A Sharable Wearable Maker Community IoT Application

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***Abstract*— If we are to engage a younger generation to become future engineering and science innovators, we need to widen participation and interaction with technology and science. Maker movements have the potential to do this by making tools, materials, and processes more readily available to people in a more informal learning setting who may not initially self-identify as makers. We address a chief limitation of such maker communities, where it can be difficult for participants to develop and continue an application outside the inherent limited time and space of the maker event. We ran a series of 6 maker events aimed at groups of six 14-15 year olds that focused on learning through making the BBC micro:bit device interact as part of an Internet of Things (IoT) application. We report on one event and a challenge to develop a *sharable wearable IoT application* to address the aim for participants that could sustain interest outside the event. This application was a club badge to send secret messages to members. The evaluation revealed a keen engagement and commitment to social wearable design, as seen through the students building and participating in the successful use of the application through authenticity. This authentic engagement to problem solving at a technical level to motivate personal goals was inspired through a sharable wearable design that participants deemed to be beneficial.**

Keywords*— wearable IoT applications for communities, identities, Human IoT interface, tangible computing

I. Introduction

Over the last few years, The Internet of Things (IoT) has become mainstream, capturing innovative industries and economists globally. Poslad [1] describes the rich functionality of ubiquitous computing, many of these ideas and applications resonate with the IoT's wearable and connected sensor driven, data enriched experiences. Both Gouaïch [2] and Poslad [1] refer to this idea of ubiquitous information and communication technologies and devices 'existing everywhere'. These technologies and devices form part of highly distributed, connected and networked systems that are mobile, wireless, active and responsive, making 'almost' seamless information and tasks available everywhere, and through supporting intuitive human usage [3].

IoT [4] is taking us far beyond the Web (with a main focus on virtual rather than physical resource access) and mobile computing (focused on Smart Phones) to more heterogeneous sets of computing devices, engineering designs and computer science such as new sources of big data science, providing improved theoretical and practical underpinnings of a ubiquitous, everywhere and anytime embedded experience for everyone [5]. Whereas the focus of ubiquitous computing focuses more on less obtrusive human computer interaction with things or devices, IoT focuses more on connecting things to each other.

The tangible and authentic[1] approach of IoT offers the potential to widen participation and to generate a more appealing approach to engaging with Science, Technology, Engineering, and Mathematics (STEM) [6], [7]. Bennett et al's [8] findings are similar to Rusk et al [9] and the American Association of University Women [10], which found that a design-based approach led to more engagement and motivation. In addition, [11] shows that when challenges or problems are set with a community focus that these tend to foster and enable widening participation. Learner led problems have demonstrated students can go beyond the basic knowledge of mathematics to solve engaging problems in computer science [12]. The evidence of student engagement in STEM through community driven maker spaces is now so compelling that we cannot ignore the potential affordances of such 'learning through making' experiences [25]. IoT enables us to take this further into knowledge building of science together, benefitting from community driven factors that foster engagement and ownership [13]. This paper investigates the potential impact of community and ownership through a personalised, sharable, wearable, device.

A. Project Objectives & Paper Structure

This paper reports on a design-based community study approach for creating, designing, experiencing, and testing a wearable Internet of Things application [14]. This study focused on the engagement of the wearable feature of the device in the context of community applications that are student-led and is part of a larger project to design and deliver innovative resources and devices at scale.

The remainder of the paper provides the background context to the study and related literature and a report on the findings of pilot study of a wearable Internet of Things application. Finally, we present some of the initial lessons

[1] Direct contact with 'real world' experiences and uses and offers purposeful engagement.

learned about what works and what does not and outline the potential future innovations and impact of community driven IoT applications.

II. BACKGROUND TO THE PILOT

A. Wearable IoT

Wearables in general refer to digital on-body devices that are mobile, low power and context-aware. Wearables can take a range of form factors often in the form of smart tabs and smart skins [1]. We can also distinguish wearables that are fixed on us, from the mobile devices that simply accompany us such as handhelds, i.e., smart phones [1]. Wearables are designed to be always-on, attached to the surface of the human body at a fixed position, usually incorporating sensors that monitor the changing mobile human context and physical environment context and can adapt device functions to these. Steve Mann defies the key requirements of wearables in terms of the eudaemonic criterion (in the user's personal space), existential criterion (controlled by user) and ephemeral criterion (responsiveness) which includes operational constancy (is always active while worn) and interactional constancy (one or more output channels are always accessible) [3]. Key applications include: health and fitness [15], enhanced navigation and information access while on the move [16], augmented reality (AR) [16], Virtual Reality (VR), easy smart building interaction, easy payment and smart wearable aesthetics that personalize sound and light displays [17]. Many wearables tend to be used as part of an IoT because their sensors generate data that is not normally stored and processed on-device but is exchanged, via a WPAN link to an Internet hub device, to a remote data storage and analysis platform [18]. We have coined the term *sharable wearable IoT application* for a wearable which mediates communication with other humans in a personalisable manner.

B. BBC Micro:Bit

The BBC micro:bit device[2] [19] is a micro-computer and microcontroller with on board sensors, Wireless Personal Area Network (WPAN) support via Bluetooth Low Energy (BLE) and a LED matrix for a display. It can be programmed visually via a graphical user interfaces such as Blocky and Touch Develop and via text-based programming languages, such as JavaScript, and Python. It was delivered nationwide to secondary schools in the UK during 2016. This wearable device has been designed to be:

1. Small enough (1/2 a credit card in size) to take with you anywhere;
2. Simple enough for beginners to experiment with and get started with to create and explore ideas;
3. Extensible, flexible and adaptable to enable advanced ideas to be designed and crafted;
4. Sustainable in both cost and imagination - a low cost device that could be extended to create interesting applications and experiments
5. Able to support both formal and informal education;
6. Be fun, innovative and creative to use, and,
7. Be usable by just about anyone who wants to explore technology and create something personally purposeful.

Although some other microcomputers, such as Arduino[3], BeagleBone[4] and Raspberry Pi[5] share some of these characteristics, they do not exhibit them all, e.g., all 3 of these, unlike the BBC micro:bit have no onboard integrated inertial sensors, LED matrix display or BLE (Bluetooth low energy) WPAN (Wireless Personal Area Network) support, requiring these to be add-ons and in some cases wired, making these somewhat more fragile to setup and maintain during their operation.

In addition, these 3 types of microcomputer device require some basic technical expertise to programme whereas the BBC micro:bit supports for a more visual programming language that can be programmed by less technically knowledgeable users. Building on previous findings of the BBC micro bit project [19] we ran a series of small projects and hands-on orientation events with six year 10 students (aged between 14 and 15) to investigate further the wearable features of the BBC micro:bit device to interact as part of an Internet of Things (IoT) application. Here, we report on one of these events and challenges to develop a *sharable wearable IoT application* to address the aim for participants that could foster and sustain their interest outside the hands-on orientation event.

C. Why the Wearable Internet of Things Focus?

The wearable provision of the IoT design was seen as important option as it demonstrated the power of technology, such as supporting engagement, feedback and a sense of presence [20]. A wearable also facilitates a wider engagement in time and space outside the limited time and space in a maker community event in which the wearable application is originally developed. This overcomes a chief limitation of a maker community which can limit the engagement with participants only to the maker event itself.

The social value and a sense of ownership are important to learning and motivation. To support and provide an inclusive potential of IoT to foster sustained learning, it was felt that the device should be wearable, as this feature could potentially provide and support a broader range of applications for students to design and create with the idea of reducing the barrier to engaging with STEM (Science, Technology, Engineering, and Mathematics) through design. However, in this small pilot a relationship with identity and ownership that is part of engagement emerged.

D. Engagement and ownership

The idea was to explore with students their engagement with 'wearable' programmable devices and to examine the

[2] See https://www.**microbit**.co.uk/

[3] See https://www.arduino.cc/

[4] See beagleboard.org/bone

[5] See https://www.raspberrypi.org/

dimensions of the meaning of this engagement. The BBC micro:bit can be thought of as a micro or scaled down version of 'FabLab'. Paul Blikstein [21] provides compelling arguments based on the return of hands-on experience of engineering design and making through new technology tools. He states, "What Logo did for geometry and programming – bringing complex mathematics within the reach of schoolchildren – fabrication labs can do for design and engineering. Digital fabrication is Logo for atoms". He sets this within Papert's Constructionism [22], illustrating the construction of knowledge happens remarkably well when students build, make, and publicly share objects. Blikstein[21] provides the pedagogical insights into value of the maker community and the digital fabrication movement. Furthermore, he examines the need for fabrication labs, which now do exist on an international scale. In these spaces, participants work at the intersection of the digital and the physical, using digital tools to generate designs that can then be built with in-house fabrication tools such as 3-D printers. However, there are difficulties with such labs as examined by Blikstein [21] due to the technical knowledge required to run the labs. The Maker movement [28], [29], exhibits a growing trend for maker spaces, by making tools, materials, and processes more readily available to people who may not initially self-identify as makers. It also provides a more informal learning setting in constructing and blending digital and physical artifacts. One of the difficulties that occur within maker communities is that once the fair, event or workshop finishes, it is very difficult for the students to continue with their projects for a variety of reasons not least of all the access to the right tools.

Authenticity is key to engagement and ownership through design and construction by the learner [23]. Students engage when they see purpose, when their learning has meaning. However, in both computer science and design and technology in the UK, there are concerns about lack of engagement [24]. However, in maker communities, which provide rich experiences for designing and building artifacts, engagement and motivation are clearly identified [25]. This framework [ibid] illustrates the learning dimensions and how learning takes place, provides convincing evidence of this engagement and ownership fostered through a community context and 'learning through making'.

Although the IoT itself and fabrication of wearable technologies in industry is widespread there is little research available to understand what role, if any, wearable devices have in learning. Finally, there have been only limited studies to-date to understand the potential value of wearable devices that have IoT properties in education.

III. Design process and methodology

The study was designed to be participatory and exploratory with the students. Students were recruited who were interested in designing some applications for wearable devices. It was a three week pilot study. Consent forms from parents were sent home before the pilot started explaining the study. Data was collected in the form of surveys, observations, video content, interviews and informal discussions. Students did not need to know how to program but an interest in design and in programming technology was required.

The procedures of grounded theory qualitative content analysis were followed [30], using an open coding procedure to examine the relationship between wearable devices and the communities within an informal learning context.

The learning activities with the students are outlined in table 1.

Learning Activity	**Description**	**Notes**
Interdisciplinary context	Introducing IoT and BBC micro:bit as a wearable device	Before the activity students were given a short survey about their thoughts about wearable, IoT and communities
Student context & purpose setting	Students think about everyday things	In pairs students discuss the kind of things they would like to do
Authenticity: active learning & collaboration	Problems and solutions: How might wearable help	They draft solutions
Sharing solutions: Diversity	Designing, Presenting and sharing ideas	
Active learning & collaboration	Deciding what to focus on and development of the prototype using BBC micro:bit software	
Practice and production; Testing out their designs	Their own initial solution	Working through how it works
Active learning & collaboration	Working with the wearable community app	The students had one week to experiment with the application
Reflections and feedback	The students kept a diary for the week to keep track of the experience	Feedback on using the BBC micro:bit as a wearable device was provided

Table 1: Learning activities and context of the study

A. *Details of the Pilot*

The pilot was set up as exploratory experiment and was student-led to find out if a wearable device was interesting to them and in what way it might be interesting. The pilot study was trying to understand whether or not learning engagement emerged and if ideas of community could be developed. The findings are discussed considering the (1) ideas that emerged,

(2) the design of solutions, (3) implementation process and (4) in the wild experimentation.

1) Ideas for wearable devices

The students had a number of initial ideas that were around the BBC micro:bit notifying them of an event, reminders and as secret communication devices that only their close friends would know the meaning. This idea of secret meaning evolved over the session into a secret club and the BBC micro:bit LEDs presenting which club a person was a member of[6]. After twenty minutes of discussion the students decided that they would design their own secret club language that the BBC micro:bit would display. This wearable combines the requirements of an aesthetic wearable with a sharable wearable application and are designed to fulfill key requirements of wearables of the eudaemonic, existential and ephemeral criteria, see Section II.A.

The students were given the opportunity to create the device into a more personal wearable with craft materials. These designs ranged from a very minimal pocket holder to more elaborate wristbands and badges. See fig 1. for an example of one of the designs created by a student.

Fig 1: An example of creating a more personal wearable design by one of the students

2) The design discussion of a solution

The students discussed further about designing ‘a secret language’ that would be displayed on BBC micro:bit as a type of badge. They considered a number of secret codes that could be visually displayed on the BBC micro:bit to share notifications that only they would know what they meant, such as, special reminders, happy birthday wishes, sharing TV events, supporting challenges and sponsoring each other etc.

Sponsoring and supporting each other became their main focus. They discussed how getting points and recognition motivated them to achieve some of their personal goals. The use of points (gamification) and social recognition to change the (travel) behavior of mobile phone users has been shown to have effect by [26], [26]. They decided that perhaps they could design a secret badge that adapted as they each achieved a particular goal. This would mean the BBC micro:bits would need to be able to communicate with each other and update their display incrementally.

[6] This is a more modern version and digital update of the Secret Seven club badge from the Enid Blyton books, see “The Secret Seven” (1949), http://www.enidblyton.net/secret-seven/

At the time of the pilot study peer-to-peer communication between the BBC micro:bits was not possible but it was possible for a BBC micro:bit to speak to another BBC micro:bit through using another device e.g. mobile phone using low energy Bluetooth (BLE). To use this functionality required creating an Android smart phone[7] application. This part of the implementation was completed by the research team and not the students due to the knowledge and time constraints of the study. Note that even though. after the study peer-to-peer BLE communication between the micro:bits became supported, use of smart phone as part of the system is still useful as this acts as a gateway for wider area communication than the shorter, often about 10 m, range of a BLE WPAN.

The students designed a simple badge that was created over time by working together. They each picked an event or activity that was important to them that they wanted to improve: e.g. to go to school earlier, walk rather than take the bus or car, read an extra 10 minutes per day, be healthier etc.

They then designed their initial targets together and attributed a value/point to each target.

Table 2: Overview of the points reward system

Student	Target	Value/Points
S1	Be healthier by eating more fresh fruit	1 point per day
S2	Walk to school twice per week.	2 points per walk
S3	Be more organized	2 points at the end of a week
S4	Get to school early	2 points for each day
S5	Be nicer to my sister	2 points if achieved in a week
S6	Tidy my room	2 points if achieved in a week

The points were communicated through their BBC micro:bit by clicking the ‘A’ button. This would send message to all the other BBC micro:bits via the mobile phones (See fig 3). The result of this message being received meant that each BBC micro:bit’s display would change the secret message.

Each point represented an ‘LED’ being turned on and displayed. For example in Fig 2 they need to have 17 points to have a completed badge.

Sketch of communication process between wearable BBC micro:bit and the students:

- Each BBC micro:bit was paired with a student’s mobile device.

[7] See https://www.android.com/intl/en_uk/

- Every time a student achieved a target goal they sent a message through the BBC micro:bit by clicking the A button.
- This communicated with secret BBC micro:bit badge app on their mobile.
- This action triggered a group message to be sent out to update the badge to display (turned on) a specific LED.
- The ‘image’ push was predefined on each phone that is LEDs to be turned on when receiving a message was pre-set.
- There was some simple logic to allow selection of ‘only’ 1 extra LED or 2 LEDs.

It is also worth noting the group phone numbers were preset. Also, S3, S5 and S6 could only send one message and this was sent at the end of the week. There was no real error handling. However, there were some options enabled (a) refresh image from last point received by pushing button ‘b’ on the BBC micro:bit and (b) from the phone browse previous badge configurations. These last two functions enable the students to control accidental changes. However, this also meant their badges could be out of sync with each other.

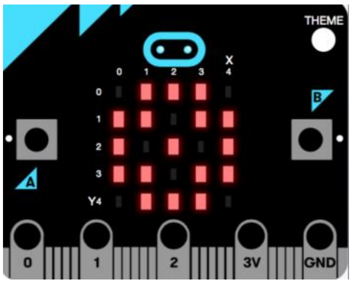

Fig 2: Example visual of a ‘shared’ LED badge

3) Implementation Process

The design pattern of the secret[8] micro:bit badge was created using Touch Develop (Microsoft programming language that runs on the BBC micro:bit) by the students. Once they had defined the rules of how the communication would work and how they thought this should be visualized the program was converted into an Android application.

The simple Android application made use of BLE GATT[9] to push messages to the BBC micro:bit and receive inputs from the BBC micro:bit button. The communication system between the devices used simple pre-defined messages to send the images (LED settings) to the device when receiving a ‘micro:bit point’ message.

[8] It was ‘classed’ as secret by the students because only they knew the meaning of the badge and why the image on the micro:bit changed over time.

[9] https://developer.android.com/guide/topics/connectivity/bluetooth-le.html

The GATT profile is a general specification for sending and receiving short pieces of data known as "attributes" over a BLE link. All current Low Energy application profiles are based on GATT.

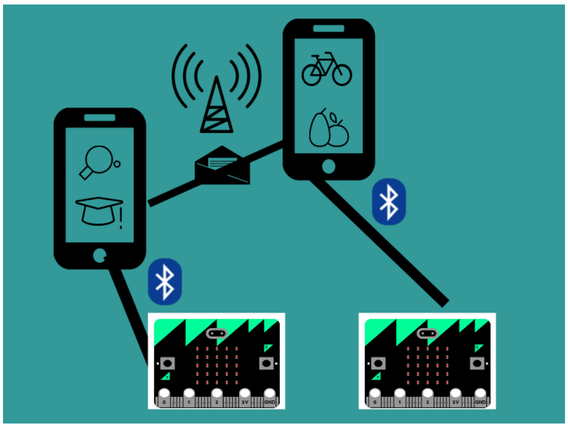

Fig 3 Architecture of secret BBC micro:bit badge applicatio

IV. Findings

The students designed the badge system in a way that they could collaborate and ‘share’ a presence together. It was interesting to see how they thought through the point system and their decisions for different activities to have different points. The findings are categorised according to three coarse groups (a) wearable device (b) designing the application and (c) community experience of sharing BBC micro:bit messages.

A. Wearable device

The students all liked the device. They found the device appealing commenting on its size and design “*It’s so small but it can do many things*” (S2). During the first session the students tried different ways to create a wearable badge with materials. Another student commented on it being quite “cool” that you can create your own design and stating “*I like the micro:bit face and the colours*”. None of the students had done electronics before or worked with sensors and they liked being able to program the device from their phone and make different patterns on the BBC micro:bit. Although appealing to the students, two of the students commented that they might not wear it all the time and they weren’t sure if school would let them.

From the surveys questions the students indicated that they found the device interesting. They liked the almost life like nature of the device and the shape and the ‘jazzy’ coloring effect. Three students commented that it was a fun device and wanted to explore more.

B. Designing the application

The design of the application resonated with the findings of Resnick et al [27]. All students contributed to the discussion and the ideas that emerged were innovative. All six students commented in the surveys about enjoying this process of design. However, they also noted that they did not often get the chance to engage in this type of activity. For example S5 commented “*I really enjoyed debating one kind of design we would create. It was fun thinking about secret communication. The time went so quickly. I wished we did more of this kind of activity.*”

When they designed the way the messages would be sent and needed to develop a ‘point system’ all the students felt it was a collaborative approach. One student stated "*I don't usually like these types of 'point system activities', as everyone usually gets very competitive and argues, but this was different we all decided what was important to us and how many points it was worth. We could ask each other for input but in the end we each could make our own decision.*" There was a sense of ownership emerging from this collaborative approach.

After the students had their initial design they were introduced to how to program using Touch Develop language and software environment on the https://www.microbit.co.uk/ [10]. They continued to work in pairs and discuss their designs and would then work together as a team to share their thinking. Many interesting ideas emerged as they extended their designs. A number of students commented on enjoying working together. For example, one student noted "*I quite liked the programming together. I hadn't really thought about this before but I liked how we worked things out together.*"

Although the students had not used Touch Develop before they found the initial activities straightforward and this helped them to stay engaged with the tasks of design and implementation. It was also interesting to see students expand their ideas and share them during this phase to include other interactions, such as the compass feature (one of the on board sensors of the micro:bit enables the micro:bit to be turned into a compass). For example one student proposed "*If we use the compass information we can use that to rotate the image and then we could all have different badges based on our orientation*".

When it came to the implementation of the Android application the students wanted to stay involved and to see how their designs and prototype 'inspired' the final application. This aspect was more challenging as the programming environment was more complex and they found this frustrating. To scaffold this, the researchers made some initial basic developments of code snippets using the Android studio environment[11]. Short instructions on how to extend the snippets and to include their design work and point system were included. This part of the work was heavily facilitated. Most students commented on this saying "*Building the real application was very interesting but the researchers needed to help us a lot. We kept running into bugs and errors that we didn't understand. It would be great to understand more and to be able to do this part myself*."

C. Community Experience for Sharing micro:bit Messages

This part of the experience was running the application. The students designed some 'rules of behaviour' of how they would run the application and share messages. During the school week they decided they would only wear the micro:bit after school and would only send their point updates after six o'clock in the evening. On the weekend they would wear the micro:bit during the day and send message updates at anytime.

There were a number of problems with the application as it was not very fault tolerant and sometimes the pairing with the mobile did not work. This caused some challenges and the experiment started a bit later than planned to deal with the technical problems. One student noted his/her concerns "*I was a bit worried we wouldn't be able to test out our ideas and all the work that had gone into the design. [..] Things were delayed and I didn't know what was going to happen.*"

The students kept a log about their experiences and any 'AHA'[12] triggers that they noted and felt were related to the wearable IoT community application. During the week of piloting the application the students set up their own WhatsApp group communication to check with each other. One student reported in his/her log "*It was great to see the first badge change happen. We all liked that and exchanged lots of messages and images on WhatsApp*". They also noted how they encouraged each other to achieve their goals. There was also a flurry of message exchanges towards the end of the experiment to make sure they reached their target together. A comment made by S3 was very compelling "*I'm really not very organised at all but I really wanted the secret badge to work so I packed my school bag early without being asked […] and got all my sports kit ready on my own. It was a surprise to my family and me*!"

S6 also commented "*It is a struggle to tidy my room. I find it boring and I would rather do other things but I recruited my friend to help me. Does that count or is it cheating?*" This was discussed on WhatsApp and they decided that it was allowed. There weren't any rules saying you couldn't ask for help.

They exchanged images of their secret badge and found that one badge was different to all the others. This started another discussion. S4 stated "*We were all curious to how that might happen and started to discuss what this might mean*." Most of the students felt they enjoyed the experience but sometimes it was too much of a distraction from other things they were doing. They liked having a secret badge and it became a talking point with other friends.

Studying the logs and discussion at the end of the experiment, it was interesting to see how they saw this as extending their identity. One student commented saying "*It reminds me a bit of the Avatar I created on my PS4. It sort of expresses a bit of yourself in a new way.*' Another student commented '*I know it was quite simple but it was a nice way to feel connected to each other. It really helped me to improve […] I didn't expect that.*"

At the end of the experiment the students were asked about wearable IoT applications and what they thought was important. They all liked the idea of community engagement, they worried about 'bullying' not 'being nice' but also commented that this happened already on social media. They valued being able to create their 'own wearable expressions'.

[10] https://www.microbit.co.uk/

[11] http://developer.android.com/tools/studio/index.html

[12] AHA' triggers/moments are moments of sudden realization, inspiration, insight, recognition, or comprehension.

V. Discussion

Although the application was limited the experience provided the students with the context to self-organize their shared experience and taking ownership of their learning. The wearable device provided the means for engagement and focus but was just part of the process. The engagement was interesting for seeing how the students designed their community application. They liked the effects of their communication being personalized through a secret code/message and that it manifested meaning to only those that were involved with the design and sending of the messages. The students expressed a sense of ownership and peer group engagement. They liked how the application gave them a means to open up conversations and to talk about what they were doing.

An unexpected side effect of the application was how quickly the students felt that they were committed to succeeding in their goals and that it had more 'value' for them because of the community commitment of the project. The conversation about '*cheating the system'* was also interesting. They had noted that they could have just clicked for points because no one was checking. However, they felt a sense of ownership because the tasks they had set themselves had meaning and purpose for them.

The tangibleness of the device as part of the connection seemed to emerge through this shared commitment, the aesthetics of engagement and valuing the shared goal. There were elements of community bonding emerging and a notion of an extended identity through this tangible experience. The experience, according to the students provided a means to express and share ideas. They felt it was a creative process and they had been able to use the process of creating and sharing ideas in other projects.

VI. Conclusions and further work

Although the results are positive and engagement with the design of creating a simple wearable IoT application was well received, the study has a number of limitations. The wearable challenge App was a small study with only six participants. The number of participants is low for two reasons, first because currently it requires much intense, personalised guidance and instruction to develop a BBC micro:bit device to support pairing with the mobile and to enable an automated mobile message application on the mobile phone, as it is still relatively new[13]. Second, these novel applications are being developed with a young audience with less well developed technical skills, even though participants are highly creative and proactive. As help and support aids are further developed and become available it should be more feasible to undertake large groups of participants without a proportional increase in human instructors.

The study was also short, in part because the communication system incurred a high maintenance cost. Again, as the device matures, operational applications should be easier to run for longer. Some of the complexities in developing even a small application would limit this possibility because to develop further experiences would require the students, in this case, to be able to update the Android WAN to WBAN gateway application themselves. The implementation was tailored for the group work as the phone numbers were 'hard coded' and so checking and verification wasn't needed. There are, of course, potential cost model challenges to be considered as the application generates texts. While the application is highly curated it does provide some interesting community possibilities for sharable wearable IoT applications.

The core finding of engagement and identity with peers provides some interesting relationships that are encountered with tangibility of the device and aesthetics. The individuation process is part of an adolescent's development where the adolescent is reworking their identity and there is a separation from parents, a group identity and mastery. Mastery over emotions during the process of separation includes the adolescent's shift in the relationship from living with all-powerful omnipotent parents/adults/tutors to autonomy. This includes risk taking by the adolescent. Learning about new things means taking risks and we have to be able to separate from the tutor and books and expression of others and make self-expression and ownership of ideas. This is not always visible in a learning context. However, in the design of the wearable IoT community application the physicality and process provided some opportunities for self-expression.

This is an important area to be further investigated of where IoT in general has the potential to offer creativity and diversity through new applications for community engagement. Building on from this research the next steps could be to explore and to understand more about the affordances of IoT in creative design, interaction and connectivity that is community centred. Future work could also investigate how such a maker community evolves over time.

There are other applications that can be developed supporting many to many sharable wearables and how to deal with conflicting states that are shared. This community approach offers other ways of voting and connecting with groups both social and formal. In terms of education, it is possible that learning about and experimenting with STEM through new types of IoT applications provides a broader participation and engagement context..

To develop this community centred investigation requires addressing how to scale up such an experience and how to enable richer functionality. There is also a need to develop appropriate privacy models [31]. Privacy brokering has been shown to be an effective method for use in decentralized systems such as market-places and communities [32]. The potential for using the Semantic Web to more richly interconnected and shared IoT devices based upon meaning although hugely beneficial also requires investigation [33] but this brings its own added challenges for IoT use such as the need to harmonise different semantic models [34] and the need to deal with the computation costs involved [35].

[13] New for the micro:bit and building an Android application; using and configuring BLE is not a beginner task.

ACKNOWLEDGMENT

We would like to thank Martin Woolley, Technical Programme Manger, Bluetooth SIG[14] who provided technical help, support and initial BLE (Bluetooth Low Energy) Android programs and specifications for the BBC micro:bit, without which getting this study started wouldn't have been possible.

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