESSION NUMBER	TOPICS COVERED	TIMES RUN	PEOPLE ATTENDING
1	Air quality, IT in schools	15	66
2	Data visualisation and logo	9	47
3	Activities	6	24
4	Feedback	2	9

Table 2 Sessions run with Co-Design schools. Note that two instances of session 2 also covered session 1 content, and another covered sessions 1, 2, and 3 content as we sought to adapt to schools' availability while balancing team resources.

website with the logo in place. They made suggestions about navigation, design, and images for both the web app and the project website. We also asked if they would be happy to use Padlet (a virtual noticeboard platform) to give feedback in the Pioneer stage of the project, and for any tips or concerns they had relating to this.

Between July and October, the project's software development team designed an initial version of the SAMHE Web App and project website based on all the input from schools. It was ready to launch to Pioneer schools in the Autumn term (September–December 2022).

Pioneer schools

A total of 123 schools enrolled for the Pioneer schools stage of the project, which involved testing the monitor connection process and trialling an early version of the web app, to which we added new functionality in phases. Working with schools at this scale, we recognised that teachers' availability would be highly variable, and we adapted our approach accordingly. While we were keen to continue engaging with schools via live Zoom sessions (as in the Co-Design stage), during the Pioneer schools stage, we centred our Zoom session around a series of Padlet boards designed to enable asynchronous feedback. The Zoom sessions were designed to complement, rather than substitute for, engaging with Padlet. This change in emphasis made it possible for time-limited schools to engage on more equal terms if they could not attend the sessions. In anticipation of having larger numbers of attendees, we also planned to use integrated Zoom polling. Padlet was chosen for several reasons: Respondents do not need to register for a (free) account if they do not wish to, allowing them to post anonymously, and our Co-Design schools had been positive about the platform. We also valued the ability to enable interactions between participating schools, both to facilitate experience sharing and to help generate consensus. Recognising that time-poor teachers would need a quick option for providing feedback, we provided short polls when appropriate as well as invited written feedback.

Below, we describe the structure of the work done by those in the Pioneer stage, focusing on the content of each release rather than the number of corresponding sessions. This is because schools were all at different stages of the project (some had only just received a monitor, some had not connected it to WiFi, others had connected but not logged on to the web app). Because of this asynchronicity, all schools were invited to all sessions, could attend as many or as few as they liked, and had the ability to catch up on missed sessions' content via Padlet.

From mid-October, all schools that had taken part in Co-Design were sent a monitor and were invited to try to connect them to their school's WiFi. Our first Pioneer session was exclusively with teachers from these schools, and it focused on monitor connection, the Padlet board we had set up for feedback, and how schools handle parental consent for participating in projects such as these. In November, our other Pioneer schools started to receive their monitors. In mid-November we held a kick-off session with teachers in which we covered the platform we would be using to get feedback from them (Padlet), how we would use Zoom, and how to log into their SAMHE Web App accounts. We repeated this session on consecutive days to allow more teachers to attend. From this point onwards, our Co-Design and Pioneer schools were all invited to attend the same sessions.

We initially planned to email schools about a week before each Zoom session to advise of the new web app content available for testing and to provide a link to the relevant Padlet board for giving feedback. It quickly became clear that many teachers did not have time to do these tasks, so we adapted to take that into account: At the beginning of all our Pioneer sessions, regardless of the main topic, we ran a poll and discussion about whether schools had managed to connect their monitor to the WiFi and whether they had logged into their account. This helped us to understand where any issues were occurring and to tailor the session to whether schools had been able to see the app or if they needed to see it live in session. We also got feedback from schools about the clarity of our instructions for monitor installation and WiFi connection, and we adapted those accordingly.

In early December 2022, we started getting feedback (via Padlet and Zoom sessions) from schools about the air quality data from their monitors that they could see in the web app. At the time, the web app showed only line graphs, with the most recent 100 readings on the x-axis, and the level of each parameter (CO_2/PM/temperature/TVOCs/relative humidity) on the y-axis. Teachers suggested adaptations to make the data shown more useful to them and to their pupils. Some had already shown the graphs to their students and fed back the students' thoughts, too. We showed mock-ups of alternative ways to display the data, and used feedback from Padlet and Zoom polling to prioritise which were developed.

Our next release to teachers consisted of activities in the SAMHE Web App, designed to get pupils thinking more about air quality and the data shown on their monitors. Due to delays with the web app development, teachers were not asked to do activities in advance, but instead tried the activities and gave feedback live in session. This was feasible only because, as with all our Pioneer sessions, there were small numbers of attendees.

Further releases covered additional web app activities, and ways of rewarding achievement and/or thanking schools for using the web app, something which pupils (during the Co-Design stage) had told us they would value (see Figure 2). Our final release during the Pioneer phase was dedicated specifically to an activity we termed Data Detectives, which allows users to investigate unusual or interesting patterns in their classroom air quality data by guiding them through a series of questions to identify possible causes. This activity has several key functions, which aim to: (1) help familiarise Web App users with their data, including building their understanding of what is normal in their space (2) provide them with some reassurance, and (3) if required, to recommend appropriate action. We were aware that through participation in SAMHE, schools might be alerted to ventilation and air pollution problems of which they previously had no knowledge, so getting the tone of this activity right was extremely important from an ethics point of view. Pioneer sessions were a great opportunity to trial Data Detectives directly with teachers before releasing it to a larger audience.

Engagement panel

In addition to the work with schools themselves, we created an engagement panel in order to capture views of stakeholders not directly working in schools. This panel will meet two or three times a year for the duration of the project, and includes representatives from local authorities; professional subject teaching associations; science museums and other STEM (Science Technology Engineering and Maths) education providers; nongovernmental organizations (NGOs), businesses, parent groups, and grassroots organisations working on air quality; professional teaching associations; teacher training

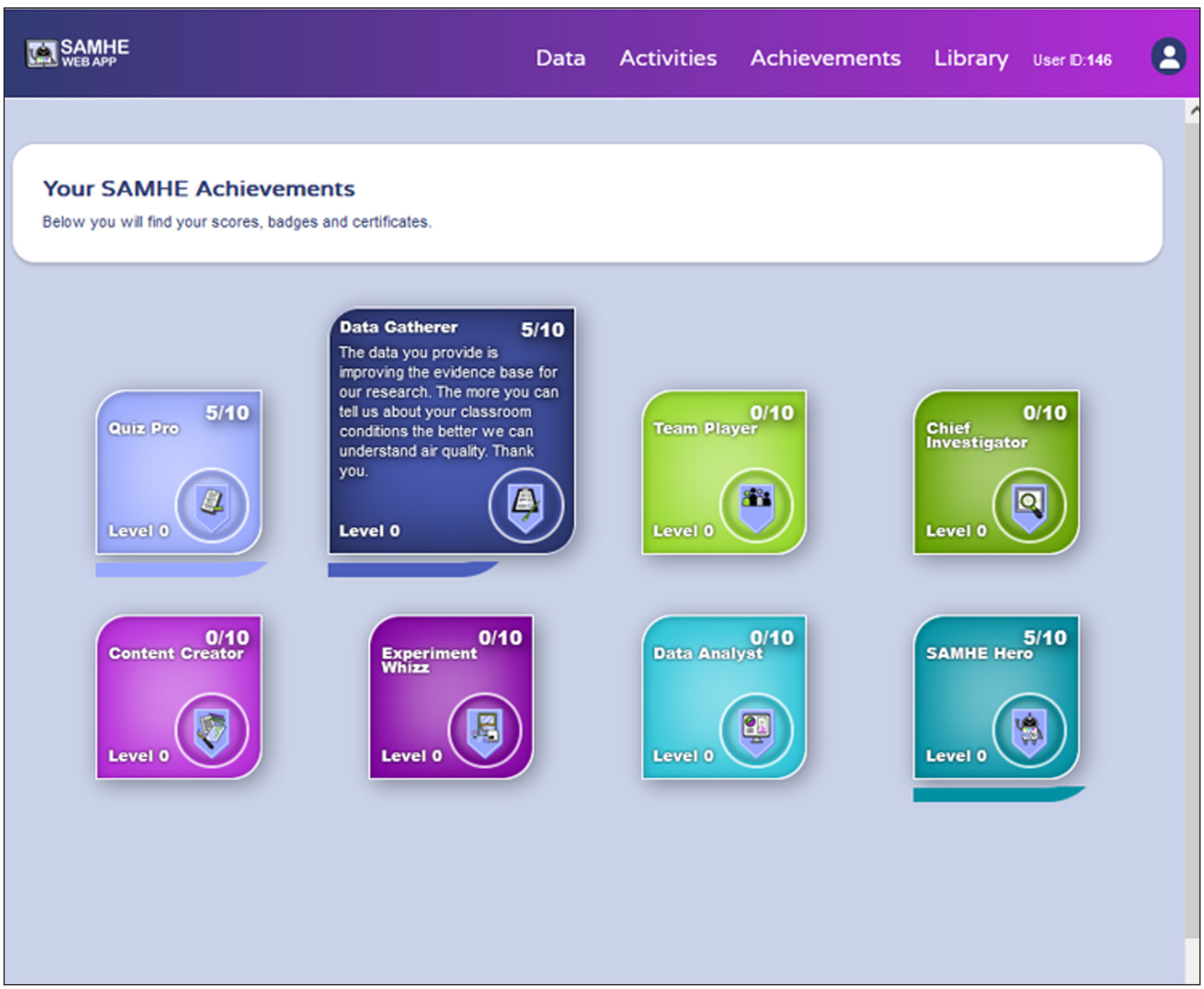

Figure 2 Screenshot of the achievements page of the SAMHE Web App, taken October 2023, showing the different badges, how you obtain them, and progress towards them.

and CPD (Continuing Professional Development) providers; teacher unions; architects; and building engineers. At their second meeting in December 2022, they were asked to give feedback on the SAMHE Web App and the resources linked within it as those resources were being developed, and their thoughts were combined with those from the Pioneer schools to help shape content.

VALUE OF CO-DESIGN

The co-design process with schools and with our engagement panel has been invaluable for shaping both the SAMHE Web App and our explanatory materials for schools. One early example was hearing teacher and pupil views that our idea of having a theme (magic, animals, sport, etc.) for the web app was much less important to them than the content within. Indeed, teachers and older pupils in particular indicated that the web app design and visual appeal was secondary to the quality of the materials and the functionality. All students wanted to see their data as soon as they logged in, so this has been made a prominent element of the home page. Through the sessions, we gained insight into how they currently view data (e.g., bar charts), and this shaped the data visualisation within the web app. We received different preferences for the complexity of the home page from different age groups. To try to accommodate different ages, we kept the elements requested by the older students that make it engaging, but improved the structure of the page to be more intuitive to younger students. Although pupils differed in their personal tastes and views about the logo, the general consensus was that sad faces might be scary or off-putting, so we avoided these in our web app design. Figure 3 shows the

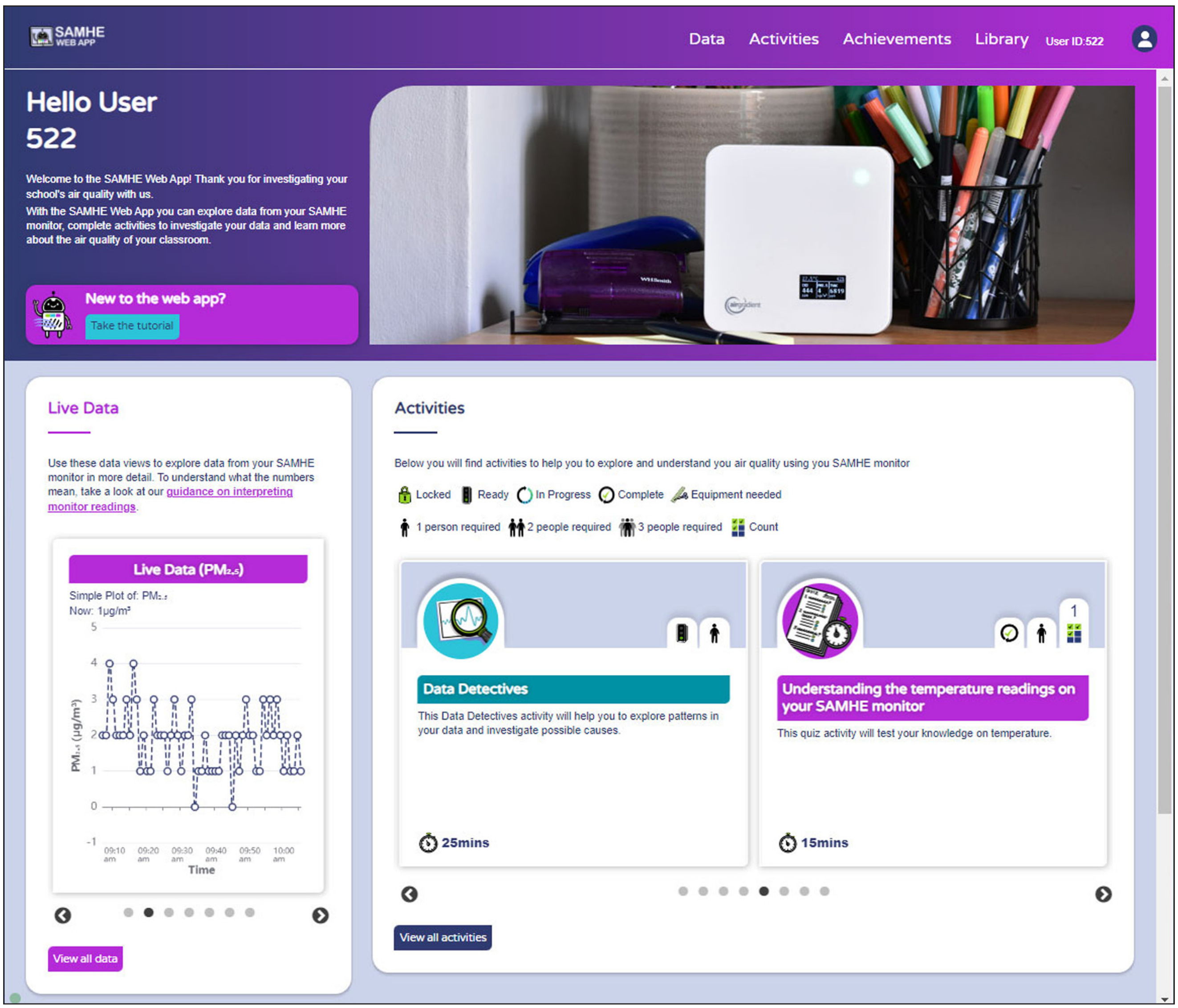

Figure 3 The SAMHE Web App, screenshot taken September 2023. On the left is live data views, and on the right are the activities that schools complete to learn about air quality, to give important contextual information, and to do experiments with their monitors.

SAMHE Web App, with the live data views on the left and the activities on the right.

We also received useful feedback on the monitor connection and web app log-in processes. In particular, teachers told us that (despite our best efforts) the documentation we had provided was overwhelming and had been time-consuming to review. Teachers reported that until the monitor was delivered, and they had something physical to deal with, they had not managed to read our communications in any detail. Taking this into account, we have made a concerted effort to improve our instructions.

Some teachers, having successfully connected their monitors to WiFi, told us that their students were concerned about the numbers and lights the monitor displays, which indicate the levels of CO_2. We had anticipated this concern, and already included materials on the website explaining and contextualising the numbers and lights and giving suggestions for what can be done to improve air quality (in the case of high CO_2 levels, this is primarily improving ventilation). In response to this teacher feedback, we made those resources more prominent on the website, and linked to them directly from the web app to make them easier for pupils to find when they are viewing their data.

We will continue to co-design elements of the project with schools, for example, to design behavioural interventions to help improve air quality. These behavioural interventions may be targeted towards areas where schools' data reveals air quality is particularly poor. An example intervention could be prompting teachers to open windows mid-morning to reduce CO_2 levels.

LESSONS LEARNED

We have learned many lessons from our experience co-designing a web app with schools. Below we divide these into lessons relating to school engagement in citizen science in general, and then more specific items related to technology projects.

CITIZEN SCIENCE WITH SCHOOLS

Communicating with teachers was challenging at times. Teachers are time poor, so written information about citizen science opportunities needs to be very short, clear, and to the point. We had issues with teachers not reading or partly reading emails, and also signing up to attend Zoom sessions but then not attending. Having a range of ways to communicate with teachers may help with engagement. We found that having Padlet allowed busy teachers to give feedback at a time that suits them, but richer comments were gained through the live Zoom sessions.

Citizen science is an excellent approach for engaging participants with science. We found that many pupils were as interested, or more interested, in the people involved in the project as the subject matter. Incorporating materials within projects about STEM careers can help appeal to these interests.

There can be downsides to projects with high levels of interaction. Adopting a co-design approach may foster high user expectations. If there is no capacity for continuous engagement at this level, careful consideration should be given to transitioning. Some schools have reflected that the web app experience we've created feels part of a very distinct and impersonal "computer world" in comparison to the Zoom sessions.

Ethics processes are incredibly important for thinking through ethical issues, such as anonymity and safeguarding, but can be very time consuming and involve multiple applications to committees if projects are co-designed as ours was. It is a good idea to speak to the ethics board in advance so they understand the project and can advise on the best approach for the ethics application. Safeguarding concerns around allowing pupils to post freely on the web app meant that only teachers were allowed to write in comments boxes. This limits the extent of direct interaction between researchers and pupils.

CO-DESIGNING TECHNOLOGY PROJECTS

Connecting devices such as monitors to school WiFi is complicated and time-consuming, with some schools connecting easily and others having to "whitelist" devices to get around schools' firewalls. This is not a new problem, with Blumenfeld et al. (2000) also noting the issue with their US-schools project in the late 1990s. We found having a direct line to the monitor manufacturer (in this case, AirGradient) was critical for making progress. Future projects should ensure sufficient resource is invested in dealing with queries. Identifying and addressing practical issues such as WiFi connection first with smaller groups is valuable as this will pre-empt the resource taken up when the technology is shared with much larger groups—even if some of these issues seem to be easy fixes or cases of misunderstanding on the part of the teacher. Future projects should simplify connectivity issues as much as possible to remove technological barriers that might prevent some schools joining.

CONCLUSIONS

We have created a web app in which pupils and teachers can see the quality of the air in their classrooms. The co-design process helped to ensure that the web app simultaneously meets teachers' and pupils' needs (for example, to support teachers in meeting various aspects of the curriculum), and meets the needs of researchers who will be using the data arising from the project. Our Co-Design schools gave us a small group of teachers and pupils with whom we could openly discuss the project. Pioneer schools allowed us to pilot activities and effectively beta test the web app. Now that the SAMHE Web App is live, we continue to get feedback from teachers via our support email inbox, comments input via the web app and at in-person connection support sessions, which we are also running. This feedback allows us to keep improving it via further development—essential for ensuring it continues to meet the needs of both schools and researchers alike.

DATA ACCESSIBILITY STATEMENT

Data from the workshops are not available as we do not have approval from participants to share in this way. An example outline of the sessions can be seen in the Supplemental Files.

SUPPLEMENTAL FILE

The supplemental file for this article can be found as follows:

- **Supplemental File 1:** Topic Guide for session 1. DOI: https://doi.org/10.5334/cstp.620.s1

ETHICS AND CONSENT

Ethical approval for the co-design work was granted by the Department of Environment and Geography Committee at the University of York in March 2022.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Conception of the project: SW, HB, PK, development of methods: SW, LW, communication with schools: LW, VB, running sessions: SW, LW, RA, SB, initial manuscript draft: SW, editing of manuscript: all authors, revision of manuscript: SW, CCF, LC, RA, LW.

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