The potential for the use of smart phones to enhance teaching in environmental engineering and environmental science modules

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September 2014

Summary

This Study considered the availability of smart phone environmental apps that could be used in the teaching of environmental engineering and environmental science. Several apps in the field of noise, water and air were found to be freely available on the Internet. Two such apps, on noise measurement and water quality analysis were tested by students. Positive results from the tests reveal the potential for the use of such apps in the teaching of environmental engineering and environmental science.

Acknowledgement

This Study was financially-supported by the eSTEeM Office of The Open University which brings together academics in Science, Technology, Engineering and Mathematics (STEM) to promote innovation, scholarship and enterprise in open and distance learning. The support is gratefully acknowledged.

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1. Introduction

The use of smart phones (wireless mobile phones embedded with an accelerometer, digital compass, gyroscope, a GPS, microphone and camera that transform them into mobile computers), for environmental monitoring has been documented by several researchers (Honicky *et al*, 2008; Mun *et al*, 2009; Lane *et al*, 2010). Smart phones with the incorporation of application software or 'apps', and sensors, can measure a number of environmental parameters (such as noise, and particulates in water and air) and store or transmit such data to a central location for further analysis. Aitkenhead *et al* (2014) carried out a recent review of technology for acquiring, processing and reporting on environmental data in the field, pointing out the potential with smart phones, said to number 1 billion out of a total of 5 billion mobile phones worldwide.

Closer to home, in a survey undertaken at the University of Sheffield (2011), some 56% of students were found to have smart phones, compared to the national average of 35%. The figure for college students in the US was 57% (Yu, 2012). The potential for use of smart phones to add value in the teaching (and practice) of subjects such as environmental engineering and environmental science clearly exists. This report considers environmental apps that could possibly be used in teaching these subjects.

2. Measurement of Noise, and Water and Air Quality

In the following Sections, the use of smart phones in the measurement of noise, and water and air quality parameters, are outlined.

2.1 Noise Measurement

Since smart phones have microphones they can detect sound and with an appropriate app, can reveal the magnitude of the sound. They can thus be used to measure the noise level in whatever environment the smart phone is in. A search of the Internet revealed in excess of 50 noise meter apps. A selection is listed in Appendix A. Weber (2013) claimed to have tested 30 of the apps against a Type 2 sound Level Meter and found the top three apps to be, in order of accuracy, SPLnFFT, SoundMeter+, and SPL Meter.

2.2 Water quality measurement

The camera on a smart phone can be used to photograph a test strip used for say, pH, and the colour from the photograph used to compare with a reference chart, to arrive at a quantitative answer. This was demonstrated by Chang (2012).Water quality parameters are usually measured with a sensor, and the sensor can be connected to a smart phone (through the audio jack) for data comparison or transmission. Several apps are available to undertake this function.

There are apps giving the water quality at selected sites on the ground. For instance, the app 'Bathing Water' (https://play.google.com/store/apps/details?id=dk.releaze.android.badevand) gives present bathing water quality and forecasts for a number of beaches along the Danish

Coast of Øresund and the Swedish Coast of Halland. There are also apps which give warnings of water pollution for recreational users (e.g. SAS [Sewage Alert Service – https://play.google.com/store/apps/details?id=uk.org.sas.sewagealert] gives information on UK beaches and warns of pollution incidents in real time).

2.3 Air quality measurement

The smart phone can be used to estimate particulate concentrations in air. The user takes a picture of the sky while the sun is shining. This can then be compared to established models of sky luminance, to estimate visibility. Since visibility reduction is directly related to the concentration of particulates in the atmosphere, their concentration can be estimated. This was the principle behind an app devised by Poduri *et al* (2010).

For gases, an external device with different low-cost gas sensors for specific gases (such as ozone or carbon monoxide) can be linked to a smart phone. Once the appropriate app is downloaded onto the smart phone, it can act as a measuring device.

There are apps which give the air quality at different cities across the world. For instance, the Beijing Air Quality app (https://play.google.com/store/apps/details?id=com.insdio.aqicn.airwidget) shows the real-time Air Quality Index (AQI), measured by the U.S. Embassy in Beijing, while London Air (https://play.google.com/store/apps/details?id=uk.org.londonair.laqn), devised by King's College, London, displays the latest air pollution levels recorded at over 100 monitoring stations across Greater London.

3. The apps and sensors available

In this study, a review of relevant apps and sensors for noise, water and air, was undertaken. The Table in Appendix A lists these, together with the suppliers and costs (where available).

4. Anticipated developments in environmental measurement using smart phones

Researchers have used smart phones to gather environmental data through 'citizen science'. Aoki *et al* (n.d.) used GPS-equipped bluetooth phones on street sweeper vehicles, with sensors to monitor carbon monoxide (CO) and nitrogen dioxide (NO_2) levels in San Francisco. Readings of levels together with phone location data received by the researchers suggested the existence of microclimates (localised pockets of different mixtures of CO and NO_2) within sections of the city. This was a very cost-effective way of acquiring environmental data. The same sensor was used in Accra, Ghana, for carbon monoxide measurement, with the sensor being given to seven taxi drivers and three students. At the end of each day, the data was extracted and the sensors recharged (United Nations Foundation, 2012).

A similar sensor, CitiSense, for measurement of ozone, nitrogen dioxide and carbon monoxide, was developed by the University of California, San Diego (UCSD, 2012). The sensor has small velcro straps that make it easy to attach to a belt or back-pack. The data collected by the sensor is transmitted via bluetooth to a mobile phone that is coupled to the sensor. The phone has an app that analyses the data and provides real-time feedback to the user about the ambient air pollution. The data collected is sent to a main computer which plots values for a given area using maps. A challenge was the power requirement, as the phones use GPS. Optimisation of the app was needed to allow the battery to last throughout the working day.

Noise, apart from being a nuisance, can lead to non-hearing related health problems such as cardiac events in adults and learning deficits in children. The European Commission adopted a Directive (European Commission, 2002) requiring major cities in the European Union to gather data on noise exposure from road traffic, railways , major airports and industry in order to produce local action plans. The Sony Computer Science Laboratory in Paris developed smart phone software to measure noise and map the data onto Google Earth (Maisonneuve *et al*, 2009, NoiseTube, n.d.). Participants can provide information on the source(s) of sound (e.g. cars, roadworks, etc.). Several campaign groups have used Noise apps to gather noise data. Residents of Isleworth near Heathrow Airport in London used smart phones to record over 1000 noise readings in a 5-week Project (BrentfordTW8.com, 2012).

Giving the opportunity to people of measuring environmental parameters in their immediate surroundings (to which they are exposed) raises their awareness of environmental issues and could influence their behaviour, leading to a more sustainable lifestyle (Maisonneuve *et al*, 2009). Data on people's exposure to pollutants could contribute to epidemiological studies, too.

5. Purchase of smart phone and ancillaries

For use in our study, a Motorola smart phone (Model Moto G) was purchased for £110. This enabled the assessment of the ease of downloading different apps. The apps investigated were found to be simple to download, and in terms of ancillaries, only test strips for water analysis had to be purchased. The test strips for measurement of Total Hardness, Total Bromine, Total Alkalinity, and pH, cost £8.99 for 50.

6. Field testing of apps

From all the apps considered, a Water app and a Noise app were selected for trialling in the field. Details of the work carried out are given below.

6.1 *Testing of a Water app*

6.1.1 Introduction

A water testing app was trialled at a School in Milton Keynes to ascertain its ease of use. From those Water apps available the AquaChek system (at http://www.aquachek.com) designed for use in monitoring swimming pools was chosen on the basis that it covered a number of different parameters (Total Hardness, Total Bromine, Total Alkalinity, and pH), with readily-available test strips (Figure 1). The water testing is carried out by dipping a test strip into the water sample and matching the resulting colours to a colour strip showing a set of discrete values. There are two options available for results: either one of the discrete values from the test strip can be chosen, or a value estimated based on the colours in the test strip.

Figure 1 The AquaChek test strip

6.1.2 Methodology

Milton Keynes Academy, a local School familiar to one of the authors (STN) was contacted to ask if they'd be willing to let their pupils trial the above app. The School responded promptly, saying they were very keen, as they valued interaction with outside organisations, and that a Class of Year 9s would be available. The authors' intention was to trial the app with Year 11 pupils but they were apparently either taking GCSE Examinations, or on study leave. The Science Teacher responsible at the School said they had iPad minis that could be used to download the app.

In preparation for the trial, a step-by-step procedure was drawn up for the pupils (please see Appendix B). This was sent to the Science Teacher for comment and modification if necessary. He found it acceptable as is. The School was requested to supply four solutions of different pH values for the trial.

On 21 May 2014, when STN turned up at the School for the trial, he discovered that the Teacher had downloaded the Water Testing App onto iPods, as the iPads weren't available.

Prior to the pupils' arrival four samples of tap water of different pH values (which had been prepared using hydrochloric acid to lower the pH, and sodium hydroxide to raise the pH) were dispensed into 100 ml glass beakers.

The trial took place from 2:00 – 3:15 p.m. There were 21 pupils (11 male and 10 female), working in 8 different groups. The groups were asked to choose three different samples, and ascertain the four water quality parameters, using the colour strips available on the app. Each group was given six test strips.

The test results were e-mailed to STN (using the e-mail facility available with the app), and three Questions in the Procedure Handout were answered on paper, individually by the students. The class later discussed these Questions as a group after the practical session. Towards the end of the session, STN asked whether before e-mailing their results, the pupils had inserted the sample name (A, B, C, D, E, or F). Several people hadn't, and so had to repeat their measurements.

Table 1 on the following page gives the values of the different parameters that were available on the colour comparator strips on the app.

Table 1: Values shown on the colour strips on the app

Total Hardness **(ppm as $CaCO_3$)**	0	100	250	500	1000	
Total Bromine **(ppm)**	0	1	2	5	10	20
Total Alkalinity **(ppm)**	0	40	80	120	180	240
pH **(pH units)**	6.2	6.8	7.2	7.8	8.4	

6.1.3 Results

The results obtained are reported in Table 2.

Table 2: Measurements reported by pupils (in Columns 3 – 6)

1	2	3	4	5	6
Sample	**pH measured using a pH meter**	**Median pH as ascertained by pupils using the app**	**Median value of Total Hardness (and range) in ppm as $CaCO_3$**	**Median value of Total Bromine (and range) in ppm**	**Median value of Total Alkalinity (and range) in ppm**
A (9 results)	2.3	6.2 – lowest available on colour strip (Range : only 6.2 reported)	250 (250 – 1000)	0 (0 - 1)	0 (0)
B (10 results)	6.0	6.8 (Range : 6.2 – 8.4)	250 (250 – 1000)	0 (0 – 1)	80 (40 – 240)
C (2 results)	7.5	8.4 (Range : only 8.4 reported)	250 (Only 250 reported)	0 (Only 0 reported)	Mean of 210 (180 and 240 reported)
D (4 results)	8.9	8.4 (Range : only 8.4 reported)	250 (100 – 250)	0 (0 – 1)	180 (Only 180 reported)

6.1.4 The Questions

The pupils were posed three Questions. Their answers are shown below.

1) Were the Instructions for the above Experiment clear, and easy to follow?

All the pupils said the Instructions were clear and easy to follow.

2) Please list any difficulties that people may have, in using the app and test strip.

Some pupils said that matching the colours on the test strip with those on the colour strip could be difficult. (The pupils were told after the session that it was possible for them to input numerical values manually into the Results page).

The quality of the screen was said to be a problem (the iPods were 4^{th} generation devices).

The sample name could easily be missed out when despatching the Results by e-mail.

3) Please suggest ways to make the use of the app easier.

Several pupils said that having a wider range of colours would make it easier to match the test strips.

6.1.5 Discussion

The pupils quite quickly became confident in using the app. Matching the colour on the test strip to one available on the app proved to be difficult, and a degree of subjectivity was used. This led to a range of values being reported.

The pH range of the app was from 6.2 to 8.4. Three of the solutions prepared by the School were of pH 2.3, 6.0 and 8.9, and thus were out of range of the app. This highlights an important point – in choosing an app, the anticipated values of the parameter being investigated must be taken into account.

With training and practice, the pupils could probably be taught how to estimate a value for a given parameter and then input this manually. This offers the potential for more precise results.

The labelling of the results prior to despatch by e-mail is something that can be missed. Again, training would overcome this possible omission.

6.1.6 Conclusion

The AquaChek App for measuring Total Hardness, Total Bromine, Total Alkalinity, and pH, is easy to use. In field applications, the values covered by the app must be appropriate for the anticipated levels of the parameters being studied. Training users in estimating values based on the colours available in the app, would be useful.

6.2 Testing of a Noise app

6.2.1 Introduction

There are a large number of noise level measuring apps for both iOS and Android systems. However, the absolute level of sound recorded will depend on the settings on the individual device hence calibration of the device is an important issue.

The noise app that was chosen for initial study using the purchased smartphone was Sound Meter from Smart Tools co. as it was free. Initial tests indicated that the app, once calibrated, was stable. However, the choice of the app does not seem to be crucial.

Field trials took place on Week Two of the Residential School for TXR120/TXR176 (Engineering: an active introduction), held at Bath University over the summer of 2014.

6.2.1 Methodology

A number of students at the Residential School already had noise meter apps on their smart phones and were asked to use those since they were familiar with them.

Each day volunteers were sought to carry out traffic noise measurements with their smart phones as well as the sound level meter supplied as part of the module activity. The Sound Meter app from Smart Tools co. was downloaded, and this together with existing apps on volunteers' smart phones were calibrated using a 2 kHz octave band noise played through a loudspeaker. The smart phone was positioned alongside a digital sound level meter (SLM) with the smart phone microphone facing the source (see Figure 2). The reading on the app was compared with that displayed on the SLM and the reading on the app was adjusted until the two devices were giving the same value. Due to the variety of devices used by the students as well as different apps, this simple method of calibration was deemed practicable and sufficient. The app and the SLM were then used to measure traffic noise along a major road. The measurement procedure required students to position a sound level meter next to a road with the smart phone placed alongside the SLM so that the microphones on both devices (the mouthpiece in the case of the phone) faced the road at the same position. Students took readings of instantaneous sound pressure level every minute for a total of 60 minutes. From this data they calculated L_{A10} which is a sound index that is taken in UK to best correlate to human annoyance to traffic noise.

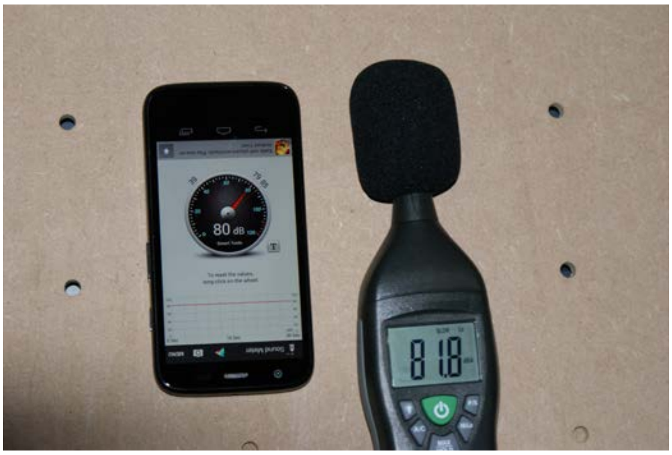

Figure 2 A smart phone with a noise app and a sound level meter, prior to calibration

6.2.3 Results

Five students in total carried out the measurements. Two used the app Multi-Measures v3.8.2 (from iTunes App Store) on their iPhone, while the others had Android devices and used Sound Meter (from Smart Tools co.). The SLM used did not have a record function, so students had to pause the continuous sound pressure level display to read a value. Neither of the free apps used in this trial had a pause or record facility. An example of data from a smart phone and an SLM is given in Figure 3. Most discrepancies are the result of an inevitable gap between reading the value from the app and reading the SLM. The L_{A10} value derived from these two data sets were 80 dBA from the SLM and 81 dBA from the iPhone app.

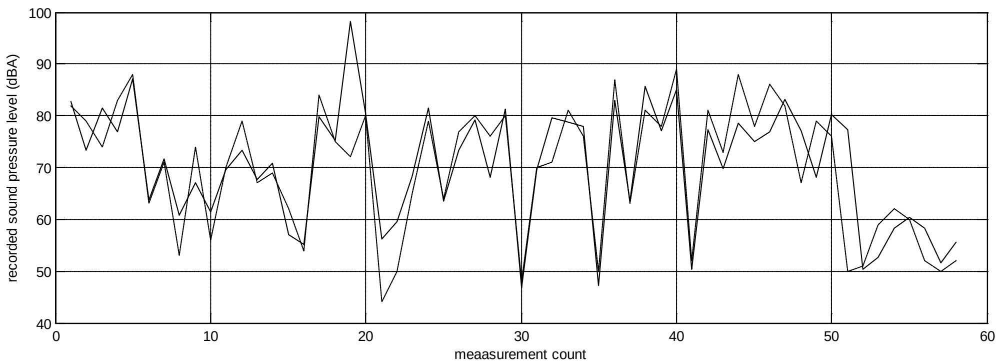

Figure 3 Example of traffic noise data measured by a sound level meter (broken line) and an iPhone device (solid line).

6.2.4 Discussion

Once calibrated, the sound level meter apps tested (and indeed others investigated by other researchers) were sufficiently stable for measurements over a period of time to be made. However, students commented that reading off the meter was difficult. This can be rectified by selecting an app that has recording functionality (such as SoundMeter by Faber Acoustical

@$19.99). Furthermore, for the smart phone to be really useful for environmental monitoring it must be able to act as an integrating SLM, in other words, be able to record the levels for a period of time (typically 10-15 minutes) and calculate noise indices such as L_{Aeq}, L_{A10} and L_{A90} from it. These functionalities were not available in the free versions of apps investigated but were in those apps with a price tag. It must be pointed out that Integrating Sound Level Meters are at least an order of magnitude more costly than a simple SLM such as that used at the Residential School.

Some apps are able to upload the users' measured value onto noise maps, but the usefulness of this functionality is limited for our purposes.

6.2.5 Conclusion

Noise measuring apps on both iPhones and Android devices have the ability to be used as environmental noise monitoring equipment. However, the question of calibration needs to be resolved for the results to be of practical use.

7. Characteristics of an effective and efficient app

Our work has shown that there are several apps that are available free on the Internet. In terms of utility, the two apps that were tested in our study were easy to download and to use. The Noise app required calibration, and while at the residential school it was possible to use a standard sound source and a comparison SLM, outside users would need a different calibration procedure. On the other hand calibration need not be carried out very often.

The microphone in a smart phone usually has a low frequency filter, as the device is primarily for recording and transmitting speech where the frequency range of importance is 350 Hz – 4800 Hz. Hence this has to be taken into account when measuring noise with significant low frequency components. However, Brown & Evans (2011) compared the sound pressure level readings of a variety of noise sources measured with a smart phone with that obtained using a Bruel & Kjaer professional sound level meter, and found that the readings were within 5 dB of each other.

The Water app chosen had a limited range for pH, this being the pH range expected with tap water. If an unknown solution were to be tested, a Water app with a wider range of pH values would be needed. It would probably be best to first obtain a rough estimate of the pH, using, say, a pH meter. This would then give an indication of the range of pH desired in the app (say, 3 pH units either side of the sample tested). The lesson from our study is that for the use of any app, the appropriate range of values must be present, for the given parameter under study.

8. Conclusions

This report has shown that there are several apps available that can be used in the field of environmental monitoring. Two of the apps were tested by novice groups of users. The apps, many of which are free, can be incorporated into the teaching of environmental engineering and environmental science. Importantly, the apps can be used in teaching communities to generate real-time data that can be uploaded to a central server and can then be available for others to use.

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Appendix A

Details of apps and sensors for environmental measurement

Name of app or sensor	Supplier	Cost
Noise		
Decibel Meter Pro app - Gives ambient, maximum and minimum sound levels in dBA, dBB, dBC, dBD and dBZ https://itunes.apple.com/gb/app/decibel-meter-pro/id382776256?mt=8	Apps Store on iTunes	US $ 0.99 GB £0.69
Multi-measures app v3.8.2 https://itunes.apple.com/gb/app/multi-measures-all-in-1-measuring/id354112909?mt=8	Apps Store on iTunes	free
Sound Meter ver 1.5.10 https://play.google.com/store/apps/developer?id=Smart+Tools+co.	Smart Tools co	Free
Sound Meter app http://www.androidpit.com/sound-meter-turns-your-smartphone-into-a-noise-detector	AndroidPIT	Free
NoiseTube app Measures ambient noise in dBA and uploads it onto Google Earth http://www.noisetube.net/#&panel1-1	The BruSense Team info@brussense.be	Free
WideNoise app http://www.widetag.com/widenoise/	GitHub	Free
SoundMeter app	Faber Acoustical LLC	US $19.99

Measures Sound Pressure Level and L_{eq} for a variety of weightings https://itunes.apple.com/us/app/soundmeter/id287615105?mt=8&ign-mpt=uo%3D6		
NoiseMap app Measures sound pressure level in dBA, and maps it. App has an inbuilt calibration tool for a limited number of handsets. https://play.google.com/store/apps/details?id=de.tudarmstadt.tk.noisemap&hl=en	TU Darmstadt Hochschulstrasse 10 64289 Darmstadt Germany	Free
Noise Hunter app Measures sound pressure level in dBA & dBC. Calibration tool included in app. Measures also L_{eq} https://itunes.apple.com/en/app/noise-hunter/id452021669?mt=8	Inter.net2day Germany	US $5.99
NoiseWatch Measures noise level in dB. Data can be sent to the Eye on Earth global public information service. https://play.google.com/store/apps/details?id=com.tsystems.humanSensor&hl=en_GB	European Environment Agency	Free?
Sound Meter app Accurate in the range 40 – 70 dB http://www.androidpit.com/en/android/market/apps/app/kr.sira.sound/Sound-Meter	Smart Tools Co. (Korea)	Free
dB Volume Meter Gives current, maximum, and minimum dB values. https://itunes.apple.com/gb/app/db-volume-meter/id592769907?mt=8	Amanda Gates	£0.69

TooLoud Pro app https://itunes.apple.com/us/app/tooloud-pro/id425137981?mt=8	RGB-Studio	US $0.99
deciBel app Displays the current, maximum and minimum values in decibels, and generates sound level charts. http://www.apps4you.org/android-application/bz.bsb.decibel.html	Peter Tschudin	Free
SPLnFFT app Results closest to $2000 noise meter (out of 30 apps tested) https://itunes.apple.com/us/app/splnfft-noise-meter/id355396114?mt=8&ign-mpt=uo%3D4	Fabien Lefebvre	US $3.99
SoundMeter+ app In comparison of 30 apps, came out second https://itunes.apple.com/us/app/soundmeter+/id583747153?mt=8&ign-mpt=uo%3D4	AuralWare	US $1.99
SPL Meter app Range 40 dB – 120 dB In comparison of 30 apps, came out third https://itunes.apple.com/us/app/spl-meter/id309206756?mt=8&ign-mpt=uo%3D4	Andrew Smith	US $0.69
AirCasting Noise app Measures average and peak noise levels in dB https://play.google.com/store/apps/details?id=pl.llp.aircasting&hl=en	AirCasting	Free?
Water		
smaTROLL - measurement of 14 parameters, including dissolved oxygen, pH, oxygen reduction potential, conductivity, salinity, total dissolved	In-Situ Inc. 221 East Lincoln	US $ 2900

solids, resistivity, salinity, water temperature, water pressure, and density, using a probe connected to a smart phone. http://www.in-situ.com/products/water-quality/handheld-systems/smartroll-multiparameter-handheld http://store.in-situ.com/smarTROLL-Multiparameter-Handheld-Bundle-p/0071970.htm	Avenue, Fort Collins, Colorado, U.S.A. 80524	
Water Quality sensor Measures pH and dissolved oxygen but needs sensor to be connected to it. https://play.google.com/store/apps/details?id=com.sensorcon.wqm	Sensorcon Inc.	Free
Mercury Sensor An attachment to the built-in camera allows quantification of mercury. http://pubs.acs.org/doi/ipdf/10.1021/nn406571t	University of California, Los Angeles	
Mercury Sensor Thin membrane containing rhodamine (which changes colour in the presence of mercury) is placed in the water. The results can be quantified by taking a picture of the test sheet with a mobile phone and using an app which compares the photo with a reference chart. Membranes also devised for iron and cyanide. http://pubs.rsc.org/en/Content/ArticleLanding/2013/AY/C2AY26307F#!divAbstract	University of Burgos (Spain)	
Microbial Contaminants Use of test kits for coliforms and *E. coli* in water. http://mwater.co/app/	mWater	Free
pH Measurement	Sensorex	Free

Sensorex probe plugged in to smart phone used for measurement of pH and temperature. http://www.fondriest.com/news/sensorex-ph-1-brings-ph-sensors-to-smartphones.htm		
pH measurement ODM pH probe measures pH. Costs ~£224. http://www.odmtech.com/pH/	ODM Technology 19633 Caber Road Martintown, ON K0C 1S0 Canada	Free
MoboSens for nitrate analysis Attach MoboSens device to smart phone. Place water sample in device. Data (e.g. on nitrate, arsenic, lead or chromium) is given and can be uploaded onto communal database accessible to anyone who has the app. https://play.google.com/store/apps/details?id=com.nano.Mobo.Sens&hl=en	University of Illinois at Urbana-Champaign	
Turbidity Measurement A photograph of a water sample in Secchi disk-type device is compared with reference measurements in a database, and a turbidity value arrived at. http://www.environmentalsystemsresearch.com/content/2/1/9	VTT Technical Research Centre of Finland	
iPoolTester Test strip is dipped into water sample. Photo of test strip is taken, and compared using an app. Can be used for measurement of total alkalinity, total bromine, free chlorine, total available chlorine, calcium hardness, and pH. http://www.sansoft.com/ipooltester/iPoolTester/iPoolTester_by_SanSoft_Inc..html	SanSoft Inc.	Free
KemTek Water Tester App Used with test strip to measure free	KIK Pool Additives Inc.	Free

chlorine/bromine, pH, alkalinity, and hardness http://www.kem-tek.com/tools-tips/free-water-tester-app/	5160 E. Airport Drive Ontario, CA 91761 Canada	
Smart Water Test App Used with test strip to measure free chlorine/bromine, pH, alkalinity, and hardness http://www.intheswim.com/Pool-Chemicals/Pool-Water-Test-Kits-and-Testing-Supplies/Smart-Water-Test-App/	In The Swim® 320 Industrial Drive West Chicago, IL 60185 USA	Free
AquaChek Test strip for measurement of pH, Total alkalinity, Total hardness, and Total bromine. http://www.aquachek.com/	AquaChek 3504 Henke Street Elkhart IN 46514-0659 USA	Free
Air		
AirCasting - a platform for recording, mapping, and sharing health and environmental data using your smartphone. Need to build monitor and connect it to smart phone http://aircasting.org/	HabitatMap 669 Carroll Street, Suite #3 Brooklyn, NY 11215	Free app but need to build AirCasting Air Monitor
Mobile Sensing - an optical technique using the camera on the smart phone to measure air visibility and relate this to particulate concentration http://robotics.usc.edu/~mobilesensing/visibility/MobileAirQualitySensing.pdf	Robotic Embedded Systems L:aboratory University of Southern California MC 2905 3710 South McClintock Avenue Los Angeles, California 90089-2905	Free
Sensordrone sensor – measures carbon monoxide, methane, propane, natural gas, ozone, chlorine http://sensorcon.com/sensordrone-1/	Sensorcon 150 North Airport Drive Buffalo, NY 14225	US $199
Sensaris Sensors	Sensaris 452 Rue de Sources	Have not been able to

The ECOsense measures: •Carbon monoxide (CO) •Nitrogen oxide (NO_x) •Noise •Temperature •Humidity The ECO_2sense measures: •Carbon dioxide (CO_2) The EcO_3sense measures: •Ozone (O_3) •Luminosity (UVA, UVB, UVC) •Temperature •Humidity EcoPM : A compact wireless PM measurement unit taking into account particles bigger than 1µ. http://www.sensaris.com/products/senspod/	38920 Crolles France	get prices
Smart Radiation Detector A Detector connected to a smart phone measures beta and gamma radiation http://www.kickstarter.com/projects/1517658569/smart-radiation-detector	Available in App Store	US $5 + $20 for shipping to UK
Sensors for CO and NO_2	Dr. Eric Paulos 464 Sutardja Dai Hall University of California Berkeley, CA 94720-1758 paulos@berkeley.edu	US $ 60 each

iSPEX Attachment for measurement of dust and other aerosols	The National Institute for Public Health and the Environment (RIVM) Bilthoven, 3720 BA, The Netherlands Hester.volten@rivm.nl	15 Euros for attachment. App is free
CitiSense : sensors for measurement of ozone, nitrogen dioxide and carbon monoxide http://www.jacobsschool.ucsd.edu/news/news_releases/release.sfe?id=1295	Jacobs School of Engineering University of California, San Diego	US $ 1000
Sharp GP2Y 1010 dust sensor for measuring particulate matter	TECO / Pervasive Computing Systems Group Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany (budde@teco.edu)	US $10
DirtyBeijing app – gives readout of PM2.5 level, and US EPA Air Quality Index Level http://air.fresh-ideas.cc/	Fresh Ideas Studio China	Free
Lapka Personal Environmental Monitor Sensors for radiation, electromagnetic fields, temperature and relative humidity https://mylapka.com/	Lapka, Inc. 391 Sutter Street Suite 303 San Francisco CA 94108	US $200

Appendix B

Using an App on an iPad mini to measure four water quality parameters in three different solutions

Instructions for students

The aim of this Exercise is to measure four water quality parameters (Total Hardness, Total Bromine, Total Alkalinity, and pH) in three different solutions using test strips and an App on your iPad mini.

Download the AquaChek Smart App onto your iPad mini, as follows :

Go to http://www.aquachek.com

Click on 'Download the AquaChek Smart App !' via the Apple AppStore

Click on 'Free' to install

Then click on 'Open'

Click on 'Bromine'

Click on the arrow (→)

Choose 'Pool'

Choose Pool Shape 'Circular'

Move the diameter cursor to 20 feet

Move the depth cursor to 8 feet

Click 'Done'

Click on the arrow (→)

You will then see four rows of coloured squares, for

Total Hardness (ppm)

Total Bromine (ppm)

Total Alkalinity (ppm)

pH (pH)

These rows can be scrolled to view the complete range of colours

Taking and recording measurements

Immerse a test strip into the first solution and take it out immediately.

Wait 15 seconds for the colours on the test strip to develop.

Compare the four colours on the test strip with the colours on the App. The top square is for Total Hardness, the next for Total Bromine, the third square for Total Alkalinity, and the bottom square for pH.

Select the colour on the App that is the closest match, for each of the four parameters.

Then click on the arrow (→)

You will get a 'Test Report' message saying 'You have successfully generated the Test Report'.

Click on 'OK'

Click on 'Email', and in the 'To' box, type suresh.nesaratnam@open.ac.uk, and in the 'Cc/Bcc' box, type in your own e-mail address.

In the 'Subject' box, write the sample name (i.e. Sample A, B, C, D, E or F).

Then click on 'Send'.

Repeat the above procedure for the two other samples that you have.

When you have finished, please write your responses to the three Questions below:

1) Were the Instructions for the above Experiment clear, and easy to follow?

2) Please list any difficulties that people may have, in using the App and test strip.

3) Please suggest ways to make the use of the App easier.