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WEARABLE, TEACHABLE AND LEARNABLE INTERNET OF THINGS: THE MICRO BIT PROJECT

Abstract— This paper reports on research undertaken as part of piloting early versions of the BBC Micro:bit. The research provides theoretical background to the scaling-up challenge and the pedagogical considerations and framework in which to investigate these challenges when learning about Internet of Things. This includes a synthesis of diverse research that substantiates further the broadening participation of teaching and learning about CS and engineering that can benefit from learning about IoT. The paper examines the key literature findings about scaling up and insight into the process of implementing a scaling-up strategy and the potential of learning about a ‘very basic’ Internet of Things device.

Index Terms—Computer Science Education, Learning about Internet of Things, STEM, Application of informal learning framework, pilot study.

The research and pilot studies were supported by BBC, UK.

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INTRODUCTION

The Internet of Things [28] over the last few years has become mainstream capturing innovative industries and economists globally. We do not yet know the full impact this will have on our everyday lives. However, these ever present interactive, to a degree smart objects that literally can and do connect ‘our heartbeat’ to the Internet are changing the world we live in. Although, Poslad [21] does not call the applications and designs ‘Internet of Things’ but describes a ubiquitous computing, many of his ideas and applications resonate with IoT’s wearable and connected sensor driven, data enriched experiences. Both Gouaïch [10] and Poslad [21] refer to this idea of ubiquitous information and communication technologies and devices ‘existing everywhere’. These technologies and devices form part of highly distributed systems connected and networked that are mobile, wireless, active in response making ‘almost’ seamless information and tasks available everywhere and supporting intuitive human usage [16].

The Internet of Things is taking us far beyond the semantic web and mobile computing to the next generation of computer science, engineering and design providing theoretical and practical underpinnings of ubiquitous everywhere and anytime embedded experience for everyone ([11]). Given the rapid rate of growth and impact of computer science technologies and the clear disruption and potential of IoT, how do we empower our young students of today to take ownership of their learning about IoT and creatively design and create innovative applications?

To address this challenge, the BBC with a large multidisciplinary set of partners launched the Micro Bit project¹ to provide a teachable, learnable and wearable Internet of Things in March (2015).

This paper reports on research undertaken as part of piloting early versions of the BBC Micro:bit.. The research provides a theoretical background to the scaling-up challenge and the pedagogical considerations and framework in which to investigate these challenges when learning about Internet of Things. This includes a synthesis of diverse research that substantiates further the broadening participation of teaching and learning about CS and engineering that can benefit from learning about Internet of Things. This contribution brings an observation account of how Internet of Things benefits from the formal philosophy of constructionism through the relationship and similarities with

¹ http://www.bbc.co.uk/mediacentre/mediapacks/makeitdigital/micro-bit
informal maker community learning experiences and design-based learning experiences in the literature. The findings that emerge both from the literature and the BBC pilot of creativity, engagement and ownership provide some initial evidence of supporting sustainability. The paper examines the key literature findings about scaling up and insight into the process of implementing a scaling-up strategy, the impact of learning about a ‘very basic’ Internet of Things (the pilot BBC Micro:bit) and the potential power of tangible ownership and the creativity of learning through making, which is the very essence and potential of learning about IoT in formal and informal settings.

THEORETICAL BACKGROUND

Often education research aims to identify programs that can be scaled up to improve system-level outcomes. However, the implementation of the programs frequently differ from setting to setting and scaling-up has proved challenging [19]. Rowan’s ‘ecology of school improvement’ [24] highlights the diverse engagements and complexity of developing a sustainable process of program-based intervention for supporting change.

Taking these research findings and similar studies that focused on a different domain for scaling-up [30][13] (applying technology to the improvement of mathematical learning at scale) the Micro Bit project researched existing and emerging theories that (1) gave a sufficient support for a diverse, complex and interconnected set of resources of people (including teachers, students, parents, communities, industrial experts etc.) curriculum details, formal and informal learning experiences, digital and physical artifacts and assets, and (2) could enable the re-use of the research findings. This paper provides the first steps towards a framework to bridge a core set of informal and formal settings of learning about the Internet of Things as part of the computer science curriculum taking into account the challenge of scaling-up.

In teaching and learning about computer science and the interdisciplinary newness of learning about IoT in this context means bringing together theoretical understanding from a range of backgrounds. The Micro Bit project is the first of its kind attempting to scale up delivery of both hardware and software resources at national level targeted for students aged 11-12.

The rational for focusing on learning about the Internet of Things is that it could actively encourage creativity in problem solving and engagement with a broader audience by supporting multiple learning entry points. Here the project could not draw directly from IoT for this evidence but needed to consider related research from the Maker Movement [12].

Paul Blikstein [6] examined the hands-on experience of engineering design and creation through an example of maker movement (FabLabs) and the importance to education in STEM and other domains through such experiences. Like many others Blikstein connects the learning process of design and making to Papert’s Constructionism [17] [18]. Blikstein also states, this in turn builds upon Piaget’s Constructivism [20] claiming the construction of knowledge happens remarkably well when students build, make, and publicly share objects.

This concept of learning and creativity through making is not new and it is clear that learning about the Internet of Things has many synergies with these maker movements [26]. However, unpicking certain aspects of the maker movement and related approaches, such as, design projects [23] to identify the pedagogical features explicitly that align with capacity building for sustained change [19] is complex. This capacity building can benefit from the findings of broadening participation work [25] that provides educational design strategies to potentially facilitate bridging the gender gap and for broadening access to young people, which relates strongly to the findings of the report from the American Association of University of Women[1].

To widen participation the researchers suggest focusing on themes rather than challenges to provide a broader potential of authenticity in engagement for the learner [29]. Essentially, the learner is more likely to engage with an activity if it has meaning/value to the learner. The combination of art and engineering materials provides a further entry point for learners to participate. Encouraging story telling into the activities enables a social construction and this role-play activity through a narrative provides a creative setting of externalizing one’s thinking to share with others. Again, strengthening the authenticity of the learning experience and ownership. Finally, the approach suggests the role of exhibitions rather than competitions being more inclusive. This final feature of presenting in such a setting supports diversity and inclusion and validation/recognition of the learner’s contribution.

So while this provides some of the general pedagogical constructs for designing resources that can facilitate broader engagement and participation for the learners it does not address building teachers’ capacity and more broadly community engagement for scaling nationally. The process of “instrumentalisation” that of taking ownership of materials and adopting and adapting and repurposing the artifacts into ‘instruments’ was the capacity building approach of teachers for scaling up by the Cornerstone Mathematics project [13]. Their insight into capacity building was informed by the design-based implementation research [19]. Their meaning of “instrumentalisation” is the process by which “teachers
and students come to use the potential of the digital artifact for their own purposes” (pg 1058). This process of authentic learning experience is not just for the students but the teachers as well. It is a process of “learning with” that provides ownership by the learners [27] and includes increased ownership by teachers [9]. However, while Cornerstone Mathematics research gives insights into scaling-up and provides some considerations for interdisciplinary learning (mathematics and technology) it does not need deal with the diversity and multidiscipline context of learning about the Internet of Things. It also does not concern itself with informal learning community context as it is concerned with the classroom context.

While bringing in similar design considerations of resources through pedagogical mapping to the curriculum thus enabling schools and communities broader participation and inclusion [7] there is also significant developments in the maker communities that shows promising results. A Tinkering Learning Dimensions Framework [5] developed by a ‘maker community’ is based on the principals of design-based implementation research method. The process of design used a jointly constructed technique to include both the researchers and the practitioners in the process of sharing their inquiry investigations and analysis of their findings. The jointly constructed knowledge provides the right conditions to facilitate ownership of the artifacts. Although, not explicitly targeted at evaluating the potential of learning about the Internet of Things the framework captures many of the learning indicators that the Micro Bit project considered key. However, it does not include capacity building through the pedagogical value of ‘sustained ownership’ by including for example a process of “instrumentalisation” which is essential to this project given the scale of delivery.

LITERATURE

In developing an education program for scaling-up and sustained ownership requires not only the availability of appropriate computer programming environments. There should also be appropriately designed learning activities and supporting material that have been applied and verified and can be easily integrated in every day school practice by well informed and prepared teachers [9]. This resonates with findings of teaching computer science to first year undergraduates at Middlesex University. The diverse knowledge and backgrounds of the students provided the context to re-think the pedagogical approach to delivering first year undergraduate computer science course [3]. They teach a combination of robotics and programming which provides the students with their own ‘maker lab’ experience (authentic and ownership of the learning experience). They see first hand the relationship between computer science and engineering. The pathways and developments are self-driven by the students. The learning outcomes and understanding for each stage is well designed and the students can develop at his/her own pace. The results have demonstrated an improvement in the performance of first year students through this innovative pedagogical approach in teaching computer science.

The importance of the findings of this approach is Booth’s research of contextualising computer science of applying the concepts to other domains [4]. This is similar to the experience that Bly [8] discovered in understanding mathematics through developing computer science knowledge. These findings of engagement illustrate the importance of an authentic learning experience that echoes the benefits of contractionist design [17], the process of learning through interaction with and feedback from digital tools that enable students to explore, build, and learn. However, care must be taken to not hide the complexity or trivialize, which is one of the lessons learned from the FabLabs, which Blikstein refers to as the key chain syndrome..Blikstein [6] reporting ‘non-triviality of navigating these new incentive systems was one of the important lessons learned in these early workshops.’[pg 10]

The ‘keychain syndrome” echoes similar concerns of avoiding sheltering children from what Alan Kay calls the “hard fun” of creative learning [14]. However, it is equally important to remember how students and teachers are engaged with experiences as illustrated by the approach in designing widening participation activities [25]. Similar research findings to this can be found in using PREOP [2]. PREOP is a syntax-free robotic programming environment, was designed to positively impact attitudes about computer science with a core goal of increasing persistence in learning. The approach, which includes early success and achievement, was felt to reduce intimidation and have the potential to keep students engaged and reduce drop out. Self-perception by students in developing confidence and engagement with authentic problems were seen as potential characteristics to address the gender divide supporting a more inclusive environment for girls.

Taking into account these findings and those from the previous section, cognitive development consists not of an accumulation of facts, but of a series of progressive reorganizations of knowledge driven by the student’s active engagements with physical, tangible and social environments as articulated by Piaget and Inhelder [20] and Vygotsky [31]. These findings provide compelling evidence of broadening participation and engagement in CS and engineering through a hands-on experience that maybe provided when learning about IoT. Although the ‘tangible’ device is a core resource in
the learning process, it is also clear that design process of the teaching and learning material, as well as, the artifacts generated are set in a context that cultivates ownership.

**DESIGN PROCESS AND METHODOLOGY**

The design process and methodology builds on the theoretical background and literature around learning through making or by design.

Table 1 is a course synthesis of bringing the theoretical background and literature to contextualize the potential relationship between broadening participation through pedagogical concerns of engagement [25] and the learning dimensions [5] from the maker community into focus. The broadening participation approach sets out the broad pedagogical approach of a project-based/design-based approach, which aligns with the maker community’s framework of learning dimensions. However, they each highlight different features that are key to learning about IoT.

<table>
<thead>
<tr>
<th>Broadening participation</th>
<th>Learning Dimensions</th>
<th>Teaching and Learning experience</th>
<th>Affordances of IoT teaching and learning context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theme based</td>
<td>Engagement</td>
<td>Authenticity</td>
<td>Affords multiple entry points</td>
</tr>
<tr>
<td>Art and engineering</td>
<td>Initiative and intentionality</td>
<td>Diversity to adapt in meaningful ways</td>
<td>Extensible, wearable and connects to the Internet</td>
</tr>
<tr>
<td>Narrative</td>
<td>Social scaffolding</td>
<td>Ownership through sharing experience</td>
<td>Tangible device supports ‘talking point’ and collaboration</td>
</tr>
<tr>
<td>Exhibition</td>
<td>Development of understanding</td>
<td>Validation and value through articulating experience and community engagement</td>
<td>Portability and ease to demonstrate interactivity of devices</td>
</tr>
</tbody>
</table>

**TABLE 1**

Summary of key theoretical concepts and learning indicators for teaching and learning experiences through the affordances of IoT

In reviewing the literature for scaling-up a core requirement is demonstrating ownership of the resources, which is exhibited by teachers and learners through transforming these resources and using them for their own purpose. The learning dimension of engagement is facilitated by an authentic learning experience, that is, it has meaning to the learner. Using a theme-based approach enables the learners to bring their own experience and motivation. The context offered when learning about IoT is that it supports multiple representations for the learners, i.e. it is a diverse context of designing, creating through both software and hardware including communication, networking and testing.

There is a potential symbiotic relationship between an IoT device due to its tangible and potentially wearable properties that strengthens the ownership and identity potential. This is especially true when set in the context of including art and engineering in designing and creating solutions. This reflects the findings of disruptive designs in e-textiles to support inclusion [15]. Both findings from [1] and [15] consider this social creative engagement to bring community value as core context of widening participation. The focus was less on the technical details and more focused on the problem solving and community contribution.

The following sections takes into account these broad requirements outline in Table 1 to determine the learning about IoT potential in the design of the initial physical device, software platform, networking and basic sensor capabilities, teaching and learning resources and the evaluation process.

**PILOT SPECIFICATION OF BBC MICRO:BIT AND SOFTWARE**

The device was designed to support (a) Core hardware elements, (b) Simple and advanced expansion capabilities and (c) 3 modes: Bootloader mode, run mode, tethered mode. Client side loader had Bootloader functionality and Tethered mode functionality. The programming of the device was through a simple web browser and included a hardware simulator.

The early pilot supported LED grid and two buttons to be used to test some of the initial learning potential and pitfalls. The physical device was programmable through a blockly language, similar to the scratch programming language (see figure 1). Taking into account the curriculum requirements for secondary school children the environment included the progression to a text-based language (python).
The programming environment enabled community sharing of programs so that students could build on each other’s work providing a community engagement experience.

Fig. 1 Prototype environment to used with teachers and students during the pilot study.

The pilot study tested in the classroom learning, community learning and engagement and the potential to scale and nationally to support a diverse education sector. The physical device as IoT functionality was very limited in these initial pilot tests and in the broader everyday community of IoT it would not be considered interesting. However, from Education perspective both formally and informally it provided sufficient learning about IoT value to test out if there was potential engagement in classroom with teachers and learners. Learning about IoT is more than the specifics of the device. There are many IoT devices but to work in a learning context, especially to broaden participation and reduce gender bias then certain less obvious value of learning about IoT factors were potentially critical as examined by related research in the previous sections and conceptually framed in Table 1. Table 1 provides the high level framework used to evaluate the pilot studies and determine factors of success or barriers to engagement and ownership with teaching and learning about IoT.

**FRAMEWORK USED FOR EVALUATING THE TEACHING AND LEARNING EXPERIENCE**

The pilot study included a sample of 14 schools providing a diverse range of context. Both primary and secondary schools were represented with the aim to determine whether to target the age group between 9 and 10 or the aged group between 11 and 12 to receive a Micro:bit. This included many considerations such as: levels of support that children would need and teachers’ readiness for the curriculum.

Information about the project and consent forms and communications to parents and children where sent out before the start of the study. The project followed a very strict and careful process of ethical approval as set out by the BBC. The data analyzed included over 3 hours of video recordings of the interviews, over 600 completed surveys and 1000 artifacts designed, created and shared during the study and observational notes. There were also informal conversations with researchers and industrial participants (data collection through emails and interview notes). This was considered a useful way of validating research findings through triangulation [28]. This procedure yielded a comprehensive set of data along with documents such as programmes and pupils’ narratives of explanations (video recordings and survey data) and prototypes. Three lessons about the device were given in school and the children were given the device to take home after lesson one. Surveys were used collect both quantitative and qualitative data from teachers, students and parents.

A benchmark of Students’ knowledge about programming before starting the pilot indicated they were new to programming. This provided an important investigation into engagement with beginners to experiment with the device.

The evaluation using the maker community framework [5] combined with the context of the project requirements of the pilot study was to understand the potential of learning about IoT through the Micro Bit project. The procedure of grounded theory was followed, using an open coding procedure where pupils’ responses and articulations were placed into conceptual sub-categories identified by the learning dimensions framework. The analysis of data was further categorized to the broader conceptual framework provided in Table 1 to examine where widening participation potential existed and aspects of supporting scaling-up.

Part of the evaluation was to see the potential to support the incremental uncovering of learning about IoT. What affordances of the IoT device are key in fostering experiential learning about IoT in young students? Which age group might be best suited? What needs to be in place to move from a pilot to realizable learning about the diversity of IoT at a national level?
### TABLE 2
Summary of the learning dimensions framework (see Bevan et al. [5] for the complete table and details) and Summary of the Findings

<table>
<thead>
<tr>
<th>Learning Dimension</th>
<th>Indicator</th>
<th>Description</th>
<th>Evidence from the data</th>
</tr>
</thead>
</table>
| **Engagement**     | Showing positive disposition and reactions towards coding and the bug:  
- control  
- confidence  
- fun  
- adventure | Learners play, make, explore, repeat an activity several times  
Learners show emotions, such as joy, pride, frustration. Learners remain after they appear finished and start something new. | Learners appreciated an immediate outcome which boosted their confidence:  
- “the first time I had a go I got it to work”  
- “[one good thing] when I wrote 5 4 3 2 1 blast off”  
- “I loved seeing the pattern on the computer”  
- “It was fun to make sentences”  
Over 95% of students demonstrated engagement. |
| **Initiative**     | Setting one’s goals  
Going beyond the set exercise | - “It was extremely enjoyable to use my creativity and ideas to make my own light up handywork and the fact I could just write whatever I wished”  
Over 68% year 7 students responded in this way.  
Links to developing persistence. | |
| **Feedback**       | Learners give and receive feedback from peers  
Active & innovative | Students shared learning experiences & ideas. Key data observer through programs developed & qualitative data | |

| Social scaffolding | Developing persistence  
Learners overcome frustrations and persist to a solution | response to feedback from surveys.  
- “It is more fun figuring it out by yourself”  
Over 68% year 7 students responded in this way.  
Links to setting one’s goals an important pedagogical point. |
| Social scaffolding | Requesting help or offering to solve problems | Both novices and experts share ideas  
- “I liked the idea that you could see other people’s creations then copy them to make your own and change it. I find it useful”  
- “I enjoyed playing on other people’s games as the bug is wearable”  
It was a collaborative experience & students built on each other’s ideas. Over 91% learners indicated this through the programs they developed and in the interviews.  
Learners demonstrated own work, shared and exchanged ideas & taught others at home. |
| Social scaffolding | Inspiring new ideas | Learners remix ideas |
| Social scaffolding | Physically connecting to other’s work | Learners build on the work of others |

| Development of understanding | Expressing realization through affect or utterances | Students show excitement expressing a realization  
They claim to newly make sense of something  
The website illustrated students creating, sharing and re-mixing their creations.  
Evidence of 84% of remix out of 350 programs analyzed. |
| Development of understanding | Offering explanation strategies, tools | Learners refine explanation through re-testing  
Interviews and observations provided evidence of offering explanations, e.g. linking to other |
Table 2 provides a summary of some of the findings that emerged from the analysis of the data through the learning dimensions framework. One key observation was the engagement of students with the learning about the device. The learners showed excitement about the device, demonstrating interest in what it can do or what they can do with it, and thereby they engaged with it creating their own goals and going beyond the sessions’ intentions. They created mash-ups of the designs and programs that were available for sharing and were keen to design and build their own ideas: “I liked the idea that you could see other people’s creations then copy them to make your own and change it. I find it useful” (age 11-12). The learners demonstrated a key confidence about learning about computer science. There were many positive developments observed during their engagement with the device and the resources, such as persistence leading towards satisfaction: “being patient then leaning back to watch it light up” (age 9-10) and “It is fun to see your program on the bug as it gives a sense of achievement” (age 11-12).

There was a strong evidence of social engagement and collaboration “I liked telling my friends how to work the bug” and understanding that outcomes are open-ended and the microbit offers scope for creativity and free experimentation: “It was extremely enjoyable to use my creativity and ideas to make my own light up handywork and the fact I could just write whatever I wished”.

There were challenges, as the pilot devices were not robust and at times the programs wouldn’t run on the device. Sometimes students forgot when using someone else’s program to create their own to save their programs and would lose all their work. Thus it was clear that a more robust environment was needed.

Considering the broader conceptual framework to determine widening participation the data was analyzed further (see table 3) with respect to RQ1: What affordances of the IoT device are key in fostering experiential learning about IoT in young students?

From the surveys, data and observations it was clearly identified that the students engaged with the device and the software. Bringing in the evidence from the literature about broadening participation the wearable and portable features becomes significant. The wearable feature implies an aesthetic quality that is often more valued in humanities, design and art rather than STEM. The wearable aspect provides potential connection to textiles and arts. This can assist to foster engagement to a broader audience, especially bridging the gender gap. The data analyzed did not definitively state that because the device was wearable it was more appealing to girls. However, what was observed was that girls as well as boys engaged equally and were curious about the device. It was appealing. Many of the students fascination was with the size of the device and what they could make it do. Device easily bridged a sense of diversity by enabling the learner to engage with different perspectives and representations of art and engineering.

TABLE 3
A summary of the findings of the affordances of IoT for teaching and learning.

<table>
<thead>
<tr>
<th>Affordance of IoT</th>
<th>Total references through dialogue, observation, physical action or quantitative data</th>
<th>No. artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching &amp; learning</td>
<td>Remarks about liking the ‘bug’ (device): Positive remarks (375)</td>
<td>554</td>
</tr>
<tr>
<td></td>
<td>Not usually liking programing but liking this approach through use of the device (67)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>76% (238) website interesting, Gender engagement 69% (215) equally appealing to girls and boys 58% (181) found it easy to use</td>
<td>313 responses from the survey after the first lesson</td>
</tr>
<tr>
<td></td>
<td>Remix of programs at school &amp; home (287)</td>
<td>350 programs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Striving to understand</th>
<th>Investigating a behavior in more detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applying knowledge</td>
<td>Interdisciplinary &amp; reflective knowledge making</td>
</tr>
</tbody>
</table>
The portability of ‘fitting in your pocket’ is also appealing and meant students could easily take this device with them. Hence, taking the device home, to another lesson or maker community session was possible. This would mean that the experimentation could potentially continue both inside and outside the classroom.

Leading from RQ1 is considering the data about sustainability and the potential to scale-up: Which age group is best suited? What needs to be in place to move from a pilot to realizable learning about the diversity of IoT at a national level?

As examined in the literature a key condition to foster sustainability and scaling up was “instrumentalisation” when the students and the teachers take ownership and transform the artifacts into their own. For the students this was well demonstrated by expressing their experiences of developing their own programs and ideas. This data was verified by the video analysis of students’ developments and narratives and the programs created and shared online. The collaborative and social/sharing experiences fostered through the learning experiences developed a sense of ownership and confidence. Both of these engagement qualities by the learners are important to foster a potentially sustainable model. The students demonstrated further understanding by helping others with their programs and designs and sharing ideas.

However, there were clear limitations of the pilot device and resources. The pilot device was too bare bones and after a while could not hold the interest for students to develop further. Although students were keen to take the device home and explore this further, the students aged 9 to 10 struggled at home, as there was limited support and the software tool wasn’t so easy to use. The students aged 11 to 12 fared slightly better in this and could mange to navigate and develop some of their ideas away from school. This was a key indicator for a maker community context for the continued learning and interest and for developing further IoT resources. However, the device would need more features and the software environment would need some better student and teacher centered resources and better designed materials would be need to support stronger sense of ownership.

DISCUSSION

The immediate access and feedback to seeing the design to working program that runs on the simulator and then onto the device brought significant engagement and motivation for the students. They could see a direct connection with their programs and what they would do. The programs were not too complex so making the links and connections was possible. However, the basic device came with its limitations, as there is only so much you can do with LEDs and buttons. This to some degree was expected and in fact to build more comprehensive developments for learning about IoT was already in the initial design.

Taking the device home was welcomed by the students but little support at home and some of the complexity of the pilot demonstrated that the older students (11 to 12 year olds) would be better suited to the usage of the device. However, the interest supported the idea of being able to carry the

<table>
<thead>
<tr>
<th>Extensible wearable connects to the Internet, “Art and engineering”</th>
<th>Touching &amp; holding &amp; wearing device</th>
<th>Portability &amp; ease to demonstrate interactivity of device</th>
<th>Tangible device supports talking point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>156 noted with ‘pride’ ‘fascination’ &amp; amazement</td>
<td>Talking and demonstrating with friends and helping others how this works. The device could go with you. Play with each other’s developments.</td>
<td>Imaginations &amp; creativity of what they can do, sharing and what they would like to make (176)</td>
</tr>
<tr>
<td></td>
<td>3 hours Video, 5 observations notes</td>
<td>67 (presenting ideas) Remix 85% (297) Programs potentially developed further at home &amp; helping others.</td>
<td>298 mixed artifacts (videos, surveys &amp; observations)</td>
</tr>
<tr>
<td></td>
<td>“the idea of programming something small that can be taken home automatically allows the promotion of independent learning and the opportunity to be better at it than me” Teachers view (65)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>298 mixed artifacts (videos, surveys &amp; observations)</td>
<td></td>
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<td></td>
<td>156 (interviews/surveys, observations)</td>
<td></td>
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<tr>
<td></td>
<td>313 survey, interviews &amp; comments</td>
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</table>
experimentations with you creating a lab in your pocket or as a wearable indicated the potential value to the learning engagement and ownership. Articulation and narratives about the embedded experience are evident in the students explaining what they did with the device and what they liked about the experience and the confidence of explaining concepts that were new to them through this learning experience.

They could articulate the controlling of the device using a program and through their explanations demonstrate an insight into the design of solutions. Part of the basic ‘bare bones approach’, although not necessarily planned, was that the environment was not too polished. The students could see behind the scenes and understand ‘experiential’ and tangible link to learning about computer science through a basic IoT device. Students expressed their amazement and connection with the fact that the device was so small but you could do many things with this. Although not articulated this links to the idea of ‘a maker lab in your pocket’ that is possible through the potential developments of IoT. While the students knew little about computer science before starting the study their knowledge and understanding had improved. Analysis of the video data illustrated students making connections with mathematics about co-ordinates and understanding programming concepts, such as loops, variable and creating the workings of a program. The initial findings in Table 2 demonstrated the process of learning about IoT in this simple context met at least the minimum of the curriculum learning needs. Also, even with the challenges of the device and software the engagement was possible both for students and teachers. However, there are number of influencing factors/variables to consider, for example when a new learning object is brought into the classroom it is common for ‘short term engagement’ to improve. Also, the attention given to the material and that a popular organization such as the BBC was involved influences such engagements.

**CONCLUSION**

This research contributes through a theoretical background to the scaling-up challenge and the pedagogical considerations and framework in which to investigate these challenges when learning about Internet of Things. This includes a synthesis of diverse research that substantiates further the broadening participation of teaching and learning about CS and engineering that can benefit from learning about Internet of Things. The learning indicators in IoT context can be re-used and applied to other learning experiences both in classroom and out of the classroom. Furthermore, the research synthesis in understanding the core requirements of a framework for scaling-up have been identified and set within the context of formal and informal learning (see table 1 for a summary). This will be developed further for exploring the initial impact of the more advanced devices and resources and in developing further sustainability through ownership of resources. The process helped in identifying that in learning about IoT in a multidisciplinary context required:

- Resources not just the hardware, network and software environment. This is especially important for scaling-up that resources can be owned and repurposed by teachers, students and communities (instrumentalisation);
- Broadening participation through the aesthetic quality of a wearable and portable device;
- The portable ‘lab in your pocket’ and wearable devices so that experimentation could continue anywhere fostering strong ownership;
- Revealing bare bones, such as, visible and tangible learning and including next steps, that is extensibility;
- Collaboration between peers and teachers and designers.
- Thematic approach to engage students and enabling multiple entry points to engaging with teaching and learning resources;

One important link was the physicality of “holding” the device that was very engaging and curiosity over what this ‘small hand held device could do’. What they (the students) could make this do. The evidence of this curiosity was very compelling at this stage. Another interesting result was that girls were as much engaged with the experience as the boys. The context of the approach of pilot to support collaborative exchanges and access to these learning experiences at an early age reflects similar findings[22]: “**majority of girls prefer descriptions of computer science that appeal to their sense of community and ability to “do good” in the world**” (pg. 11).

These were similar findings in the literature in broadening participation and inclusion of resources that were not necessarily technology centered but were creative and/or design-based facilitating inclusive approach and ownership. An important point to consider when teaching and learning about IoT is that the device is a small part of the learning. While it provides a degree of authenticity and tangibility supporting learning engagement, other factors that might seem peripheral, such as, a wearable device or thematic learning context need to be valued if broadening participation is an objective of the experience.
The paper provides the first step to the framework that illustrated broad context for engagement/ownership and the relationship to specific learning dimensions that provides some general insights when learning about such an interdisciplinary area as IoT.

ACKNOWLEDGMENT

The authors would like to acknowledge the significant contributions of Michael Sparks of the specification of the pilot BBC Micro:bit, Fiona Iglesias in leading the engagements with schools and partner collaborations, contributions from BBC research and development team and the 29 Micro Bit Project partners. This publication reflects only the authors’ views and the BBC is not liable for any use that may be made of the information contained therein.

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