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ENERGY IN SCHOOLS: PROMOTING GLOBAL CHANGE THROUGH SOCIO TECHNICAL DEPLOYMENTS

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Abstract

Reducing carbon emissions is a key priority across the globe, and in the UK, schools have been identified as the second largest users of non-domestic energy. In this paper, we present an IoT solution for schools that aims to unite senior leadership, teachers, and pupils in the goal of reducing or shifting their energy consumption and carbon emissions. We achieve this by prompting behavioural change through instrumenting schools with sensors, visual displays, and a variety of educational resources which use the BBC micro:bit to interact with the data produced by these sensors, enabling pupils to engage in educational activities to solve real world problems. By increasing the visibility, availability, and interactivity of data, we enable a new space for dialogue between facilities managers and building users. We summarise some of the challenges and lessons learned so far, with preliminary results indicating our approach is effective in raising the profile of energy management and shifting demand. Future monitoring and evaluation will provide more detail on the effectiveness of our IoT solution.

1. Introduction

Reducing carbon emissions for the benefit of ourselves and future generations is a well-recognised global challenge. There are many projects around the world attempting to address this, and the UK government has recently funded a number of such projects looking how best to achieve emissions savings across the domestic and non-domestic sectors [1]. Identifying energy use as a clear candidate for reductions, a rollout is underway to replace at least 80% of smart electricity meters and grids across domestic properties and SMEs. It is proposed that such a rollout could reduce emissions in the EU by up to 9% and annual household energy consumption by similar amounts [2].

Schools are estimated to be the second largest consumer of non-domestic energy, making them a lucrative candidate for energy savings [1]. However, in organisations such as schools consisting of many stakeholders with differing agency, it can be hard to enact change. It is easy to see why—to reduce energy consumption, behavioural change is required, which means all stakeholders (senior leadership, teachers, pupils) of the school must be aware of the energy consumed and actively reduce consumption. Previous studies have touched on the lack of communication, tensions and differing priorities that can exist between these stakeholder groups [3] [4]. This is where difficulties arise: awareness of consumption is driven by data, data provides information, and information supports change, but schools have neither the monetary resource nor expertise to instrument their buildings with the required IoT sensors and technological infrastructure.

In this paper, we present preliminary results of our IoT (Internet of Things) solution for schools that aims to unite senior leadership, teachers, and pupils in the goal of reducing (and shifting) their energy consumption and carbon emissions. We achieve this by prompting behavioural change through instrumenting each school with sensors, visual displays, and a variety of educational resources (including the use of the BBC micro:bit [5]) which interacts with the data produced by the sensors. In addition, by increasing the visibility, availability, and interactivity of data, we enable deep analysis and a new space for dialogue between facilities managers and building users. We contribute: (1) methodological detail on how we engage with every stakeholder of a school, from children and teachers (through learning resources), to senior leadership (providing equipment at no significant cost to the school) (Section 2); (2) an IoT platform designed for non-expert use (Section 3); and (3) a summary of the unique challenges that we faced (Section 4) and the lessons learned (Section 5) during a trial deployment of our solution to three schools in the UK[1].

2. Project Background and Methodology

The project is formed of three phases: (1) preliminary research, (2) initial deployments to a small number of schools, and (3) wider deployments to the whole of the UK; the functionality

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[1] This project is funded by the U.K. government as part of the BEIS NDSEMIC programme.

of the platform is emerging through a process of codesign. This paper documents phases 1 and 2.

Our preliminary research phase consisted of a participatory design programme involving a range of stakeholders in the design of interventions, and iterative trials. We recruited a pilot school to initially explore the issues facing schools with energy use, and to support a codesign approach to developing our solutions. Three schools took part in phase two of the project: two primary schools and one secondary school. Through a series of energy and behavioural audits, workshops, and interviews with stakeholders across the two phases, we identified the potential motivating factors and barriers to behaviour change.

We designed a platform featuring technological, educational, and behavioural interventions to support schools to not only shift their energy use from the peak times of 4-7pm, but also reduce overall consumption. The platform combines real time smart energy metering, modern IoT sensing, and curriculum aligned learning materials which use the BBC micro:bit to interact with data produced by sensors and smart meters. The combination of accurate smart energy metering and IoT sensors enable senior management to observe and realise actionable change within their school. Teachers and students are given agency through an engaging plug-and-play IoT learning experience that educates them on their energy consumption, with gamified school metrics garnering competition between schools generating further agency. To constantly remind the school of their united goal, a display is placed prominently in main thoroughfares supplying real-time, up-to-date statistics on school performance. For additional impact, we delivered training to groups of students turning them into "energy champions" for the school. To support the cost of such infrastructure, schools are moved onto a time of use tariff saving schools up to £1000 per annum, which is then used to fund the platform and its installation, and to give senior management additional motivation to promote change.

3. The Platform

3.1. *Architecture*

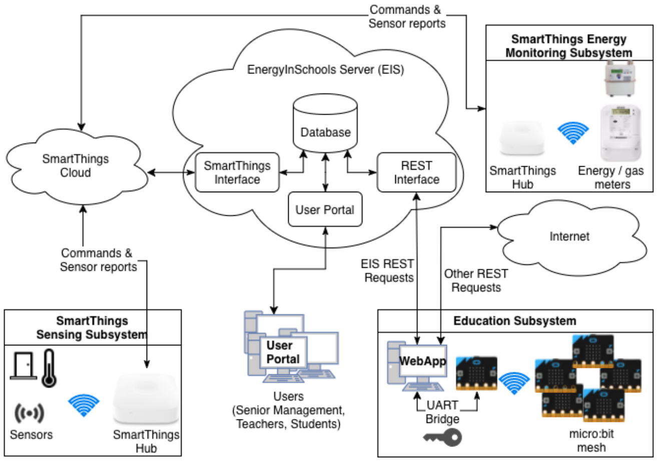
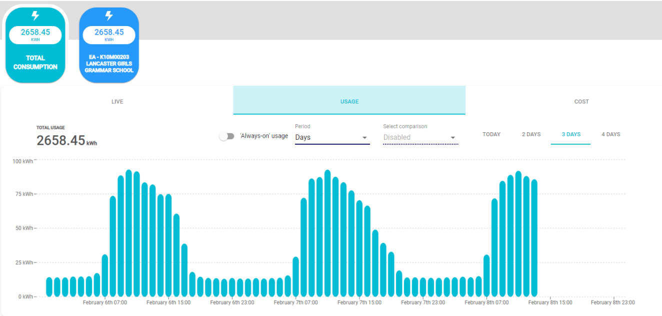


Fig. 1 The Energy in Schools (EIS) IoT architecture.

IoT solutions for energy reduction focus on the installation of energy monitors, and for good reason: they allow management to see the running costs of a building giving agency to act. But running cost often needs to be combined with other information to provide actionable change: adding a temperature sensor to a building immediately allows senior management to see if it is needlessly heated overnight. More importantly however, is that in a school setting senior management are not solely responsible for leaving doors and windows open or appliances and lights on, students and teachers are too. All stakeholders of the school needed to be engaged.

To this end, our platform (Figure 1) combines accurate energy monitoring, smart sensing, and an engaging, low-barrier curriculum aligned IoT experience. The platform is divided into three subsystems: Sensing, Education, and Energy Monitoring. Each subsystem can communicate bidirectionally to the EnergyInSchools server (EIS). All users access information through the User Portal where: accurate energy statistics for energy managers (Figure 2), lesson plans for teachers, and a customised block-based micro:bit programming editor for students (Figure 3) are made available. The education subsystem enables students and teachers to use the BBC micro:bit to react to changes in data, interact with building sensors, and investigate data stored in the EIS server. A school may feature one or more of each subsystem.

For the remainder of this section we discuss the educational aspect of the platform, followed by an evaluation.



Period
Days

Select comparison
Disabled

Fig. 2 A screenshot from the Energy Manager portal showing the energy consumption of one school across three days.

3.2. *An Engaging Educational Experience*

The micro:bit has become known to teachers and students alike as an engaging, fun introduction to the concepts of computer science through simple programming via web based editors (Figure 3). As well as featuring a number of sensors, the micro:bit is equipped with Bluetooth Low Energy (BLE), enabling communications with smartphones and computers, and thusly the wider Internet. Whilst BLE is an ideal communication solution for many industrial IoT infrastructures, there are user experience implications in its use within schools: (1) Pairing BLE devices is challenging, even more so for novices; (2) A BLE enabled (and compatible) laptop is required to connect to the Internet.

Instead, we developed a broadcast, plug and play, synchronous micro:bit mesh based on Glossy [6] (detail outside the scope of this paper) that enables reliable delivery of packets to all proximal micro:bits, using the radio module normally reserved for BLE operation. Devices communicate condensed REST [16] requests over the mesh and other devices provide access to the Internet via a bridge to an Internet connected computer, running software that translates condensed REST requests to fully formed requests. REST requests can be made to any endpoint as long as a translation is provided for a condensed request. Given unrestricted access to the Internet through technology, children can enable scenarios that on the surface are safe, but can put children at risk. This concern is especially prevalent with technologies that enable new attack vectors through the use of IoT. [13]. This whitelisted approach safeguards our users by only allowing pre-approved endpoints.

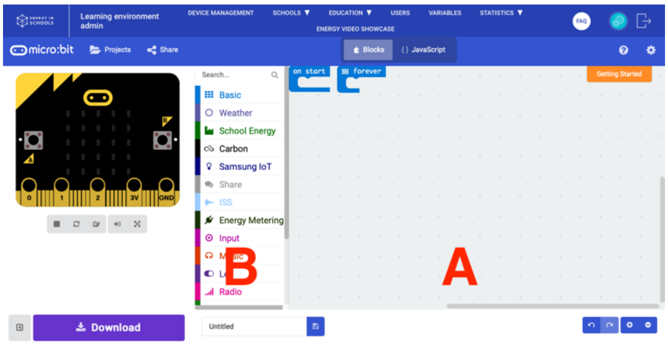
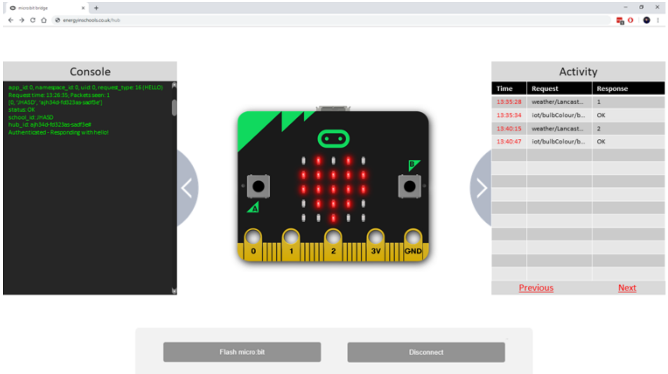


Fig. 3 A block-based programming experience based on Microsoft MakeCode [10]. Users piece blocks selected from the toolbox (B) together on the canvas (A) to build programs.

To allow the micro:bit mesh to access the Internet, a teacher simply loads a WebApp (Figure 4) and packets are forwarded seamlessly to Internet endpoints. Other solutions may require an additional device (such as a Raspberry Pi) to perform bridging functionality, however by using a WebApp, only a computer with a WebUSB enabled version of Chrome installed is required. This approach also benefits from real time updates.



```
app_id: 0, namespace_id: 0, uid: 0, request_type: 16 (HELLO)
Request time: 13:26:35; Packets seen: 1
[0, 'JHASD', 'ajh34d-fd323as-sadf3e']
status: OK
school_id: JHASD
hub_id: ajh34d-fd323as-sadf3e#
Authenticated - Responding with hello!
```

Time	Request	Response
13:35:28	weather/Lancast...	1
13:35:34	iot/bulbColour/b...	OK
13:40:15	weather/Lancast...	2
13:40:47	iot/bulbColour/b...	OK

Previous Next

Fig. 4 The WebApp that communicates to a bridged micro:bit over USB serial, translating packets it receives into Web requests.

The micro:bit acting as a bridge provides authentication to the EIS REST APIs by executing a dynamically generated program (downloadable only via a teacher account in the User Portal) containing keys for a session. Keys are transferred from the bridged micro:bit to the WebApp and authentication keys are only injected into requests to EIS APIs. Using this architecture, the bridge provides an authenticated entry point to the EIS system for the entire mesh, allowing other micro:bits to consume data about the school and perform actions when data changes.

The platform also enables sensor data (such as temperature, light, door state, energy consumption) to be reported from the BBC micro:bit, allowing teachers and students to perform real IoT deployments.

3.3. *Enabling Cross Curricular Learning*

Traditional energy monitors measure the magnetic field emitted by the movement of electrons down a wire and normally require the isolation of the power line to operate. In a classroom, this would mean cutting into cables to isolate powerlines, an irresponsible and dangerous thing to suggest to school children.

The micro:bit features a magnetometer, used to sense changes in proximal magnetic fields. We found that the magnetometer can be used to quite accurately measure consumption if positioned on a power cable correctly (Figure 5).

When the micro:bit's energy monitoring capability is combined with our IoT infrastructure, energy consumption data is reported to an EIS REST endpoint for display to senior management, teachers, and students, with an optional download for further analysis. Not only does this approach enable low-cost appliance energy monitoring at scale, but it empowers an entire class of children to measure, report, and *investigate energy consumption anomalies as part of a scientific process*.

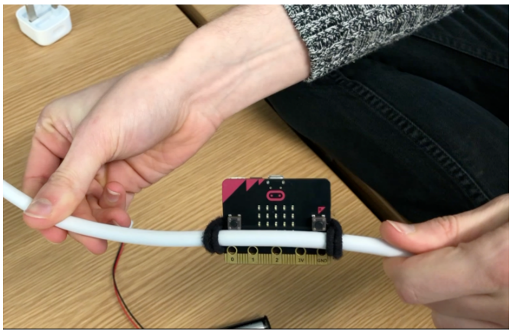


Fig. 5 A micro:bit attached to a powerline for energy monitoring using just a hairband.

3.4. *Evaluation*

End-to-End Performance: We measured the end to end delay of the micro:bit to a REST endpoint and back again, including transmission across the mesh, processing by the WebApp, and the HTTPS request to the server. Figures are captured using traces from a Logic analyser, with only two microbits in the mesh. The total time taken was 230 milliseconds (ms), with 32.5 ms spent communicating across the mesh to the bridge, 161 ms spent communicating the request to the WebApp, to the endpoint, and back again, and 36.5 ms communicating from the bridge via the mesh to the original transmitter.

Security: Currently no encryption is provided at the micro:bit mesh layer, so packets can be read by any micro:bit in the mesh. However, whilst most protocols place device (Media

Access Control) addresses in their packets, we place no uniquely identifiable information in micro:bit packets, providing security through anonymity.

Another attack vector is the bridged micro:bit which provides a trusted link to the EIS server. Only programs that contain correct keys for the current school can access EIS REST APIs, however, this does not prevent masquerading as a bridge micro:bit and serving manipulative responses.

Users are shielded from dangerous scenarios by constraining API parameters through carefully designed blocks, and restricting access to only a subset of APIs that we define. Implementing end to end encryption is future work (we plan to place symmetric keys in programs downloaded from the portal).

Extensibility: The system is designed with extensibility in mind. New translations for condensed REST requests can be added dynamically from the EIS server and updated by a simple page refresh in the WebApp; similarly new blocks can be added to the programming editor for use in the User Portal.

Setup time: Once the WebApp is loaded the user simply selects a micro:bit from a list of connected USB devices. If a micro:bit is connected with a valid set of keys for EIS REST APIs, the Web App begins forwarding packets to their requested destinations.

4. Challenges

The project encountered a range of challenges, some of which were anticipated and others becoming apparent as the project progressed. The themes of these challenges were identified through informal feedback from stakeholders throughout the project, as well as formal recorded interviews with pupils, teachers, senior management and IT staff. Quotes used are taken from these interviews.

4.1. *Finding Time*

In theory, education is agile, iterative, and collaborative, with teachers encouraged to be reflective practitioners. However, in practice, the '*hectic life of the school*' limits this development time. As a result, whilst curricula may vary from year to year due to Governmental or staffing changes, teaching is often broadly similar, and based on familiar work.

Teachers found that they struggled to find time to learn new technology and look over the provided lesson plans. One teacher said the project had taken more '*homework*' for them than any other area of their work and another commented that they '*don't normally read plans in such detail because I'm just delivering something I've done ten times before*'.

At the school level, teaching timetables and topics are usually planned a year in advance, and the relatively short time scale and lead time of the project proved difficult to fit into the already packed timetables as they '*normally do things with enormous lead time'*.

This problem is further exacerbated in secondary schools, where flexibility in the timetable is limited due to the impact on other teachers, room timetabling and curriculum areas. Lack of time prevented all of the sessions being tested, resulting in only three of the sessions being taught. Despite these issues, the reaction to the learning environment was extremely positive, engaging both the staff and students in energy saving and making them more energy conscious. One primary school teacher commented that: '*This is the sort of thing children should be doing in primary school, fundamentally. There's no doubt that this is what they need to be doing to me.*'

4.2. *Engaging all stakeholders*

Although the project was designed to capture a range of agents, the complexity of relationships both within and between schools, was not fully appreciated. Support staff and cleaners were not included in our stakeholder assessment, with one cleaner commenting: '*I don't know anything about the logistics of running a school, and people would get really angry if I stuck my nose in'*. Some of the methods of introducing the project to the staff (e.g. staff meetings, assemblies) did not capture all stakeholders.

4.3. *Obtaining knowledge, skills and confidence*

We found considerable skill, knowledge and confidence differences across our test schools, both with regard to energy efficiency and technology.

Secondary schools typically have a dedicated IT team: a head of IT with a degree in computing, and a number of IT teachers and support staff. Primary schools, on the other hand often have limited IT support (typically one day a week), bought in from a centralised organisation, with their time already committed to a backlog of other IT issues. The primary teachers we worked with had little or no experience of coding, and confidence was the main issue for them.

Business managers, caretakers, and head teachers have no formal energy management training, despite it being within their role and job descriptions. Knowledge and skills are either transferred from the domestic sector or acquired on the job. Heating and cooling systems and water heating were not clearly understood, and the timing and mechanism of automation of these systems was a mystery at some sites. However, having access to the energy data was a useful tool in helping schools to visualise and understand patterns of use, even when the school was unoccupied.

4.4. *Limited access to resources and the Internet*

Schools restrict Internet access to safeguard children and we found that even where there is an IT team in place, they do not have control over their firewalls, outsourcing control and responsibility to the Internet service provider (ISP).

This created deployment challenges when installing the platform: we had to raise a formal request to the ISP to open up network ports via a ticketing system, sometimes taking up to three weeks to be resolved. Deployment issues were also encountered in a rural school where phone signal was limited.

With total school spending per pupil falling by 8% combined with a 55% cut to local authority spending on services, there is little capacity and resources to support non-essential training to help staff develop new knowledge and skills [17].

5 Lessons Learned

Greater Lead Times and Support. Equipment needs to be tested, installed, and configured weeks before its intended use date so that teachers can familiarise themselves with technology and infrastructure can be tested. More training and support for teachers is required to increase their confidence in using the technology. Increased lead times would also better inform the ideal locations for IoT infrastructure and identify any deployment issues beforehand.

Simplification of Terminology. Lesson plans for educators assumed familiarity with terms like "algorithms" and "variables" and even the term "IoT"; some stakeholders had no real understanding of any of these terms. In the next phase of the project we will work to provide a more gradual sequence of lesson plans that build fundamentals before IoT concepts are introduced. A wider aim will be to provide a simpler vocabulary of terms for use with the IoT.

Engaging all Stakeholders. There were stakeholder groups that were missed by the project, including support staff. As disparate stakeholders were responsible for different packages within the project (e.g. micro:bit teaching delivered by year 6/7 teachers, energy management activities delivered by business managers) there was a lack of cohesiveness in the schools' execution of the project. In addition, IT staff in secondary schools potentially have a key role to play with regard to managing energy use, and were not included in the original training plans for the use of the portal. The training package needs broadening out more widely, and further mechanisms for engaging different stakeholders need to be considered.

Creating a Culture of Energy Saving. From behavioural and energy audits upon commencing phase two, it was clear none of the schools had a culture of energy saving or environmentalism. After, however, teachers fed back that the profile of energy conservation has been raised across the school, indicating that the project had begun to create an energy saving culture.

6 Conclusion

There are potentially great benefits to instrumenting schools with modern technologies and empowering all stakeholders, however there are considerable human, technological and sector-specific barriers to overcome in these environments. Early results indicate that our deployed IoT architecture works well in a school setting, although extra support and training is needed to enable schools to use the technology confidently and effectively, and to develop an effective culture of conservation.

Our new approach to stakeholder empowerment is effective in raising the profile of energy management. From analysing savings from conserving energy, preliminary results indicate that it has a positive effect on demand reduction with schools earning an average of £220 in 10 weeks by shifting some of their energy use from the expensive time slots. However, some key agents are currently being missed, and a more cohesive approach needs to be developed within schools.

7 Related Work

7.1 *Social & Behaviour Change*

In [14], a social practice approach is taken, using energy champions to prompt environmental behaviour change in a workplace setting. And in [15], the authors produce a best practice guide for behaviour change towards energy reduction in a non-domestic educational setting. They use a combination of the Capability, Opportunity and Motivation behavioural model (COM-B) and the Theoretical Domains Framework (TDF). The above informs the social aspect of our intervention.

There is little research in schools that details fine-grained energy use to support effective behaviour change.

7.2 IoT Architectures

A variety of solutions exist for IoT deployments [13, 14, 15, 16], but none are designed to be used in education. In a school setting, frustrating, expensive, and complex technical setups lead to lack of adoption [17], therefore a plug and play, low infrastructure approach is vital for a positive IoT experience. [13] presents an architecture for energy monitoring within a school setting. The authors offer a technology-rich solution to engage stakeholders, built on open source principles and fine-grained access to data. Data is accessed by students and teachers with supplementary gamified applications [7], providing analytical opportunities on the energy consumption of the school. We build on such concepts, but also seek to engage a wider range of stakeholders through curriculum aligned learning materials.

7.3 Educational Technology

The Arduino [8] and Raspberry Pi [9] are widely known technologies associated with education, but these devices have seen adoption by hobbyists and technologists, rather than educators. Instead, the BBC micro:bit [5] a small, programmable, physical computing device has become known to teachers and students alike as a fun, engaging introduction to the concepts of computer science, offering advances in the classroom through its visual appearance, use of integrated components, and simple block-based, no-installation programming environments [10] [11]. The micro:bit features an LED display, a compass, accelerometer, temperate and light sensors, and wireless communications. 800,000 micro:bits were given (for free) to students across the U.K. with a further 2 million devices sold [12].

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