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# The Sense-it App: A Smartphone Toolkit for Citizen Inquiry Learning

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# The Sense-it App:

## A Smartphone Sensor Toolkit for Citizen Inquiry Learning

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## ABSTRACT

The authors describe the design and formative evaluation of a sensor toolkit for Android smartphones and tablets that supports inquiry-based science learning. The Sense-it app enables a user to access all the motion, environmental and position sensors available on a device, linking these to a website for shared crowd-sourced investigations. The authors describe the four investigations with the toolkit: environmental noise, sunlight levels, air pressure and rainfall, and the speed of lifts (elevators). These show a variety of methods to initiate, orchestrate and conclude inquiry-based science learning. Two of the missions are in the context of a study to develop a community of inquiry around weather and meteorology. The others are intended to engage members of the public in practical science activities. Analysis of the missions and the associated online discussions reveals that the Sense-it toolkit can be adopted for engaging science investigations, though the practical issue of calibrating sensors on personal devices needs to be addressed.

## KEYWORDS

Citizen Inquiry, Citizen Science, Crowd-Sourced Learning, Inquiry Science Learning, nQuire, nQuire-it, Sense-it, Smartphone Sensors

## 1. PERSONAL MOBILE SENSORS

Mobile phones and tablet computers are equipped with an increasing range of sensors. Originally introduced to control interface functions, such as increasing the screen brightness in sunlight or orienting the display when the device is turned, they can also offer a personal science toolkit to explore the surrounding world. This has been made possible now that sensors in mobile devices are becoming more sensitive and better calibrated and the controlling software emits a rapid stream of data at a full range of levels.

The sensors come in four broad types:

A.  Motion sensors measuring acceleration and rotation using a 3-axis coordinate system (e.g., accelerometer; tilt sensor),
B.  Environmental sensors measuring ambient conditions (e.g., thermometer; barometer; light),
C.  Position sensors measuring the physical location of the phone (e.g., GPS; proximity to an object), and
D.  Body sensors (e.g., fingerprint, heart rate).

Software applications (apps) for mobile phone sensors include obvious ones for noise[1] and light[2] sensing, but also some ingenious apps such as GammaPix[3] (Drukier, Rubenstein, Solomon, Wójtowicz, & Serio, 2011) that employs the camera to detect ionising radiation and Zephrus[4] that detects wind speed from the device's microphone.

Consumer mobile sensors have been applied to crowdsensing (Ganti, Ye & Lei, 2011) where members of the public are recruited in projects to collect environmental data such as levels of pollutants in the atmosphere or rivers. These require additional low-cost sensors attached to mobile phones. Citizen environmental projects using just the sensors on standard mobile devices include monitoring traffic conditions (Mohan, Padmanabhan & Ramjee, 2008) and sharing pictures of daily meals by people controlling their diets (Reddy et al., 2017).

This paper describes a toolkit for learning that makes available the full range of motion, environmental and position sensors in a mobile device. The Sense-it app[5] was first developed in 2013 for the 'nQuire: Young Citizen Inquiry' project, funded by Nominet Trust, and has since been tested with students in a design-oriented college (Herodotou, Villasclaras-Fernández & Sharples, 2014) and as part of a research study of citizen-initiated meteorology (Aristeidou, Scanlon & Sharples, 2015a). It engages people of all ages in practical science activities where they have control over not only the data they collect, but also the initiation of investigations and sharing and discussion of findings. The intention is that people of all ages will experience the excitement and challenge of doing science by employing their own devices as environmental probes in locations around their neighbourhood, or further afield such as on holiday, and learn from the process.

A more recent initiative by Google has developed the Science Journal app[6] for running science investigations on smartphones. It has some similarities to Sense-it in that it enables the user to record and compare multiple trials. However, the Science Journal app currently only includes the light sensor, microphone and accelerometer. While it allows the user to make notes on a trial, it does not provide facilities to share the data with other users, nor for members of the public to initiate new investigations. At the time of writing, the Science Journal website proposes five investigations[7], two of which require additional equipment. The nQuire-it website currently proposes 32 investigations, with seven involving the Sense-it app.

In this paper we provide a brief survey of projects on the application of citizen science to education and introduce recent work in 'citizen inquiry' that fuses citizen science with inquiry-led learning. We show how the Sense-it app has been integrated with the nQuire-it website for members of the public to initiate scientific investigations and share results. The paper offers an analysis of the toolkit in use by college students and by a community of amateur meteorologists, drawing on log files from the software, participants' responses to a questionnaire, interviews with the researcher, plus comments, replies and forum postings on the platform. Both studies were of inventive use of the Sense-it and nQuire-it for inquiry-led learning, so it was not appropriate to undertake an evaluation of learning gains since that would have required a pre-test of domain knowledge, yet the participants were creating their own domains of interest as part of the study. Instead, in line with other studies of inquiry-led learning (see e.g. Alberta Education, 2005) we carried out a formative evaluation to help the researchers and teachers understand the users' processes and strategies, and also to identify issues for further research and development. These issues include: calibration of sensors on personal mobile devices, accuracy of measurement, design of investigations for effective learning, and sustainability of inquiry learning communities.

## 2. CITIZEN SCIENCE

Citizen science activities engage members of the public in carrying out scientific investigations on behalf of, or in partnership with, professional scientists (see e.g. Silvertown, 2009). Some citizen science projects, such as the US Annual Christmas Bird Count (Cohn, 2008) or Galaxy Zoo to classify astronomy observations (Lintott et al., 2008), enable thousands of people to interact with scientists in activities that require mass engagement to collect or classify data. But these projects do not offer opportunities for citizens to initiate their own investigations and undertake the entire process of planning an investigation, selecting the equipment, recruiting participants, collecting data, and analysing and presenting results. While there are claimed benefits to volunteers through enjoyment, finding a social community and participating in real science (Raddick, 2009), there is a lack of evidence relating to the learning benefits of engaging in citizen science projects. A study by Brossard and colleagues (Brossard, Lewenstein & Bonney, 2005) of participants in a citizen science project on ornithology found the participants had gained knowledge of bird biology, but there was no statistically significant change in participants' attitudes towards science or in their understanding of the scientific process.

In a previous project, to address these issues of how to engage young people in personally-meaningful inquiry-based learning, we designed an online environment named nQuire that guided children through an entire cycle of inquiry, connecting learning within and outside the classroom. The typical approach was for the teacher to propose or negotiate a 'big question' in class, such as 'is my diet healthy?' or 'are birds scared away from cities by noise?'. Then the children used mobile devices (for nQuire these were netbook computers, but nowadays they would be tablets) to collect evidence. For example, to explore whether birds are scared by noise, the children worked in groups to measure the ambient noise in different parts of the playground, then they placed bird feeders in quiet and noisy areas. They took photos of birds feeding and measured the amount of food eaten after two days. The unexpected result from that study was that more food was eaten from noisy areas than quiet ones. Their photos of the habitats showed that a greedy pigeon, unaffected by noise, ate food in the noisy area. A repeat controlled experiment in a garden with two trees, one with a noisy radio attached, did show the expected result that small birds ate more from the quiet environment (Anastopoulou et al., 2012).

The birds and noise study was proposed by the children, aged 12-13, in collaboration with their teacher and a wildlife expert. It involved them in a complete investigation in an authentic setting, with unexpected but explainable results. Overall, the nQuire project showed that children were able to operate the equipment and we observed the groups engaging in scientific methods including framing appropriate questions, planning investigations, selecting measures, and collecting and comparing data. A controlled test of the children's scientific inquiry skills, using a measure devised for the project, showed a significant improvement in the accuracy of their understanding of inquiry science decisions from pre- to post-test for the children using the nQuire system (Sharples et al., 2014). A measure of their attitudes towards science showed that 'enjoyment of science lessons' was maintained for the nQuire group from start to end of the project, but declined for a non-intervention control group.

## 3. CITIZEN INQUIRY

Despite these modest successes, the nQuire project would be difficult to scale into widespread adoption without substantial investment in equipment, lesson planning and teacher development. It required the running of a series of well-planned classroom lessons and outdoor or home activities, and placed high demands on the teacher to integrate the data collected by the students into a coherent final lesson where they shared and presented results and drew conclusions.

For these reasons, in our more recent work we have explored the concept of 'citizen inquiry' (Villasclaras-Fernández, Sharples, Kelley & Scanlon, 2013) as the fusing of citizen science and

inquiry-based learning. In citizen inquiry, members of the public (of all ages) explore aspects of practical science through shared investigations on a web-based platform. It combines methods of crowd-sourced project initiation (similar in concept to Kickstarter[8], but with the aim of recruiting participants to join the investigation rather than gaining financial backing), social networking, and reputation management to enable science inquiry projects to be initiated and managed by citizens with differing levels of scientific knowledge and expertise.

For a citizen inquiry 'mission', an individual or group initiates a new investigation around a question or topic of interest or concern. They encourage others of all abilities, including trained scientists, to join and contribute to the mission. The data collected as part of the mission is made visible to all, and available for download and sharing. As the mission progresses, the participants discuss the topic online, through comments and replies linked to the mission and each item of data, and they attempt to reach a consensus about the findings. Social network features allow users to 'like' data items and be notified of comments and likes from other users. Themes (such as 'investigate the weather') can combine a set of missions with differing aims, methods and contributors.

The benefits of citizen inquiry, compared to our earlier approach, is that anyone (student, teacher, member of the public) may initiate an investigation, it draws on the power of the crowd to provide data and comments, and it can be applied across a broad range of topics in the physical, environmental and social sciences. However, unless a teacher or science expert is available to guide the investigation and draw conclusions, there is a risk of ill-conceived and poorly-structured activity.

## 4. SENSE-IT: A MOBILE APPLICATION FOR CITIZEN INQUIRY

Central to citizen inquiry is the use of personal mobile devices for collecting and sharing data. Given the broad range of possible themes and missions, it was important to offer a generic toolkit, rather than a set of specialist topic-specific tools. The sensors on mobile devices can be accessed by software developers[9] but there has been no previous application that gives a user the opportunity to view data from any sensor on a mobile device, nor to process and connect multiple sources of data to learner-led science investigations. This is the basis of the Sense-it app.

Sense-it is an Android app that can be downloaded from Google Play[10]. It gives the user access to all the sensors on an Android smartphone or tablet. A data stream from one or more sensors can be viewed on the mobile device as a dynamic graph. The user can also record data by setting the rate of sampling, then starting and stopping the data stream. The captured data is stored in .csv format for downloading to a spreadsheet. The third method of interaction is to connect Sense-it with a web-based platform named nQuire-it[11], to upload data to its citizen inquiry missions.

Development of the Sense-it app was carried out in collaboration with Sheffield University Technical College (UTC), a technology college specialising in project-based work in collaboration with industry. The teacher from this college proposed that a set of sensor tools on mobile devices would engage the students in practical science investigations. A design workshop with students aged 14-15 developed the initial interaction design and example investigations. Development of Sense-it then continued at The Open University (OU), with trials among OU staff members and with Sheffield UTC.

Figures 1 to 4 show the modes of interaction with Sense-it, through three tabs: Explore, Record and Share. These are described below.

### 4.1. Explore

Selecting the Explore tab displays all the sensors that can be accessed on the user's mobile device, which depending on the device could be 15 or more (Figure 1). Clicking on the icon for a sensor shows a dynamic graph of the sensor output. For example, clicking the Orientation icon shows three moving graphs with the orientation of the device in three axes (tilt, pitch and rotation).
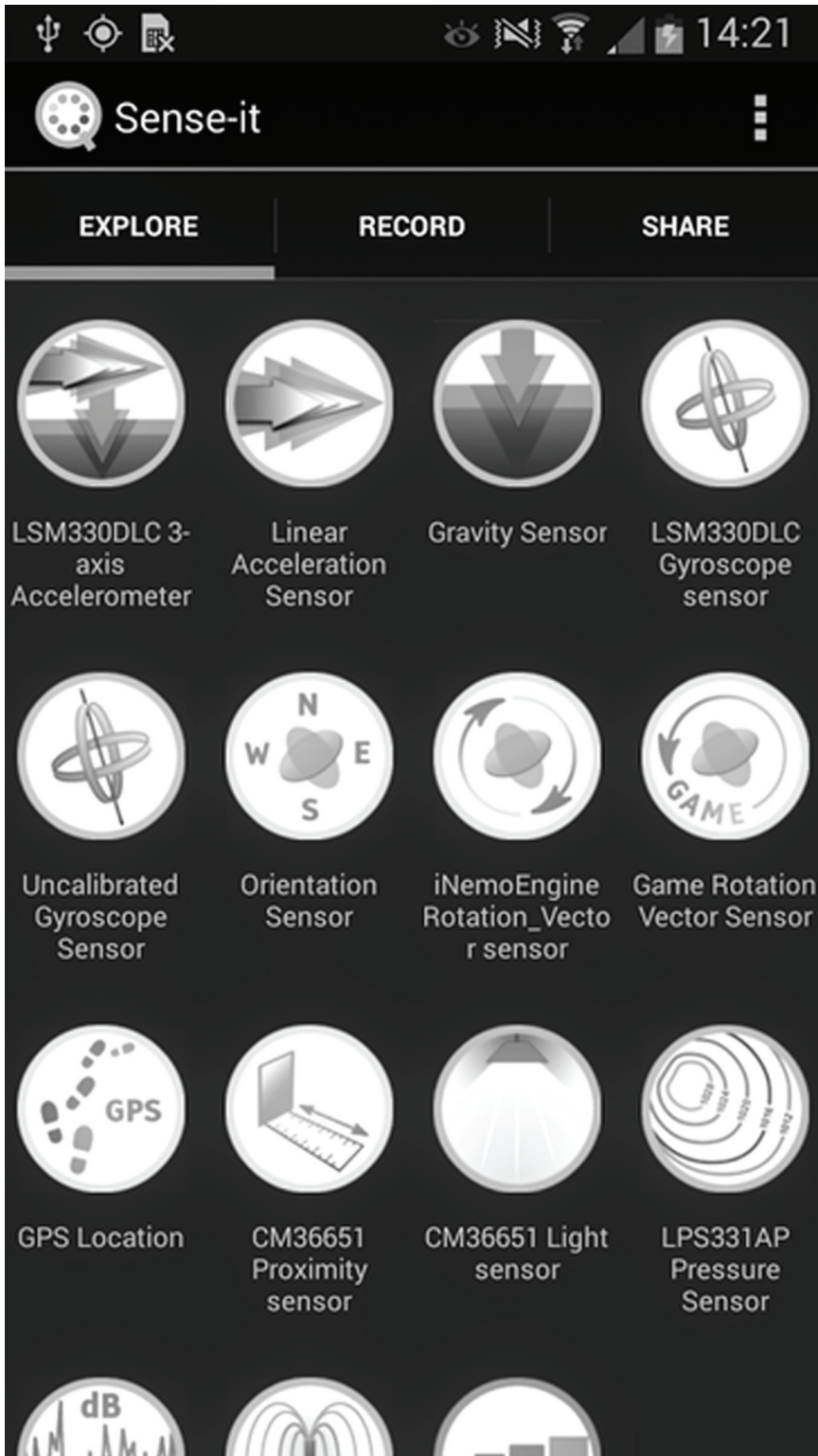
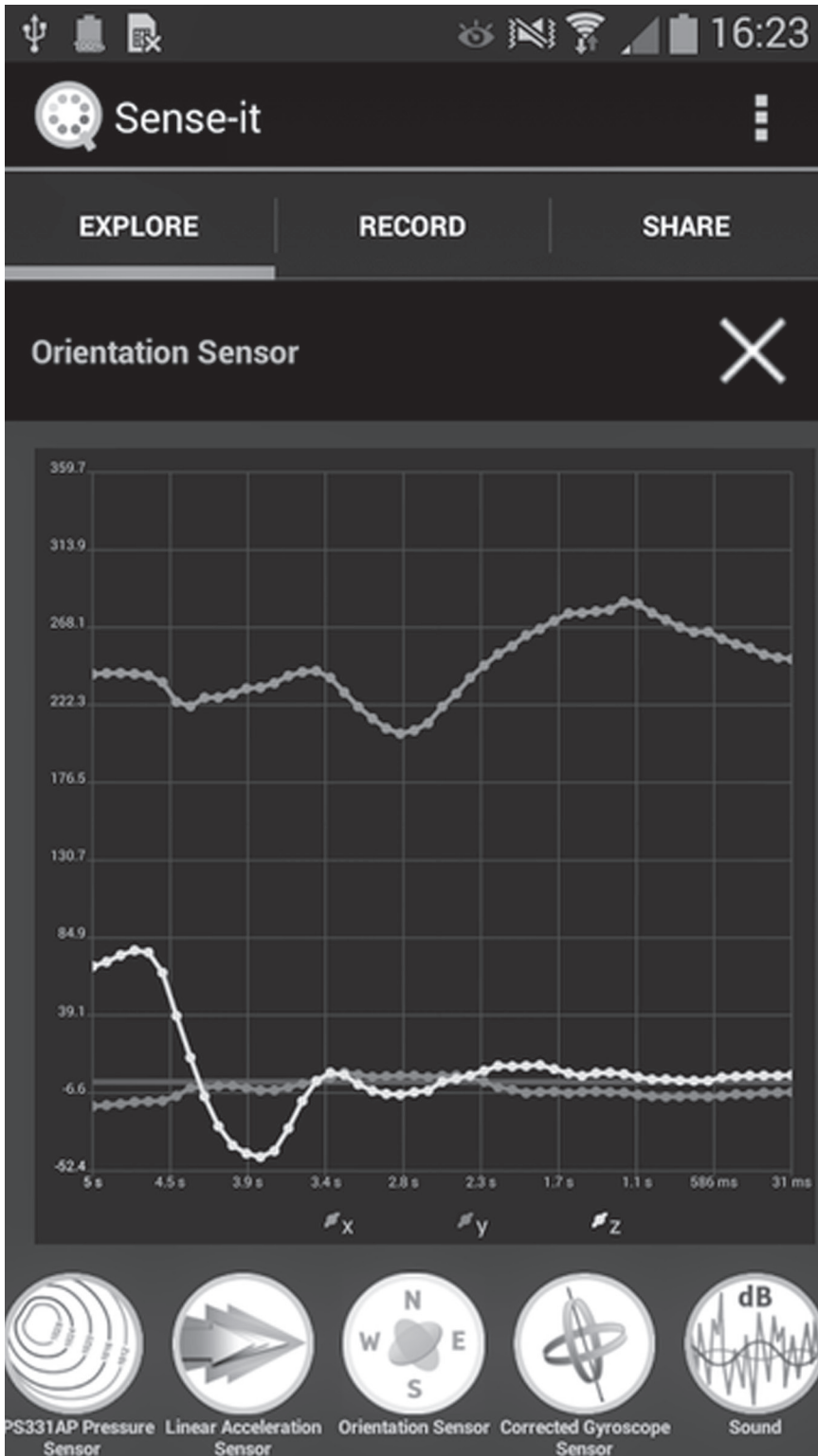Figure 1. Sense-it app

**Figure 2. Explore tab of Sense-it**

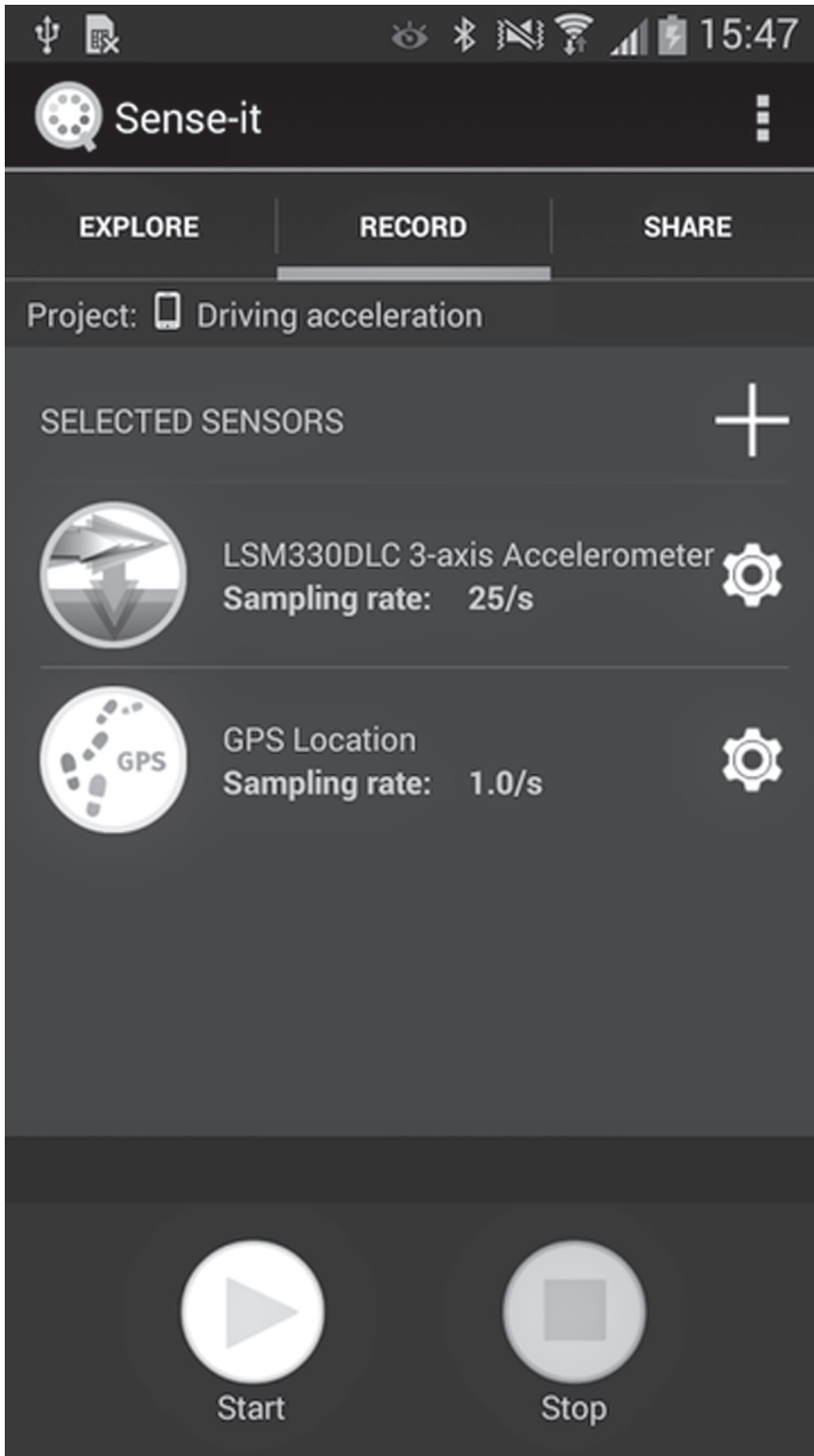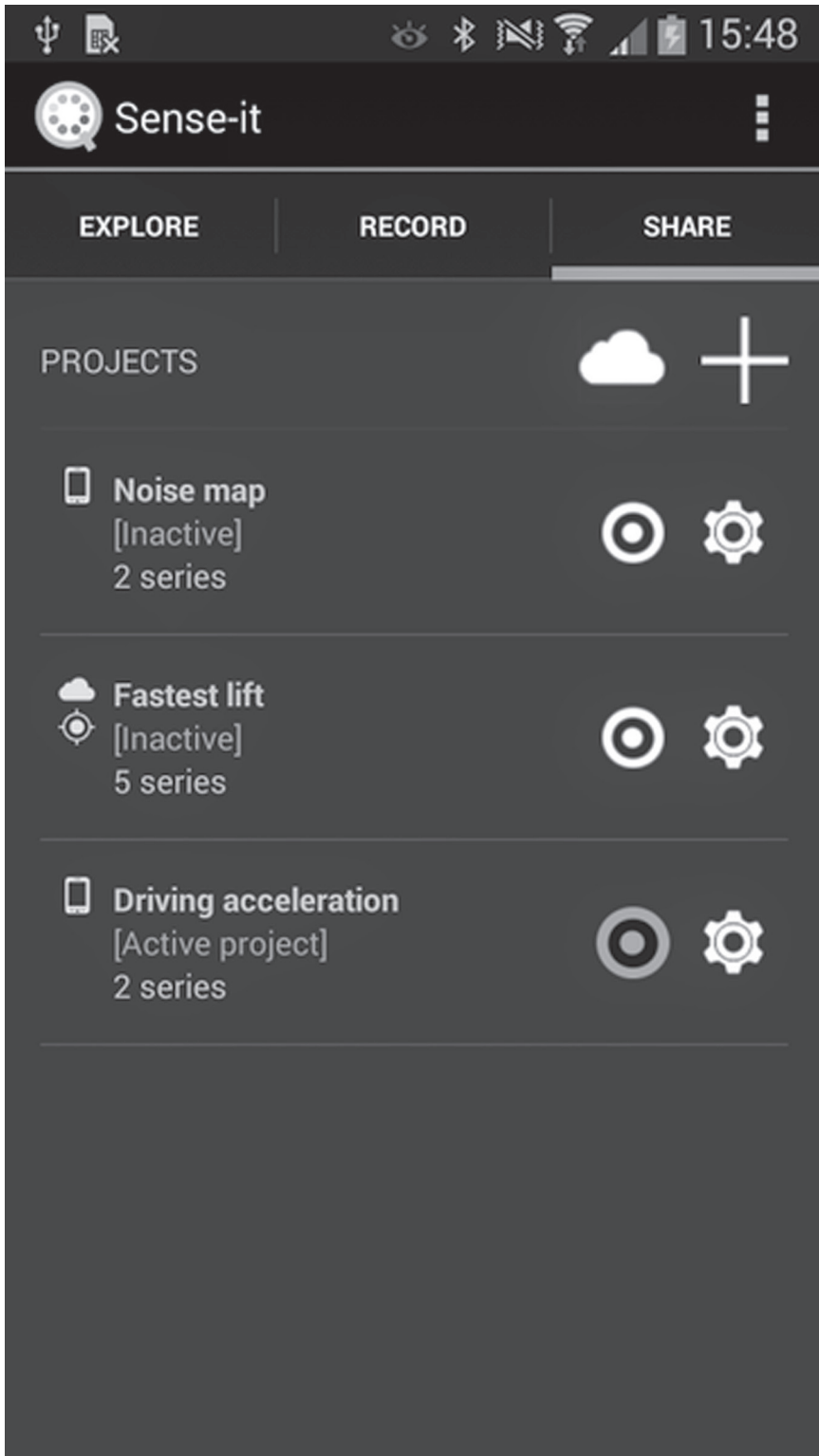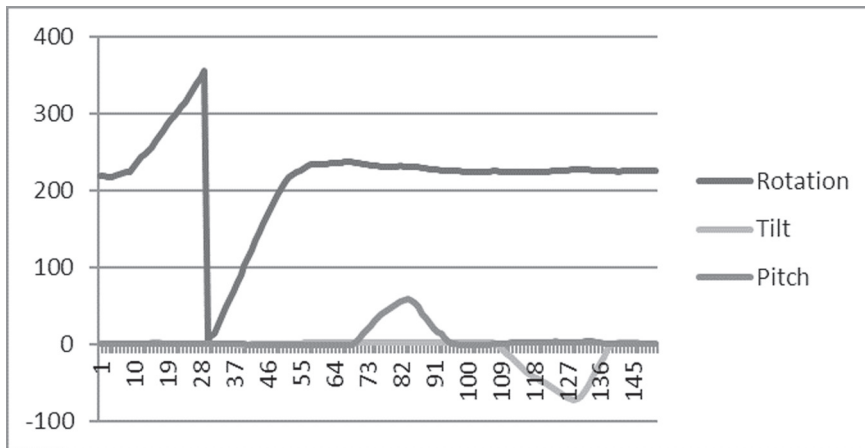**Figure 3. Record tab of Sense-it**

**Figure 4. Share tab of Sense-it**

**Figure 5. Data exported from Sense-it into Excel. The X axis shows time in milliseconds; the Y axis shows the value output by each of the sensors**



## 4.2. Record

Selecting the Record tab allows the user to choose one or more sensors, set the sampling rate, and then start and stop the data sampling. The recorded data can be viewed as a static graph for each sensor, or the stream of data exported in .csv format to a spreadsheet for analysis. Figure 5 shows the data, imported into an Excel spreadsheet, produced from the Orientation sensor, sampling 10 times per second, when an Android device is rotated, then tilted and pitched.

## 4.3. Share

The Share tab allows a user to set up projects that collect and view a series of data samples under one name (e.g. 'My orientation samples').

From the Share tab, by clicking the 'cloud' icon the user can also connect directly with the nQuire-it platform, to join on or more of its missions. On joining a mission, the title of that mission is added to the list of projects. By selecting it, the sensors are automatically configured to collect data for the mission. For example, selecting 'Noise Map' configures the GPS sensor and the Sound sensor to sample data 10 times per second. Then, any data item can be uploaded and displayed on the nQuire-it platform, to be shared with other people who have joined that mission.

## 5. NQUIRE-IT: A PLATFORM FOR CITIZEN INQUIRY

The nQuire-it platform was also developed during the nQuire: Young Citizen Inquiry project. It provides a site to support a variety of citizen inquiry missions in the physical and human sciences, ranging from 'objects and their stories' to creative ways to measure the height of a building or tree. The nQuire-it site has a responsive interface so that it can be accessed on internet-connected smartphones and tablets as well as laptop or desktop devices. The Home page (Figure 6) shows featured missions (all missions can be selected from the View menu). Any visitor to the site can browse these missions, viewing the data and comments. To add new data or comments, or to create new missions, the user must register with the site. Registering with Google credentials allows the user to link missions to the Sense-it app.

The platform currently supports three types of mission:

Spot-it missions are to spot, identify, and share visual images of natural phenomena, for example unusual cloud formations or extreme weather. Typically, the user uploads an image and a title (e.g. "sunset and cirrostratus formation, above Brugge" and may add a comment with further description.

**Figure 6. The Home page of the nQuire-it platform**



Win-it missions set science challenges for other people. An example challenge is "Why are deserts hot during the day but cold at night?" Other users offer responses, then on the closing date users can vote for the best response.

Sense-it missions propose investigations that involve collecting and analysing sensor data. A typical mission is "Does it rain more when the air pressure is low?".

We describe below four Sense-it missions, to show the variety of citizen inquiry activities that can be conducted with a combination of the Sense-it app and nQuire-it platform.

## 5.1. Record the Sunlight

This mission (Figure 7) was created and facilitated by Maria Aristeidou, a PhD student at the Open University, and co-author of this paper. The aim is for people to use the light sensor to measure the ambient light level at midday, and compare it across different locations, and over time.

## 5.2. Air Pressure and Rainfall

The aim of this mission is to investigate the question 'Does it rain when the pressure is low?'. Users measure barometric pressure, using the pressure sensor on some newer mobile devices and record whether or not it is raining. This mission was initiated by a member of the nQuire-it community.

## 5.3. Noise Map

This mission is to record the ambient noise at different locations, e.g. to find the quietest or noisiest working environment, or the noise in a particular setting such as on a London Underground train. It was created by Mike Sharples, a co-author of the paper. (A Spanish version of Noise Map has also been initiated by a user of nQuire-it based in Buenos Aires).

**Figure 7. The Sense-it mission 'Record the sunlight'**



## 5.4. Fastest Lift

The idea for this mission came from the workshop with Sheffield UTC and was proposed by a college student. The aim is to find the fastest lift (elevator) by going to the ground floor of a building, holding the device firmly against the lift wall in a vertical position, starting the recording, travelling to the second floor and stopping the recording. The uploaded accelerometer data is automatically processed to find the maximum velocity (Figure 8).

**Figure 8. Plot of one data recording on nQuire-it for the 'fastest lift' mission**



## 6. CREATING SENSE-IT MISSIONS

The nQuire-it platform provides an environment to create new Sense-it missions. Clicking on the Create tab on the platform (shown on the top right of Figure 6), opens an authoring tool. Here, a user can initiate a new mission, give it a title, add instructions to other users on how to engage with the mission and collect data, and configure the sensors for the mobile device. Then, whenever that mission is synchronised with the Sense-it app on a mobile device, the app automatically configures just those sensors selected by the author of the mission and sets the sampling rate. The mission author can also select a chain of transformations for the data, including: selecting one of the sensor streams, finding the maximum, minimum or average value, and integrating the data (e.g. to compute velocity from acceleration). Figure 9 shows the authoring tool, with processing to select the 'tilt' stream from the orientation sensor, then to record its maximum value.

**Figure 9. The authoring tool for Sense-it missions**
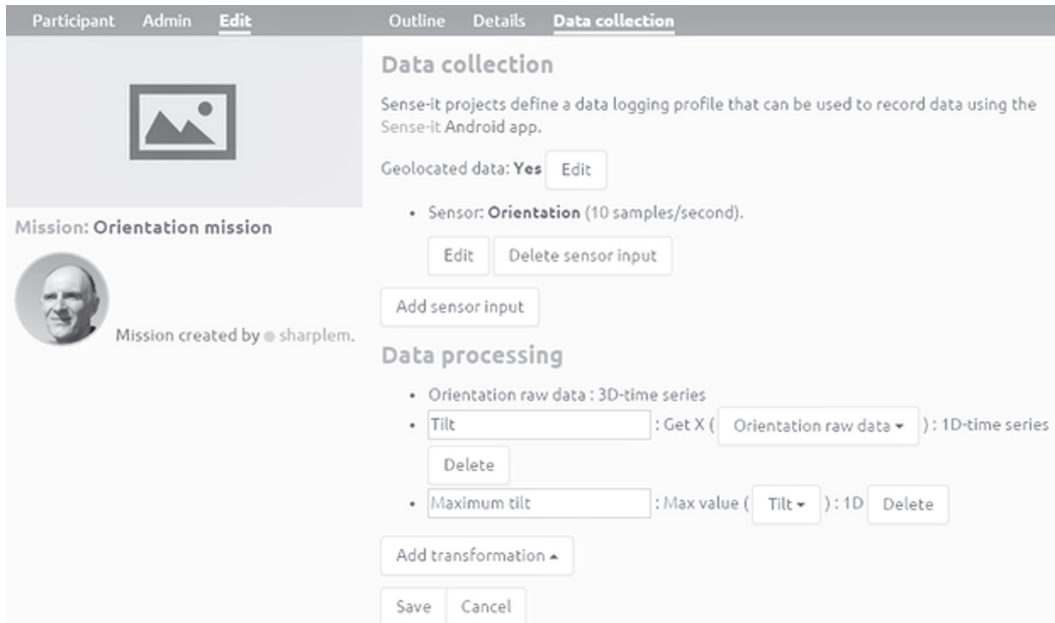


Data produced by all the contributors to a Sense-it mission can be saved a spreadsheet for further processing, comparison or display. This ability to export all the data for a mission is an extension of the facility under the Record tab of the Sense-it app to save the data produced by a single user.

## 7. FORMATIVE EVALUATION

The Sense-it app and nQuire-it platform were developed through a process of design-based research (DBR) (Barab & Squire, 2004) involving an iterative sequence trials for design, implementation and testing. The purpose of a design trial in DBR is both to inform development of the technology and to provide insights into its use and value. For this project, the insights related to the usability of the toolkit, types of educational investigation proposed by users, evidence of learning activities, and issues related to scientific accuracy or educational value. Since a typical citizen inquiry activity is initiated by a member of the public and does not follow a pre-prepared curriculum, it is not appropriate to measure learning gains as there is no way to test prior knowledge. Measures of success of the project include evidence of engagement of trained scientists supporting members of the public in shared activities initiated by citizens, use of scientific language and procedures, and insight into issues and opportunities for further development.

Early testing was carried out at The Open University and included heuristic usability evaluation (Nielsen & Molich, 1990) of the Sense-it and nQuire-it software with experts in human-computer interaction. This led to modifications of the interface and interactivity.

The first design trial was run with students from Sheffield UTC (N = 96, aged 16-18). The students were asked to assess the Sense-it prototype in order to improve its design and propose citizen inquiries using the tool. Students' answers were analysed using thematic analysis. The answers were organized into clusters of congruent meaning and reduced to summary categories. Their suggestions for improvement related mainly to the user interface, such as more meaningful use of colour. Inquiries suggested by the students included: 'How loud is it when you do Maths compared to English?', 'How

bright does light need to be to wake you up?', 'What is the acceleration and top speed of the lifts in UK?'.

A second trial was also conducted with Sheffield students (N = 43, aged 16-18), using an enhanced version of the Sense-it app and nQuire-it platform. Students worked in groups with the Sense-it app and completed evaluation worksheets. They were asked to propose science investigations that could be hosted on the nQuire-it platform, identify aspects of the tools they liked the most and aspects they liked the least and suggest design improvements. The information was again grouped into themes. The main themes that emerged from the analysis were that students were in general satisfied with the interface and interactivity of the app and platform. The least satisfactory aspects were logging into the platform from the app and understanding graphs uploaded from Sense-it. Their suggestions for improvements related to the addition of more and varied missions, guidance and explanations on what they might do with it, and social aspects such as adding a rating system, updates from other members and a chat room. Examples of the missions they created were: 'How much do you move when you sleep?', 'Computer loudness test: which computer is louder?' and 'Find the noisiest UK ponds'.

The third trial, named Weather-it, was carried out over 14 weeks with adult volunteers. The aim was to explore the formation, activity, and sustainability of a citizen inquiry community on the topic of weather and meteorology. It used an enhanced version of the nQuire-it platform that had benefitted from improvements proposed in the previous two trials. The participants were members of the public recruited from existing weather, education and science communities (such as UK Weather Watch[12]) as well as social networks. A total of 101 people registered for this trial, of whom 78 engaged with the nQuire-it platform.

## 8. FINDINGS

Findings from the Weather-it study have been reported in Aristeidou, Scanlon & Sharples (2015a,b). Only results relevant to the Sense-it app are presented here. In total, the participants created 24 missions, added 422 data items, contributed 441 comments and made 188 forum postings. The findings are presented in four categories: activity on the platform; evidence of learning; calibration of sensors; successful and sustainable investigations. Calibration of sensors emerged as an unexpected issue from analysis of the sensor data and comments, particularly in the 'Record the sunlight' and 'Air pressure and rainfall' missions.

### 8.1. Activity on the Platform

Activity on the platform during the Weather-it trial (78 participants) was analysed by Social Network Analysis to reveal which people contributed data to which missions, who commented on whose data, and who posted to which forums. The most popular Sense-it mission was 'Record the sunlight' (146 observations) which required people to measure the light intensity in different parts of the world at midday. Commenting on specific missions and data items was more popular than making contributions to forums.

Activity on the nQuire-it platform during the Weather-it trial was also analysed for engagement, based on metrics devised by Ponciano & Brasiliero (2015) for contributory projects. The measures used were Activity Ratio, Relative Activity Duration, and Variation in Periodicity. An additional measure of Lurking Ratio was added to indicate when a participant lurks on the platform (browses but does not contribute). A cluster analysis of the data grouped the users into five categories: Loyal, Hardworking, Persistent, Lurking, and Visiting. The largest category was 'visitor' (N = 43), representing people who contributed to the project on one or two days. This category was further divided into 'active' and 'hesitant' visitors. These profiles were enriched by questionnaires and interviews with some participants. The surveys (N = 61) indicate a mixture of beginning (62%), intermediate (25%) and expert (13%) knowledge of meteorology. Many 'active' participants reported interest in the project but a lack of time to engage further. Only four out of the twelve participants in the 'hesitant visitor'

category joined out of interest in the topic, with most joining because of friendship with other participants or out of interest in the software and community. An important finding is that while 68% of the survey respondents indicated that they felt like a part of the community, a third did not identify with the community due to lack of time, number of visits, and notifications, but also perceptions of difference in ages and uncertainty over how to behave in such a community. Nevertheless, many people who reported not feeling part of the community were categorised as 'active'. This suggests that further work is needed to make all participants feel 'at home' in a citizen inquiry community with a diversity of ages, abilities, and interests.

An examination of the learner interactions during Weather-it shows differences in facilitation, process and outcome. Record the Sunlight was intended to have short duration and was facilitated by the researcher for her PhD project. The measurements were from eleven different places in Europe, ranging from 2 to 37 readings and 1 to 5 people measuring in each place. Graphs were produced for the measurements in every location indicating the variation in readings for the period and the average Lux. According to the final results, Limassol had the highest average sunlight for that time interval and Stockholm the lowest (Figure 10). Data from the 'Record the sunlight' mission show that users followed the correct recording method and produced steady plots representing the sunlight level at the specific area at noon. Only eight out of 146 contributions (5%) were counted as invalid. These showed irregular plots (e.g., the mobile device was not placed on a flat surface), wrong time of recording (e.g., morning instead of noon), or very low measurement values for sunlight (e.g., 125 Lux).

The 'Air Pressure and Rainfall' mission was proposed by one of the participants and recorded 34 contributions. The contributions were made mainly in Milton Keynes, London and Bilbao. Analysis of data showed no clear relation between air pressure and rainfall, but it did identify calibration issues with air pressure sensors, and also produced a lively discussion on the complexities of relating rainfall and air pressure. Although this mission was available for as long as the 'Record the sunlight' mission, it was less popular as fewer mobile devices contained air pressure sensors.

Noise map has recorded 96 items. Fastest Lift, requiring a more complex set of actions to record the velocity of a lift (elevator), has had 28 contributions over a period of 7 months.

## 8.2. Evidence of Learning

Evidence of learning is necessarily indirect. It is extracted from self-reports of learning from those who completed the section of the survey relating to learning experience (N = 28), and excerpts from the set of comments, replies and contributions to forums on the nQuire-it platform. All contributions

Figure 10. Average light levels for cities measured on the Record the Sunlight mission
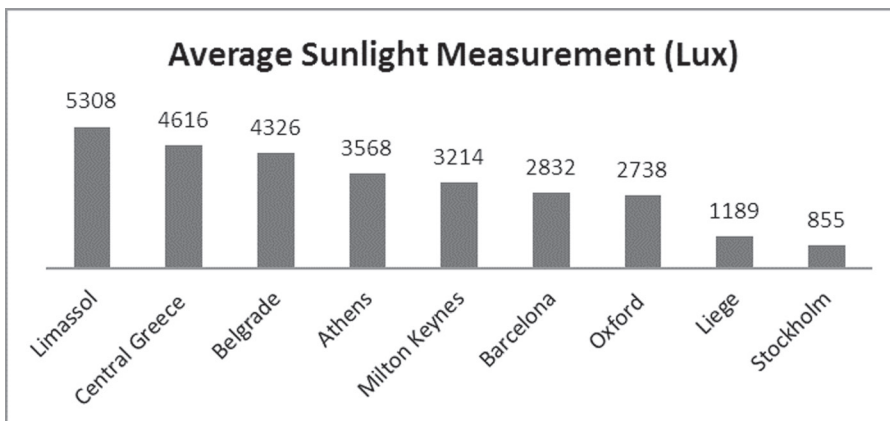
to Sense-it missions were subjected to a thematic analysis to identify words or phrases that might indicate evidence of knowledge gains or adoption of scientific practices.

### 8.2.1. Knowledge Gains

From the survey, 64% of the respondents indicated that they had gained knowledge of meteorology during the trial. Some textual responses to the survey indicated learning about the potential of personal mobile devices and sensors for learning:

*I've learned about the sense information monitored in a smart phone.*

and the social value of citizen inquiry:

*People who have no meteorology degree can take initiatives too:) and maybe, in the future, they will have some good ideas about questions or solutions.*

Comments on the nQuire-it platform show examples of learning about the process of collecting data and from the results of the investigation:

*I tried measuring through the window and with the window open, I got a big difference (and yes, the windows were just washed ☺ ). I knew windows absorb some light but the difference was really big.*

(Belgium, Record the Sunlight)

*Belgrade has a good average. I wouldn't expect this!*

(Germany, Record the Sunlight)

*I wasn't aware of how a noisy neighbourhood I live!!! ;-)*

(Argentina, Noise Map)

These comments offer insight into learning processes. The first indicates conceptual change (in understanding how windows absorb light), the second and third show learning from unexpected evidence. However, these are isolated examples and more work is needed to explore how citizen inquiry activities can be designed and facilitated to support different types of learning, including learning about science topics, learning about the properties of materials and instruments, learning from evidence, and learning how to conduct valid science investigations.

### 8.2.2. Enhanced Scientific Practices

There was evidence of trained scientists contributing to missions. The following comment accompanies the 'Air pressure and rainfall' mission:

*Meteorologists use the relative pressure. So when they draw their maps each area's air pressure is elevated/normalized to the sea level pressure (SLP). This is done in order to get rid of altitude variations within our data (the higher you are the lower the pressure). So as a first step all weather stations / sensors need to be adjusted to give the relative (sea level) pressure and not the absolute value. This way we can have reliable data.*

Participants also commented on some postings using scientific language and reference to science practices. For example, the forum accompanying the 'Record the sunlight' mission contains the following exchange. A participant writes:

*I tried to do three measurements today -- one with my phone lying on the window frame in my bedroom, one with holding the phone out of the window and one going out to an open area. Surprisingly, I got very different results (around 300 lux, around 700 lux and around 1500 lux). I expected the numbers won't be the same but thought they would be more similar. Conclusion, don't be lazy like I was trying to be and really go out for the experiment:)*

To which the creator of the mission responds:

*I placed my phone on the grass, while it was raining, to do the measurement. i was excited, I am not sure about my phone:D*
*I'd say that the numbers of your measurements are quite similar though. Today is cloudy in the area, when it's sunny you may even get 10-15 000! We should keep an eye on the sun in the next days.*

And the participant replies:

*I didn't know the numbers can go so high. Now I'm curious to see differences between sunny and cloudy days (and also sunny days in UK and sunny days elsewhere:).*

This was an exception. In general, there has been little interaction on the nQuire-it site between experts, novices and amateur scientists. None of the Sense-it missions received expert comments on the data, apart from one comment on sensor calibration (see below). This may be because the data plots are not immediately visible – the user needs to click to show either the data plot or its location on a map – or because the missions have not engaged interest from expert scientists. Either way, more research is needed into how to create and maintain investigations of interest to scientists.

## 8.3. Calibration of Sensors

One issue hampering the use of mobile devices to conduct studies of scientific value is calibration of sensors. Inaccuracy of sensors on mobile devices has been reported elsewhere (see e.g. Blum, Greencorn & Cooperstock, 2012; Hemminki, Nurmi & Tarkoma, 2014). For example, Blum and colleagues found a mean compass error for three smartphones[13] of 10°, increasing to 30° in some urban areas.

Prior to the creation of the 'Record the sunlight' project, the researcher carried out a small study to test whether the light sensors on mobile phones were correctly calibrated. A first step involved measuring the light of a halogen 42-watt bulb with plain glass, bought new and suspended on a wire with no shade and no other ambient light in the room. Eight mobile devices were placed flat, directly under the light bulb and about 1 metre away, and recorded the 20 samples of light, repeating the measurement three times. An approximation to the theoretical illuminance of the particular light bulb at that distance was calculated by the inverse-square law[14] to be equal to 66.85 Lux. The results showed a wide divergence of measurements ranging from 33 to 1000 Lux. The conclusions from this experiment were that there was large discrepancy between the theoretical illuminance and the measurements. Furthermore, there were differences among the mobile devices of the same brand and model. These led to a more thorough investigation involving the help of experts.

First, advice was sought from a calibration expert. One method proposed for calibrating the application, would be to add a scaling feature to the software, allowing the user to increase or decrease the level by reference to a calibrated professional light level meter. A professional light meter was

used by the researchers to calculate the difference between the measurements by mobile devices and a calibrated sensor. Shortcomings of this method were the absence of such a scaling feature on the Sense-it app and that most people using the app would not have access to a professional meter.

Then, a camera expert was contacted for further investigation. As scaling between devices was one of the possible options, device datasheets were studied in order to provide information such as integration time and wavelength response. Some of the mobile devices used in the experiment had linear sensors in them, which means that if the light input doubles, the output will also double (in some other cases when the input doubles the output quadruples). For such linear sensors, a scaling relation may work as long as the scaling is done for the same light source between devices and not between a halogen bulb and sunlight. This inability is due to the possible difference in wavelength responses.

However, the light sensors on some phones only output a limited number of levels since they are used primarily for dimming the screen in sunlight rather than giving accurate Lux readings. Moreover, some sensors have 'max' values, beyond which they will not be sensitive to any increase in Lux, and this may be an issue when measuring bright sunlight. Another important factor affecting the measurements is the tolerance associated to particular sensors which may relate to the uncertainty of the output of the chip for a given light input; for example, a device sensor may have a tolerance of +/- 15% varying the results compared to other devices. Finally, hardware damage (e.g. a scratched or dirty sensor cover) may also affect the measurement values.

The need for calibration scaling will occur for other sensors, such as atmospheric pressure, compass and magnetic field. Though they give continuous readings, not restricted to pre-set levels, they can be poorly calibrated. As an illustrative example, the lead author's Samsung GT-19300 phone, consistently gives an atmospheric pressure reading of 19-21mbar lower than that recorded by a local Milton Keynes weather monitoring station. As a weather expert commented on the 'Air Pressure and Rainfall' mission, meteorologists normalise air pressure recordings to Sea Level Pressure "So as a first step all weather stations / sensors need to be adjusted to give the relative (sea level) pressure and not the absolute value. This way we can have reliable data." Adjusting the reading for the altitude of Milton Keynes removes most of the deviation (13 mbar).

Learning how to calibrate sensors on personal mobile devices is, in itself, a valuable science education activity. There is evidence from comments that a few participants were considering calibration and stability of the sensors:

*The fact that is not so stable means that it should be discarded? (Record the sunlight)*

The Sense-it app might be configured to do automated calibration of some sensors (e.g. atmospheric pressure) based on location or presence of nearby accurate 'ground truth' sensors (Miluzzo, Lane, Campbell & Olfati-Saber, 2008) but that by-passes the educational opportunity to perform and share calibration data. It could be preferable to provide better guidance, on the nQuire-it site, as to how to carry out individual and shared calibration activities.

## 8.4. Successful and Sustainable Investigations

The inter-relations between participant intentions, mission guidelines, scientific complexity, and facilitation of sensor missions all appear to influence their popularity, persistence and outcomes. So far, we have not been able to find an ideal sensor-based mission that satisfies the requirements of:

- Broad appeal for novice, enthusiast and expert scientists;
- Engagement with investigations of personal relevance and meaning;
- Value in exploring a phenomenon of scientific interest;
- Accuracy of sensor data;
- Ability to share and present results in a meaningful form.

One investigation that may meet these criteria is 'Birds and Noise Pollution'. This arose through discussions among children aged 11-14 for the nQuire project, developed further with wildlife experts. The issue to investigate is whether birds are scared away from city centres by noise. The impact of noise pollution on birds is an issue of current scientific interest (Ortega, 2012). One method to investigate this is to measure the mean ambient noise levels at different locations in a constrained area such as a school grounds, then place bird feeders in quiet and noisy locations, and measure how much food is eaten by birds from each of these locations, to see if there is a relationship between noise levels and food consumed. Experiments such as this require a greater level of investment in time and equipment than the missions reported in this paper, so the 'sweet spot' for citizen inquiry may come through collaboration among organisations such as schools and hobby clubs, along with individual enthusiasts and trained scientists. This would require publicity and mediation by organisations such as (in the UK) the Royal Society for Protection of Birds.

Another general issue is sustainability of the missions. Our study of the evolution of the Weather-it community of weather enthusiasts on the nQuire-it platform showed continuing participation during the 14 weeks of the study when the community was actively facilitated by Aristeidou for her PhD research (Aristeidou, Scanlon & Sharples, 2015b), but a rapid drop-off in participation when that facilitation ended (Figure 11). It would appear that active facilitation of a group of missions, on the platform and on social media sites such as Twitter and Facebook, is required for sustainability. The iSpot site for wildlife investigations[15] combines facilitation from an 'iSpot Team' with a system for reputation management that recognises active, helpful and accurate participants, rewarding them with virtual badges (Silvertown et al., 2015). A similar combination of professional facilitation and reputation management would be needed to ensure continued engagement of users with nQuire-it.

## 9. CONCLUSION

Sense-it is an innovative application that makes data streams from all the sensors on an Android mobile device available for examination, play, and inquiry-based learning. Linked to the nQuire-it platform, Sense-it provides a means to enact 'citizen inquiry' that involves members of the public in initiating and facilitating collaborative science learning missions, based on data collected in the

Figure 11. Number of contributions during the Weather-it facilitation period and at the end of facilitation
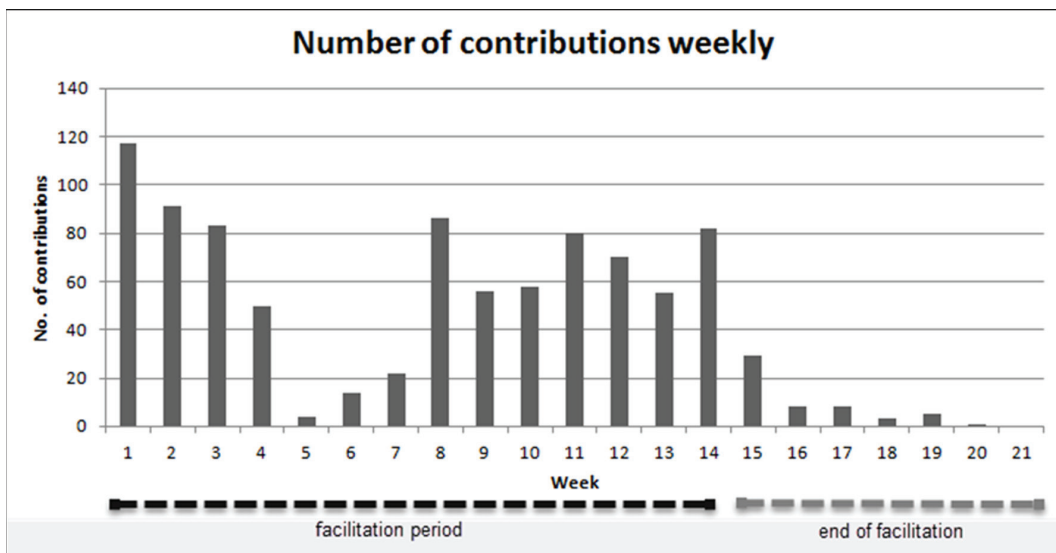
wild. The three design trials led to refinements of the app and platform, so that these are now fully integrated and usable by members of the public. The trials with students from Sheffield University Technical College produced suggestions for citizen inquiry missions that could appeal to young people. The Weather-it trial with volunteer adults showed engagement with the sensor app and platform and offered some evidence of learning about scientific topics and the practices of scientists. More work is needed to share the learning with other participants and to bring expert scientists more fully into the activities. This suggests a need for active facilitation of missions, to recruit participants, develop missions with scientific value, capture and disseminate insights as they arise, and share results.

An issue of calibration emerged as the study progressed. Sensors on mobile devices are becoming more accurate, with continuous data and calibration by manufacturers. It is, however, essential to calibrate sensors if the device is to be used for accurate data recording, and this process of calibration can be a valuable learning opportunity.

The central issue is that the platform has not yet achieved fully successful and sustainable investigations. We suggest that developing a successful toolkit for sensor-based citizen inquiry requires: creating missions with a combination of personal meaning and scientific value, promoting the approach and site through national and international science organisations, providing continual facilitation, and implementing a system of reputation management and reward. We are exploring how this can be achieved for a variety of themes.

The nQuire-it platform can be accessed at www.nquire-it.org. The Sense-it app can be downloaded free, from https://play.google.com/store/apps/details?id=org.greengin.sciencetoolkit&hl=en_GB. The nQuire-it platform is open source. Code is available at https://github.com/IET-OU/nquire-web-source

## ACKNOWLEDGMENT

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## ENDNOTES

[1]     E.g. Sound Meter, https://play.google.com/store/apps/details?id=kr.sira.sound&hl=en
[2]     E.g. Light Meter, https://play.google.com/store/apps/details?id=com.bti.lightMeter&hl=en
[3]     www.gammapix.com
[4]     https://play.google.com/store/apps/details?id=b4a.zephyr&hl=en
[5]     https://play.google.com/store/apps/details?id=org.greengin.sciencetoolkit&hl=en
[6]     https://play.google.com/store/apps/details?id=com.google.android.apps.forscience.whistlepunk&hl=en
[7]     https://makingscience.withgoogle.com/science-journal/activities
[8]     www.kickstarter.com
[9]     http://developer.android.com/guide/topics/sensors/sensors_overview.html
[10]    https://play.google.com/store/apps/details?id=org.greengin.sciencetoolkit&hl=en_GB
[11]    www.nquire-it.org
[12]    http://www.ukweatherwatch.co.uk/
[13]    iPhone 4, iPhone 4s and Google Galaxy Nexus

[14]    Illuminance = $\dfrac{Luminous\ power}{4\pi d^2}$ , where $d$ is the distance from the light source

[15]    http://www.ispotnature.org/

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