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Sense-it: A Smartphone Toolkit for Citizen Inquiry Learning

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Abstract

We describe a toolkit for Android smartphones and tablets that enables a user to access all the sensors available on the device. Data from individual sensors can be viewed as dynamic graphs. Output from one or more sensors can be recorded to a spreadsheet, with the sampling rate set by the learner. As a tool for inquiry learning, the sensors can be linked to 'missions' on the nQuire-it website, allowing learners to sample and share data for collaborative crowd-sourced investigations.

Four nQuire-it missions have employed the sensor toolkit for investigating environmental noise, sunlight levels, air pressure and rainfall, and the speed of lifts (elevators). These four investigations represent a variety of methods to initiate, orchestrate and conclude inquiry 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 practical and engaging science investigations, though the issue of calibrating sensors on personal devices needs to be addressed.

Keywords: inquiry science learning, smartphone sensors, crowd-sourced learning

1 Introduction

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 (Bossard, 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 was that in the study, more food was eaten from noisy areas than quiet ones. Their phots 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, showed the 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, involved them in a complete investigation in an authentic setting, with unexpected but explainable results. 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 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.

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.

2 Citizen Inquiry

For these reasons, in our more recent work we have explored the concept of ‘citizen inquiry’, 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 to Kickstarter[1], but with scientific curiosity rather than financial incentives), social networking, and reputation management to enable science inquiry projects to be initiated and managed by citizens with differing levels of knowledge and expertise.

Typically, an individual or group will initiate a new investigation (or ‘mission’) around a question or topic of interest or concern. They will encourage others of all abilities, including trained scientists, to join and contribute to the mission. All the data collected as part of the mission is made visible 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 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 the citizen inquiry approach over personal inquiry learning, are that it does not rely on a teacher to initiate a project (though a teacher may propose a citizen inquiry theme or a mission as part of a school project), 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.

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[1] www.kickstarter.com

3 Sense-it: mobile technology for citizen inquiry

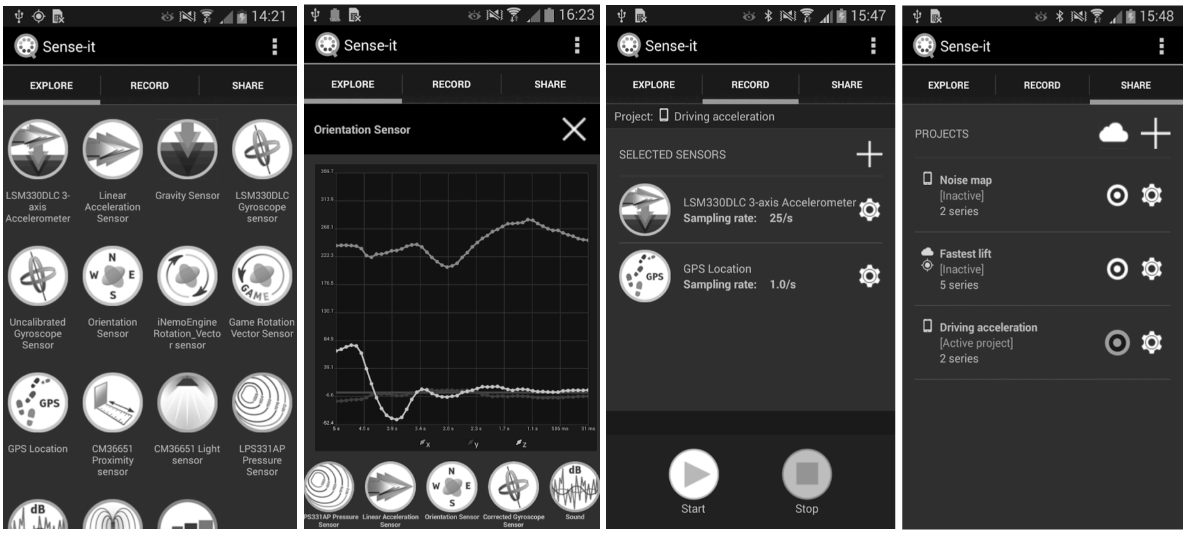
Central to citizen inquiry, is the use of mobile devices for collecting and sharing data. Given the broad range of possible themes and missions, in designing mobile technology it was important to offer a generic toolkit, rather than a set of specialist domain-specific tools.

A modern mobile phone comes equipped with a wide range of sensors including:

- Motion sensors, to measure acceleration and rotation.
- Environmental sensors, for ambient air temperature, noise, illumination, air pressure, magnetic field and humidity
- Position sensors, including GPS location and orientation

All these sensors can be accessed by software developers[2] but there has been no previous application that gives a user the opportunity to access and 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 application (app).

Development of the Sense-it app was carried out as part of the nQuire: Young Citizen Inquiry project, funded by Nominet Trust. The project involved 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.



Project: Driving acceleration

LSM330DLC 3-axis Accelerometer
Sampling rate: 25/s

GPS Location
Sampling rate: 1.0/s

Noise map
[Inactive]
2 series

Fastest lift
[Inactive]
5 series

Driving acceleration
[Active project]
2 series

Figures 1-4: The Explore, Record and Share tabs of Sense-it

Sense-it is an Android app can be downloaded from Google Play[3]. 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

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[2] http://developer.android.com/guide/topics/sensors/sensors_overview.html
[3] https://play.google.com/store/apps/details?id=org.greengin.sciencetoolkit&hl=en_GB

downloading to a spreadsheet. The third method of interaction is to connect Sense-it with a web-based platform named nQuire-it[4], to upload data to its citizen inquiry missions.

The main screen of Sense-it shows three tabs: Explore, Record and Share (see Figures 1-4).

3.1 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).

3.2 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 Excel, produced from the Orientation sensor, sampling 10 times per second, when an Android device is rotated, then tilted and pitched.

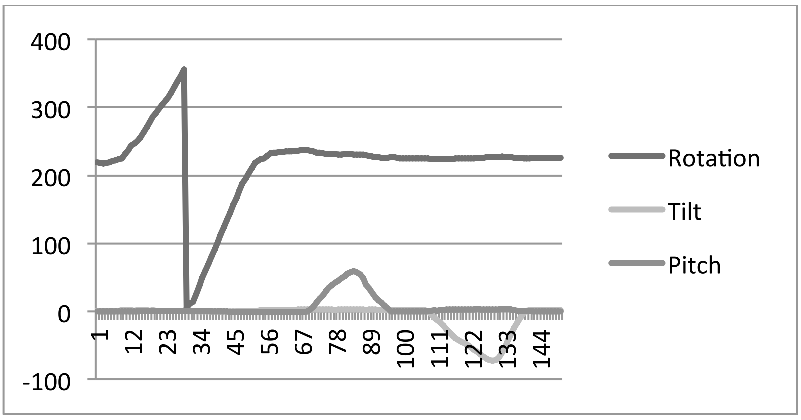

Figure 5. Data exported from Sense-it into Excel

3.3 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'). The user can also connect directly with the nQuire-it platform, by clicking the 'cloud' icon, to join on or more of its missions. On joining a mission, the title of that mission is added to the list of project and the sensors selected and configured to collect data for the mission. Any data item can then be uploaded and displayed on nQuire-it, to be shared with other people who have joined that mission.

4 nQuire-it: A platform for citizen inquiry

The nQuire-it platform (www.nquire-it.org.uk) (Figure 6) was also developed during the nQuire: Young Citizen Inquiry project (see Herodotou et al., 2014). It provides a site for a variety of citizen inquiry missions, 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..

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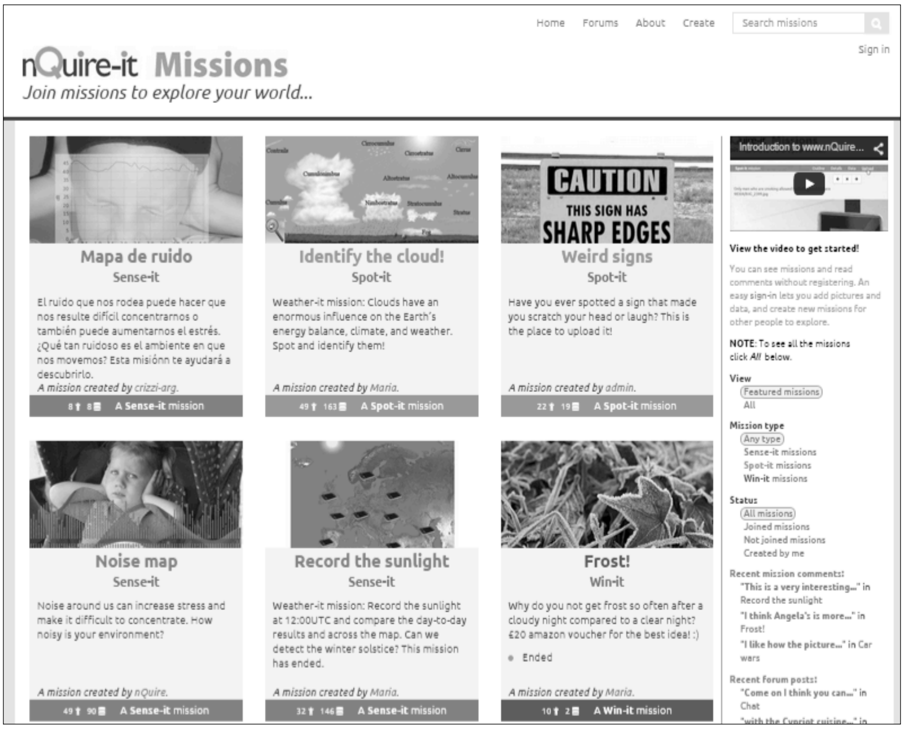
[4] www.nquire-it.org

For this paper, we focus only on one category of nQuire-it mission – that connects with the Sense-it mobile app. A Sense-it mission provides a means to initiate sensor-based citizen inquiries, collect and share data, and report results.



Mapa de ruido

Sense-it

El ruido que nos rodea puede hacer que nos resulte difícil concentrarnos o también puede aumentarnos el estrés. ¿Qué tan ruidoso es el ambiente en que nos movemos? Esta misiónn te ayudará a descubrirlo.

A mission created by crizzi-arg.

8 ⬆ 8 ▤ A **Sense-it** mission

Identify the cloud!

Spot-it

Weather-it mission: Clouds have an enormous influence on the Earth's energy balance, climate, and weather. Spot and identify them!

A mission created by Maria.

49 ⬆ 163 ▤ A **Spot-it** mission

Weird signs

Spot-it

Have you ever spotted a sign that made you scratch your head or laugh? This is the place to upload it!

A mission created by admin.

22 ⬆ 19 ▤ A **Spot-it** mission

Noise map

Sense-it

Noise around us can increase stress and make it difficult to concentrate. How noisy is your environment?

A mission created by nQuire.

49 ⬆ 90 ▤ A **Sense-it** mission

Record the sunlight

Sense-it

Weather-it mission: Record the sunlight at 12:00UTC and compare the day-to-day results and across the map. Can we detect the winter solstice? This mission has ended.

A mission created by Maria.

32 ⬆ 146 ▤ A **Sense-it** mission

Frost!

Win-it

Why do you not get frost so often after a cloudy night compared to a clear night? £20 amazon voucher for the best idea! :)

● Ended

A mission created by Maria.

10 ⬆ 2 ▤ A **Win-it** mission

View the video to get started!

You can see missions and read comments without registering. An easy sign-in lets you add pictures and data, and create new missions for other people to explore.

NOTE: To see all the missions click *All* below.

View
- Featured missions
- All

Mission type
- Any type
- Sense-it missions
- Spot-it missions
- Win-it missions

Status
- All missions
- Joined missions
- Not joined missions
- Created by me

Recent mission comments:
- "This is a very interesting..." in Record the sunlight
- "I think Angela's is more..." in Frost!
- "I like how the picture..." in Car wars

Recent forum posts:
- "Come on I think you can..." in Chat
- "with the Cypriot cuisine..." in

Figure 6: The nQuire-it platform available at www.nquire-it.org.uk

To date, four Sense-it missions have been created on the nQuire-it platform, as follows:

4.1 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.

Record the sunlight

Sense-it

Weather-it mission: Record the sunlight at 12:00UTC and compare the day-to-day results and across the map. Can we detect the winter solstice? This mission has ended.

A mission created by Maria.

32 ⬆ 146 ▤ A **Sense-it** mission

Figure 7: The Sense-it mission 'Record the sunlight'

4.2 Air Pressure and Rainfall

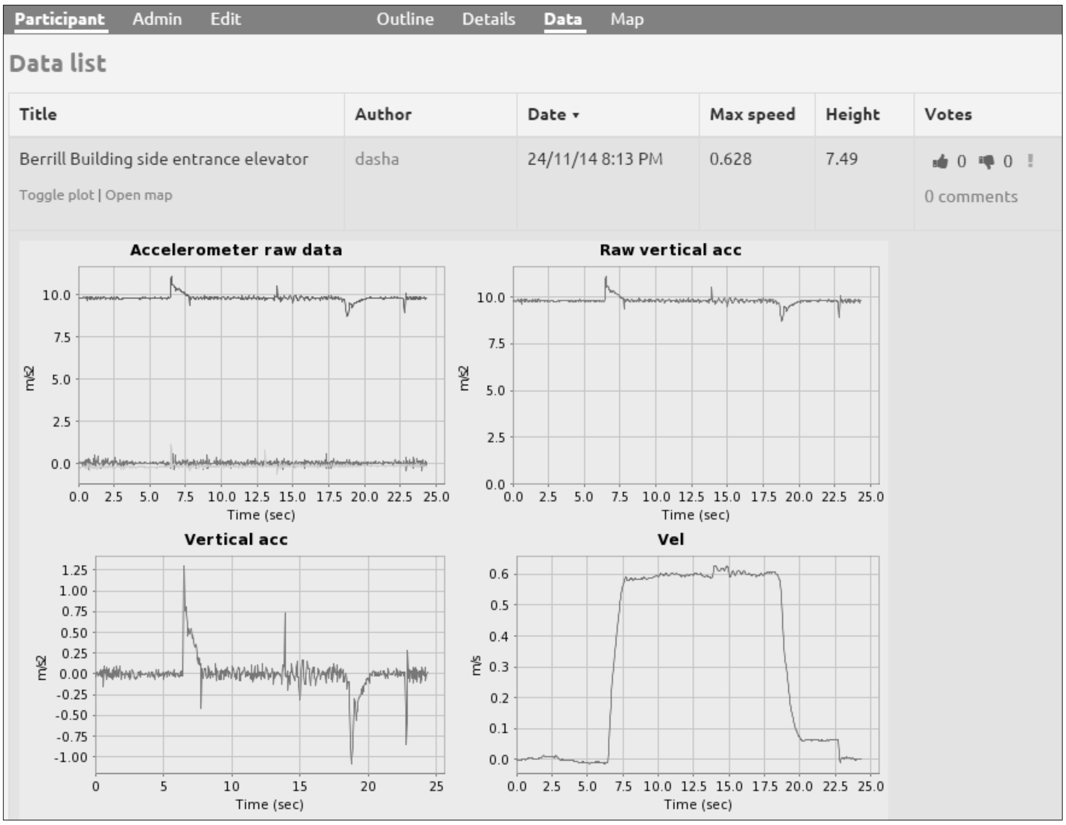
The aim of this mission is to investigate the question ‘Does it rain when the pressure is low?’. Users measure barometric pressure, using the pressure sensor on some newer mobile devices and record whether or not it is raining. This mission was initiated by a member of the nQuire-it community.

4.3 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).

4.4 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).



Data list

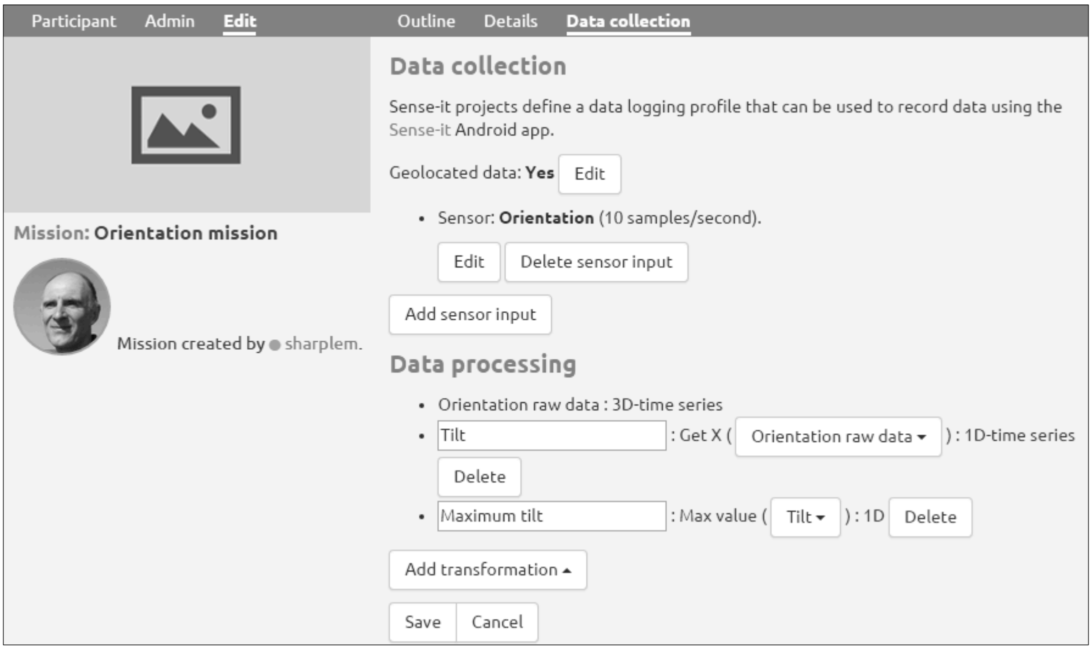
Title	Author	Date ▾	Max speed	Height	Votes
Berrill Building side entrance elevator Toggle plot | Open map	dasha	24/11/14 8:13 PM	0.628	7.49	👍 0 👎 0 ! 0 comments

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

5 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 present 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.

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 to save the data produced by the single user.



Data collection

Sense-it projects define a data logging profile that can be used to record data using the Sense-it Android app.

Geolocated data: **Yes**

- Sensor: **Orientation** (10 samples/second).

Mission: **Orientation mission**

Mission created by sharplem.

Data processing

- Orientation raw data : 3D-time series
- Tilt : Get X (Orientation raw data) : 1D-time series
- Maximum tilt : Max value (Tilt) : 1D

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

6 Evaluation

The Sense-it app and nQuire-it platform were developed through a process of design-based research (Barab & Squire, 2004) involving an iterative sequence of design, implementation and testing. Early testing was carried out at The Open University and included heuristic usability evaluation (Nilesen & Molich, 1990) of the interfaces with experts in human-computer interaction. Later testing involved usability trials with students from Sheffield UTC. Participants in the missions have mostly been adult volunteers, recruited for a study of crowd-sourced meteorology (reported in Aristeidou, Scanlon, & Sharples, 2015).

6.1 Evidence of learning

It is not possible to carry out an evaluation of learning outcomes, since setting pre- and post-tests of domain knowledge would not be appropriate for this informal mobile learning activity. Instead, we report issues arising from mission comments and discussions on the nQuire-it forums. A social network analysis of user engagement will be reported elsewhere (Aristeidou, Scanlon & Sharples, 2015). Comments from the adult users posted on the forum and to missions included general responses to the app and mobile phone sensors, including:

"I was very pleasantly surprised about the sense-it application used for the experiments. I had no clue the little device in my pocket had so many sensors (I had an idea about some, but not all) and that the output of the sensors could be so easily recorded. I keep using the mobile application for things of my own."

They also showed evidence 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 :p). 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)

6.2 Calibration of devices

An important issue was calibration of the sensors. Prior to the creation of 'Record the sunlight' project, trials took place 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 Lux of the particular light bulb in that distance was calculated with the inverse-square law (Lux = $\frac{Lumens}{4\pi d^2}$) to be equal to 66.85. 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 Lux 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, was 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. Shortcomings for using this method were the absence of such a scaling feature on Sense-it app and the use of the application by people without access to a professional meter. Yet, a professional light meter was used to calculate the difference between the measurements by mobile devices and a calibrated sensor.

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 damages (e.g. scratched/dirty monitor) may also affect the measurement values. The need for calibration scaling will occur for other sensors, such as atmospheric pressure and magnetic field. Though they give continuous readings, not restricted to pre-set levels, they can be poorly calibrated (for example, the air pressure sensor on the lead author's Samsung Galaxy Nexus phone consistently gives an atmospheric pressure reading of 19-21mb lower than that recorded by a local weather monitoring station).

6.3 Facilitation and measurements

An examination of the learner interactions for each of these missions shows important differences in facilitation, process and outcome. Record the Sunlight was intended to be short duration and was facilitated by Aristeidou, with 146 contributions. Within the data, there were eight invalid measurements which were removed from the analysis. The measurements were from eleven different places in Europe (Milton Keynes, Oxford, Stockholm, Athens, Belgrade, Liege, Lausanne, Barcelona, Limassol, Central Greece and Great Missenden) 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).

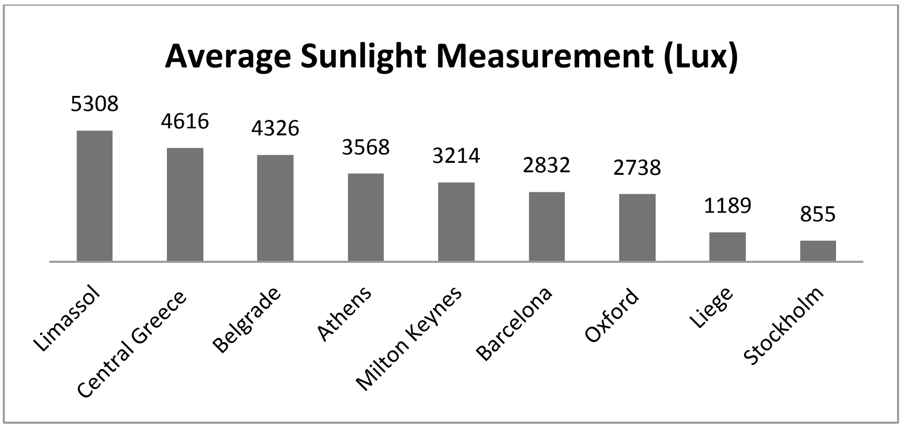


Figure 10. Average light levels for cities measured on the Record the Sunlight mission

Air Pressure and Rainfall recorded 34 contributions. The contributions were made mainly in Milton Keynes, London and Bilbao. The analysis 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 not many mobile devices supported an air pressure sensor.

Noise map recorded 92 items. Fastest Lift, requiring a more complex set of actions to record the velocity of a lift (elevator), has had 25 contributions over a period of 5 months. The relations between intentions, guidelines, complexity, and facilitation of sensor missions all appear to have influence on their popularity, persistence and outcomes.

7 Conclusions

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 wild.

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 .

8 Acknowledgements

We wish to thank Nominet Trust for funding this project, and Sheffield UTC for the support of teachers and students as collaborators in the design of nQuire-it and Sense-it.

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