Non-Expert Sensor-Based Laboratory Development: A Prototype Mobile Application for Rapid Development, Deployment, and Sharing of Laboratory Experiments

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Abstract

Laboratory activities are ubiquitous in schools and universities and allow students to investigate the relationship between real-world phenomena and theoretical models in a controlled setting. As well as traditional 'hands-on' laboratories, both simulations and increasingly remote laboratories are widely used and their educational benefits have been supported by the research. Despite the prevalence of laboratories across educational programs, both the number of new experiments being designed and the sharing of the design of these new experiments has been more limited than might be considered desirable. However, developments in sensor and actuator technology, fuelled by the increasing interest in the Internet of Things (IoT), mean that more data is accessible from a range of 'things' which have been specifically designed to easily share information about themselves and their environments. This presents an opportunity for the design and delivery of laboratory activities based on the real world data available from IoT enabled 'things' without long lead times and expert technical knowledge of the sensors or interconnection technology. This 'non-expert' design of sensor based laboratories has application for both remote and hands on laboratories in schools and universities, but is only valuable if teachers are both willing and able to make use of the solutions. This paper reports on the results of a case study into an educational mobile application which makes use of IoT enabled wireless sensor technology to allow educators to easily design, deliver and share laboratory activities based on real world sensor data. Of particular interest is whether teachers would be willing and able to make use of the framework. The prototype developed is an Android application that makes use of TI SensorTag sensors and provides a low cost, flexible solution for the rapid non-expert design, deployment and sharing of laboratory activity design and data. Initial feedback from high school teachers and students using the application shows positive results, but also suggests key aspects that would need to be incorporated in approaches to supporting teacher engagement.

Introduction

Laboratories have long been recognised as important educational tools in the teaching of the sciences. They allow students to explore real-world phenomena using controlled and simplified versions of reality designed to highlight some physical behaviour (such as gravity) while removing distracting behaviours. The nature of laboratories and their pedagogy has changed little over the hundreds of years they have been used [1–3]. However, there is growing interest and research into new types of laboratories such as simulations and remote laboratories and a recent (possibly consequent) focus on the pedagogy and learning outcomes of laboratory-based learning [4–6].

The Advancing Science by Enhancing Learning in the Laboratory (ASELL) project is an example of the current interest in changing the ways that laboratory experiences are designed. ASELL aims to support educators in putting into practice the learning on non-traditional laboratory formats that have been reported in the literature [7]. One focus area is inquiry-based science investigations and, to this end, the project has developed conceptual tools that allow educators to design investigations that deliver the most suitable level of student inquiry for their cohort and learning objectives. A core tool in this approach is the 'inquiry slider' which measures variations in the level of inquiry for different facets of a lab activity.While new research and tools support the design of new types of experiments, educators are still often limited in their understanding of how to best support students' interaction with physical behaviours under study in a laboratory activity. This problem of restrictions to the physical design of an experiment is due, at least partly, to available equipment and laboratory environment limitations (for example, how can acceleration due to gravity be measured in a laboratory setting, especially given budget and time constraints typical of most schools?). In addressing this, the literature on remote laboratories is useful as it demonstrates the feasibility of instrumenting a rich range of lab-based equipment, allowing for greater variation in the laboratory design [8–10]. Limitations in the uptake of conventional remote laboratories also indicate possible problems with using or sharing such instrumented equipment: specifically that development of these labs requires specialised skills and long lead times, and there is often resistance from academics who prefer to have personal input into pedagogic and physical design of the laboratory activities [9].

Recent technological developments provide new opportunities to build on the potential demonstrated by instrumented laboratory equipment. Specifically, Internet of Things (IoT) enabling technologies can potentially support educators by providing new mechanism whereby students can more readily measure the physical behaviours they are investigating (for example, accelerometers available in many smart phones could possibly be used to measure acceleration due to gravity inside and outside a laboratory). These IoT technologies, such as wireless communication, smart sensors and actuator and cloud-based services, allow educators more choice and flexibility in the design of laboratory investigations.

Given the experience with remote laboratories, the question remains of whether educators will make use of the enabling technology that exist for teachers to be able to design new forms of laboratories to support objectives such as inquiry-based investigations. The skills required, long lead times, high costs and personal input into the laboratory design may influence whether teachers would be willing or able to make use of new tools and technology.

This paper aims to explore the potential that IoT supporting technologies provide to create a technical solution that teachers are able and willing to use in rapidly developing laboratory investigations. Further, we are also interested in the extent to which this approach facilitates the sharing of the resultant designs, thereby improving the overall pool of investigations available to teachers (though this aspect will be the focus of a subsequent paper). The approach taken to addressing this question has been to develop the technical framework and then use a case-study based approach to assessing teacher and student reactions to the use of the framework. The lessons learnt from the case study will be able to be used to guide the work of those proposing to support teachers in their use of IoT technologies in the classroom. The paper gives background information on the development of the IoT, smart sensors in general and the TI SensorTag in particular, as well as discussing the design and development of a technical solution. Results of the case-study are reported, and the future steps to be taken have been outlined.

Background

The term "Internet of Things" was first coined by Kevin Ashton in 1999 and was bought to more common use by a paper published by the International Telecommunication Union (ITU) in 2005 [11]. Starting originally from the goal of allowing man-made objects to be uniquely identifiable by computers (initially using Radio Frequency Identification (RFID) tags), the number of devices has grown to a point where projections are for 50 to 100 billion devices to be connected to the internet by 2020 [11]. The literature gives a number of definitions for the term IoT, but for this paper we take a broad view that the IoT refers to the global network that connects smart objects, the technologies required to support this network (such as sensors, actuators, communication devices) as well as the applications and services which make use of the network [12].

The Cluster of European Research Projects on the Internet of Things (CERP-IoT) identified a range of domains where the IoT was predicted to have application[11] . Many of these domains have developed to such a degree since the publication that devices are readily available commercially to support a range of application domains, including vehicle tracking and parcel delivery monitoring, automatic energy monitoring and remote control of home appliances and wearable glucose measuring and monitoring devices for diabetes [13,14]. Interestingly, the educational domain is not identified in the list of IoT application domains, although there is recognition that the 'disruptive' effect of the emerging technologies will cause an 'educational revolution'[11].

To fully realise the vision of the IoT as allowing "people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service" [11] requires the further development of a number of enabling technologies such as identification technology (for example IPv6 to provide enough unique addresses for 'things'), communication technology, and power and energy storage technologies (for example wireless power) amongst others [15].

The development of the IoT to date has resulted in a number of platforms, cloud-based services, sensor and actuator devices that have been developed specifically to interact with each other to collect, store and analyse data, as well as allow the remote control of smart devices (such as turning on a home appliances remotely depending on measurements taken). Smart sensors (which include data processing abilities), are becoming more common in every day environments. Mobile phones, for example, act as smart sensors and can retrieve, manipulate and deliver information that they collect from the environment such as temperature. Other examples are the TI SensorTag (current version CC2650STK) which includes a number of low power sensors (ambient and infrared temperature, humidity and barometric pressure sensors, a 3-axis gyroscope, 3-axis magnetometer and 3-axis accelerometer) or the Samsung SmartThings [16,17].

Smart phones, wearable devices, and the integration of 'smart' technology into home appliances, buildings, cars, machines and clothing, all contribute to the availability of data previously only available with sensitive equipment or within a laboratory environment. These devices allow data to be easily collected and viewed without any specialist skills. Despite the increasing availability and decreasing cost of real world data, there is relatively little literature on incorporating such IoT devices and services into an educational environment in general or to explore how the concept of the IoT can change the way laboratories, in particular, are designed or delivered.

The effect of new technologies on laboratory environments *is* evident in the miniaturisation of electronic sensors, lower energy supply requirements, and improved data storage and communications options which have resulted in wired and wireless sensors, data loggers (electronic devices which log data collected from either built-in or external sensors) and the remote control of actuators in remote laboratories. Wireless sensor and actuator networks (WSANs) are in use in industrial and commercial environments [18] and to some degree, WSANs have been incorporated in lab activities, but this has been from the perspective of sensors and actuators performing their traditional roles in a hands-on laboratory, rather than making use of the affordances they offer. One further factor limiting the incorporation of IoT technologies into laboratories has been the proprietary nature of many IoT solutions, which limit communication between smart sensors and cloud services. However, the interfaces to smart devices are increasingly becoming standardised and it is now possible to develop tools to interface to a range of devices [11,19].

The availability and declining costs of smart sensors, data storage and sharing on cloud based applications and the increasing standardisation of IoT `things' provides an opportunity to use these devices and IoT concepts to develop a system that allows for non-expert development of laboratories. One project reported in the literature has done initial work on developing such a system [20]. Nguyen and Lowe [20] developed their design particularly for *remote* labs aiming to address some of the challenges of conventional remote labs such as the high costs, long lead times, specialised skills and desire by educators to have input into the physical and pedagogic design of their laboratory activities. That proposal, which is the basis for the technical solution described in this paper, envisaged a remote laboratory environment where STEM educators with no special coding or mechanical design skills, could select the sensors and actuators they need for a remote laboratory, connect these to a central 'master' in a 'plug and play' manner, and use a computer interface with 'drag and drop' style template to design the laboratory that students could use. Sensors were connected to Arduino Uno boards (slave modules, effectively turning a conventional sensor into a smart sensor). Slaves could be plugged into the master developed on the Arduino Yun, that in turn communicated with the server through which the remote user could design or execute the laboratory activity. The result allowed educators to quickly develop low cost remote laboratories. There were identified drawbacks, however, such as the requirement for a continuous power supply, physical connection to the internet which limits where sensors can be used, the development required in order to include new sensors, and the requirement for locally installed software [20].

System design for rapid, non-expert development of laboratories

Design of a technical framework that would allow teachers to rapidly develop inquiry-based investigations began with the architecture described by Nguyen and Lowe [20]. Adaptations were made to deliver an IoT based model where sensors and actuators are regarded as 'things' by a central server and to address the issues of continuous power requirements, physical connection to the internet, and limited number of sensors supported.

The TI SensorTag was chosen for the prototype as a low cost (USD29.00 per unit), low power, wireless and robust collection of smart sensors that allows the design of an interface to read, configure and control the sensors, making it a suitable candidate for incorporating into the design of a system that allows non-experts to develop and deploy laboratory activities that make use of smart sensors. The TI SensorTag stands out for the open nature of it interfaces, access to the data it advertises and the support TI gives for using the SensorTag to be used in development (and educational) environments (rather than supporting a proprietary IoT solution). As an example, the EvoThings platform which supports the development of IoT applications, demonstrates new SensorTag applications which can be freely developed [21]. Other devices such as Raspberry Pi, Arduino and BeagleBone also support the open development of new applications for connected smart sensors, however they do not have the ease of use available with the TI SensorTag. The interface to the sensor was designed to be as generic as possible to accommodate future Bluetooth enabled smart sensors or actuators.

To address the issue of a continuous power supply and in accordance with an IoT based model, it was decided that the 'master' and 'server' components of the solution would be implemented as an application that could run on mobile devices (rather than on an Arduino board and internet based server as in the Nguyen and Lowe [20] design). Building on the very useful features of a 'plug and play' system, with a very simple user interface design component, the SnapLabs App was developed for use in case study.

SnapLabs

SnapLabs is a mobile application that allows non-expert users to design and deploy wireless sensor based laboratory investigations. The first iteration of the SnapLabs application supports the TI SensorTag, and is currently available for Android devices. The development of this application is envisaged in phases with the initial phase being a 'stand alone' system where an institution can design and use their laboratories without requiring any connection to external servers. Future developments will allow for laboratory designs and data to be stored in a cloud which can be accessed by other users for the sharing of designs and data. This would facilitate the system's use as a remote laboratory, where data can be accessed from remote sensors through the cloud. In addition, later versions would allow for generic smart sensors to be used in the lab design and will be available for both Android and iOS.

The SnapLabs application is made up of the following components:

- Authenticated access – this is currently local authentication and user creation. The roles associated with a user can be either 'Teacher' or 'Student'.
- Quick Investigation Design – a drag and drop interface that allows users to design a laboratory using any of the SensorTag sensors and select whether to display these just as a value, in a graph, or as a grid. Only one sensor can be included in this design and the sampling period for each sensor is set to the default value and is not configurable. The interface is shown in Figure 1.

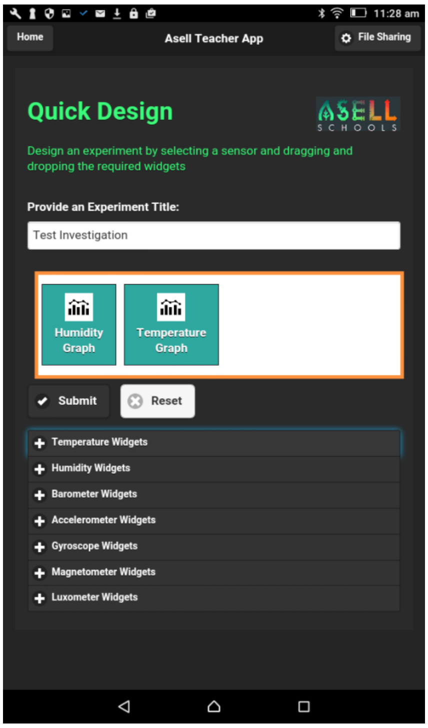

Figure 1: Quick Investigation Design Interface

- Detailed Investigation Design – this is available to the 'Teacher' role and allows users to select any number of SensorTags to add to the investigation design. Each sensor for each SensorTag can be configured to display the data as a value, graph and/or grid and the sampling interval for each of these can be set. Additionally users can select whether to allow data storage and a video feed for the laboratory. This component also allows users to edit any existing laboratory design. A portion of the interface is shown in Figure 2.

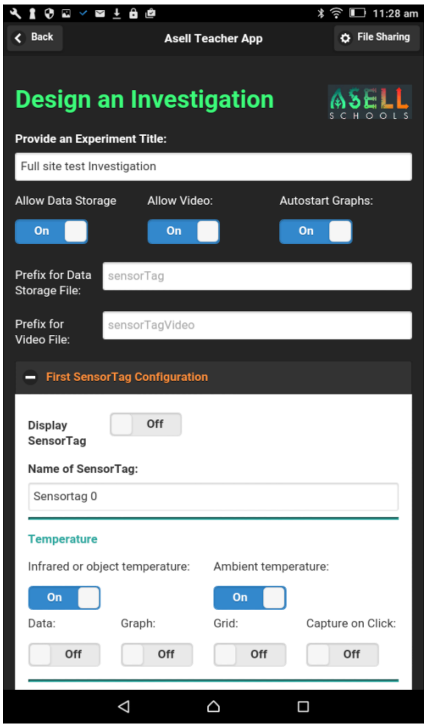

Figure 2: Detailed Investigation Design Interface

- Exemplar Investigations – the application includes a number of pre-configured example lab activities that can be run by any user. The selection interface for these is shown in Figure 3.

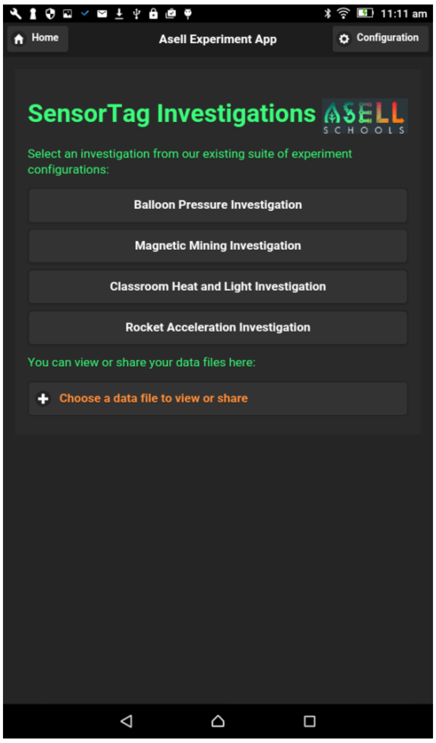

Figure 3: Exemplar Investigations Interface

- Investigation execution – any user can select to execute a investigation design. By selecting the investigation name, they app launches the designed interface and users can connect to a SensorTag and begin to see the sensor results. This component is responsible for managing connections to the SensorTag. Examples of investigation interfaces are shown in Figure 4.

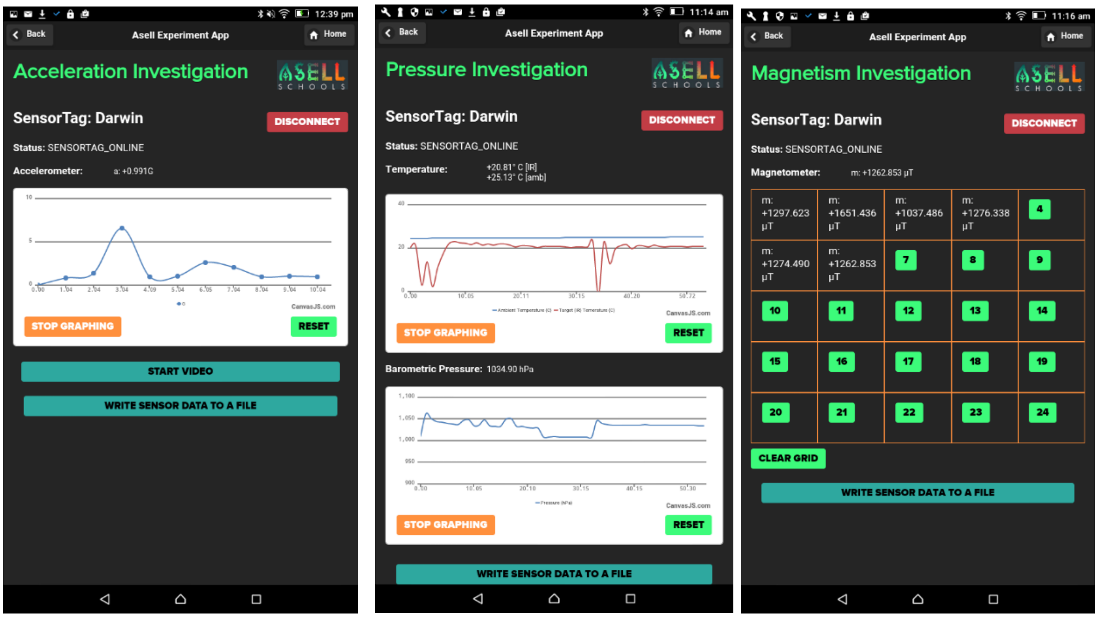

Figure 4: Investigation Execution Interface

- File Handling – allows for users to share and view their laboratory designs and data. Laboratory designs are saved by default once designed. Data can be saved during the laboratory activity if configured. Users with the ‘Student’ role have access to only the data they have created, while the ‘Teacher’ role has access to all files on the device. Files can be shared via email or the can be downloaded from a server. Logging in with the ‘Teacher’ role automatically runs a local server from which all the files are available to be downloaded. Some of the interfaces for this function are illustrated in Figure 5.

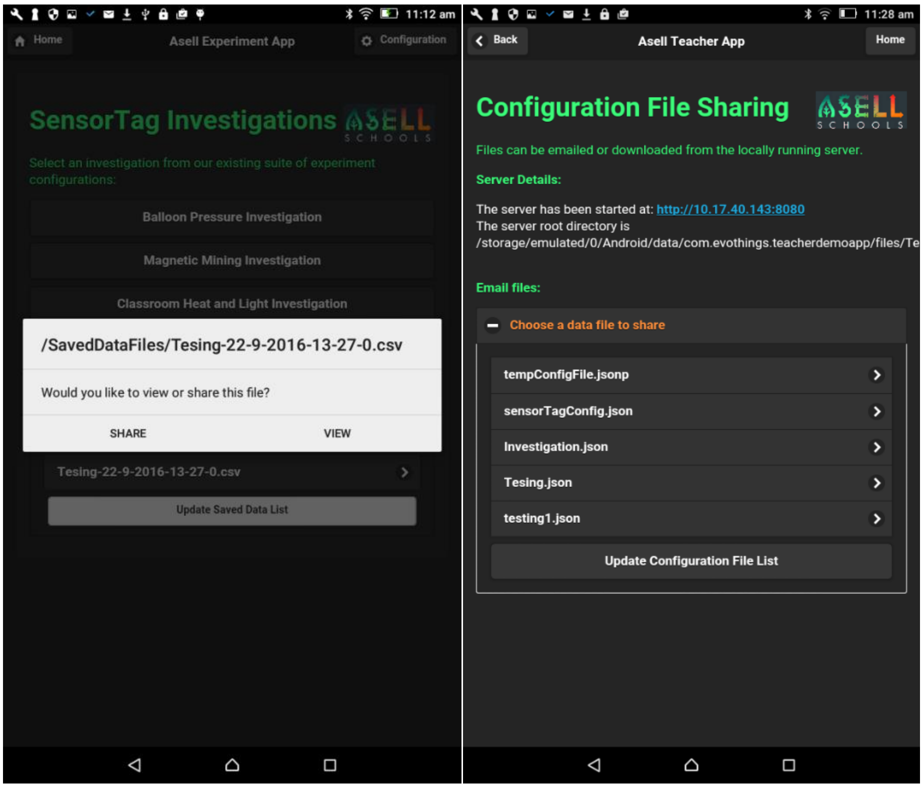

Figure 5: File Handling Interface Examples

- Configuration – Teacher roles may configure names for SensorTags (in order to identify them in a classroom) as well as the file handling variables such as folder names.

Case Study

To determine whether a technical framework could be developed that educators would be able and willing to use in rapidly developing inquiry-based science investigations, a case study was undertaken. The case study was done as part of an ASELL Schools workshop introducing a cohort of students and teachers to their inquiry-based learning concepts and tools for laboratory activities. This case study focussed on teacher and students’ receptiveness to the laboratory format, their observed ability to use the app easily and the reported willingness to use Snaplabs app in future classroom activities. Based on the outcomes, further research will focus on measured learning outcomes that can be achieved with the Snaplabs app and comparison with other laboratory formats.

The cohort included 40 students and eight teachers from academically selective schools. The teachers were given a 15 minute description and demonstration of the SnapLabs application and the SensorTags, and then were free to use the devices as desired. The technical framework was used in a 45 minute laboratory activity with the students. The SnapLabs application and SensorTags were explained briefly to the students, and they were given steps to follow to use the devices and become more familiar with them. The students were then given 25 minutes to use the application and sensors to design and execute an experiment. The guidelines were to use the devices to measure the ratio between the lightest and darkest parts of the laboratory room but they were free to change the experiment to investigate any other phenomenon. Feedback from both the teachers and students was collected by discussion after the case study, as per the structure of the ASELL workshop.

Observations

The responses from both groups were positive, with suggestions being made for improvements and changes before the system would be suitable for use in schools. Both groups were able to quickly navigate through the application and find the functions that had been demonstrated to them, but both suggested that the user interface could be improved to be more intuitive and have a better 'look and feel'.

The teachers acknowledged the potential for both the general concept of laboratories being executed using a mobile device application, and for the SensorTag and SnapLabs solution in particular. Teachers appreciated the ease with which laboratories could be designed and had a number of ideas of how the application could be used within the syllabus to augment existing labs (though specifically, not replace them). In the context of the ASELL workshop, the ideas from the teachers focussed on the inquiry-based nature of the laboratory activities that the system could be used for by allowing students themselves to change the laboratory design or design their own activity. Of interest to teachers was the ability for students to 'play' with the SensorTags which are more robust and portable than traditional sensors in the laboratories.

The students responded very well to being able to control the design of the laboratory activity. They experimented with the sensors and lab design during the activity. The novelty of the smart sensors (as opposed to traditional laboratory sensors) and the mobile application engaged the students.

The negatives reported were the stability of the connections to the SensorTags. As the SensorTags cannot be uniquely identified until a Bluetooth connection is made, the current system connects to the closest SensorTag. If connections are lost, the application may connect to a new SensorTag resulting in confusion. This would need to be addressed before the solution could be used in a classroom setting. Additionally feedback on the nature of the interface suggested that improvements could be made in the usability of user interface component of the application.

Teachers were able to use the technical framework to design applications, and showed interest in using the technology (with improvements) in future trials.

Future steps in the development of the SnapLabs application will address the user interface and usability problems reported. Additionally, future versions will build on the IoT model and have the option of storing experiment designs and data collected on a cloud where it can be accessed and shared (with authentication and permission) between students and institutions. Future developments will also include extending the application to be able to connect to a range of Bluetooth enabled smart sensors or actuators to extend the usability.

While a high school cohort was used for this case study, it is expected that the nature of the application in allowing flexible design of laboratory activities and its support for inquiry based learning means it will be able to be used both in primary school and in to universities. This would be further enhanced by future developments supporting a range of smart sensors and allowing distributed collection and access to data.

Conclusion

The SnapLabs and SensorTag design for the non-expert design and deployment of laboratory activities has shown positive feedback from the case study into its use. The combination of the mobile application and the SensorTag as a solution allows students and teachers to design their own sensor based laboratory activities rapidly, at low cost, without the requirement for specialist skills. Teachers were willing and able to design inquiry-based activities for students and the students themselves could use the application and sensors to design and execute their labs. The case study has resulted in strong engagement from teachers on the future of Snaplabs and they have shown a willingness to use further iterations of the solution in classrooms to augment current lab activities. Additionally the feedback has provided an indication of where this solution can be improved and extended. The results of the research have shown how IoT supporting technologies may be used to provide teachers with additional tools to design and deliver inquiry based laboratory investigations.

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