Teaching with physical computing devices: the BBC micro:bit initiative

(Authors' version for distribution)

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ABSTRACT

There is a growing interest in small programmable devices that can be used in schools and in extra-curricular contexts to teach computer science. The BBC micro:bit is one such device; through a collaborative venture, micro:bits were recently distributed to every 11-12 year old in the UK. Although the technology itself is often of primary interest, a focus on how teachers can use the technology in the classroom to help students learn is increasingly being drawn out in the literature: this paper adds to that body of work. Having interviewed 15 teachers and 54 students about their use and experience of the micro:bit, we present an analysis of the varied ways in which teachers are using the BBC micro:bit, and note a range of instructional styles. We classify different approaches to teaching with physical computing, identifying teachers who we describe as either inspirers, providers or consumers. Finally we make recommendations for more teacher professional learning opportunities around physical computing. The results of this qualitative study will be useful to teachers and teacher educators wishing to work more effectively with physical computing in the classroom.

CCS CONCEPTS

• Social and professional topics → K-12 education; **• Hardware → Sensor devices and platforms**;

KEYWORDS

BBC micro:bit, computer science education, K-12 education, pedagogy, physical computing

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1 INTRODUCTION

Physical computing is becoming more prevalent in schools with the development of new low-cost devices. One of these is the BBC micro:bit, distributed to students in the UK in 2016. We report here on a study of teachers' and students' perceptions and use of the BBC micro:bit in the initial weeks after its distribution; in doing so we focus on the pedagogical approaches used by teachers, and relate the results to physical computing in general.

For several decades, constructionist toolkits, physical computing devices and robots have been developed for education [6]. Examples of physical computing devices range from programmable robots such as the Bee-Bot [1]; programmable input devices or output devices such as the Makey Makey[2]; educational microcontrollers such as the Crumble[3], electronic and maker kits such as LittleBits[4]; single board computers such as the Raspberry Pi[5] and robotic kits such as Lego Mindstorms[6]. Whereas initially kits and robots were used to facilitate scientific investigations [6], modern devices can be used to teach programming and make computing accessible to a wider range of (young) people. These devices have very different features but all offer the user a physical computing experience which cuts across hardware and software. The resulting process of creatively designing tangible interactive objects or systems using programmable hardware is what is now referred to as *physical computing* [25].

1.1 The BBC micro:bit initiative

The BBC recently led a collaborative venture in the UK to develop a portable and low-cost programmable device – the micro:bit[7]. The micro:bit consortium funded and produced one million devices, enough for every 11-12 year-old in the UK. The BBC micro:bit (see Figure 1) is a pocket-sized codeable physical computing device. It has a built-in display, buttons, motion detection, temperature and

[1]http://www.tts-group.co.uk/bee-bot-rechargeable-floor-robot/1001794.html
[2]http://www.makeymakey.com/
[3]http://www.redfernelectronics.co.uk/crumble/
[4]http://littlebits.cc/
[5]https://www.raspberrypi.org/
[6]https://www.lego.com/en-us/mindstorms
[7]http://microbit.org

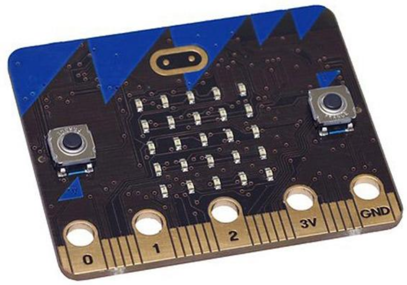

Figure 1: The BBC micro:bit

light sensing, and it supports Bluetooth Low Energy (BLE) wireless communications [1]. It can be programmed via a desktop PC, laptop or tablet running one of several different operating system agnostic web-based programming environments: a Scratch-like block editor, Microsoft's Touch Develop, MicroPython or JavaScript.

The micro:bit initiative was motivated in part by the recent introduction of Computing as a mandatory subject in schools in England, prompted by the Royal Society's 'Shut Down or Restart' report [33]. The Computing curriculum replaced the ICT national curriculum in September 2014, promoting computational thinking and elevating the importance of programming [7].

In 2015, schools with 11-to-12 year olds (Grade 6) were asked to register with the BBC to request one free micro:bit per eligible child plus devices for their CS teachers. In September a small number of prototype micro:bits were made available to partners and selected teachers for trial and training purposes, while a range of teacher training events were offered. From March 2016, later than previously advertised, schools started to receive devices for teacher familiarisation and most schools received their full delivery between April and July 2016. In total nearly a million micro:bit devices were delivered to schools across the UK, generating widespread interest throughout the country and around the world [10].

A website was developed by the BBC and collaborating partners[8] which contained a number of resources, primarily stand-alone activities, for students and teachers to use. These resources are referred to in this paper as the "official" resources.

1.2 Teaching with physical computing devices

Perspectives on teaching physical computing will necessarily depend on the focus of the teaching activity. Researchers have reported on a variety of aspects and outcomes of physical computing including creativity [29], cognitive load [9], student perceptions [15] and motivation [17]. In an earlier paper, we reported on pupils' experiences in terms of usability, creativity, the tangibility of the device and their learning of programming, and reported that the device encouraged students to work creatively and motivated the learners because of its physical nature and novelty [30]. In this paper we turn our attention to the teachers.

The research questions being considered here are:

(1) How is the BBC micro:bit being used in the Computing classroom?
(2) What teaching approaches are adopted by teachers when using physical computing?

2 PEDAGOGY AND PHYSICAL COMPUTING

The advantages of physical computing and the experiences it delivers, particularly in a K-12 computer science (CS) education context, can be drawn out from relevant research. There are a variety of ways proposed to teach with physical computing.

Bricolage, coined in 1966 by Levi-Stauss [32] to describe a problem solving approach using materials at hand, and tinkering, playful trial and error, are terms associated with Papert's constructionsim [34], novices learning to program [26, 31] and the maker movement [20]. Specific resource sets, such as Przybylla's [24] *Interactive Garden* Arduino[9] based microcontroller construction kit, have been developed to support a tinkering approach to learning CS where approaches to problem-solving are not pre-defined. Instead trial and error is encouraged in an imaginative and creative environment with students finding out about CS concepts when they happen upon them. Other research has also highlighted bricolage as an approach and the resultant creative opportunities, linking this to the tangibility of physical computing [29], but studies are generally small-scale with little evidence for whether the approach supports learning.

Others suggest tinkering and bricolage should be just one piece of the pedagogy puzzle, adding more direct teaching of some skills and concepts to supplement trial and error exploration [3]. This blended approach is seen in Kafai et al.'s [16] crafts-oriented Lilypad Arduino[10] curriculum. Instructional techniques and teaching materials include a starter kit to support learning basic skills, expert consultations to help with design work, the drawing of designs, short code concept lessons, reading code activities, debugging projects, starter code examples, remixing design challenges and sample projects. Such *blended approaches* to teaching computing are evidenced in a growing number of non-physical computing programming curricula, some where the more difficult, or all, concepts are explicitly taught [12, 13, 23].

Both free play and structured tasks are included in the TangibleK curriculum [5] which introduces robotics and tangible interfaces to Kindergarten children (aged 5 to 6). Underpinning the curriculum is the Positive Technological Development (PTD) framework [4]. With a sociocultural focus the framework includes assets such as confidence and competence, behaviors such as collaboration ad creativity and classroom practice such as final projects and expertise badges. The resultant curriculum [5] incorporates an engineering design process, an approach to debugging and the teaching of specific programming constructs. The design cycle of *ask, imagine, plan, create, test & improve and share* is used throughout the curriculum. Debugging steps are also explicitly taught to pupils to support their development process. The authors carried out a study with 53 learners using this approach and claim that students were both interested in, and able to learn, many aspects of robotics, programming and computational thinking.

[8]http://microbit.org

[9]https://www.arduino.cc/

[10]https://www.arduino.cc/en/Main/ArduinoBoardLilyPad

In an Australian study, Lego WeDo robot construction lessons were given over a 6-week period with a small cohort of 16 Grade 1-2 pupils following an approach of *'model, explore, evaluate'* [22]. In this study, McDonald & Howell reported development in emergent literacy and numeracy, digital access and basic engineering concepts although they recommended further investigation of the balance between teacher control and pupil autonomy. Jin et al [14] trialled a teaching sequence to reduce the cognitive load that could be induced by physical computing. They trialled a sequence including introduction, program demonstration, learner guided activities with support from the teacher and post discussion. The authors concluded that cognitive load was managed by their approach and content knowledge increased; however there was no control group used [14]. Whether cognitive load demands are the same in microcontroller projects as in robotics activities is an area for further investigation.

As well as engineering principles informing approaches to teaching physical computing, Schulz & Pinker [27] have suggested consideration of a problem solving approach used in science. Informed by scientific inquiry, they propose a physical computing model (PhC) of four phases: *preparation*: formulate a goal, plan an attempt, anticipate and share problems, divide the goal into subtasks; *implementation*: choose input/output and processing, coding; *performance*: run the program, observe the outcomes; *evaluation*: merge outcomes and program part, identify the problem, decision to change one variable, divide the goal into sub-tasks, restart (a part of) the loop, identify uncertainties and sources of error. A pilot study (n=15) found that the model could serve to help evaluate students physical computing activity, although some students found implementing their ideas difficult. Students also found identifying, testing and fixing problems challenging, with students often ignoring outcomes if they were not what they expected, using a trial and error approach and changing more than one aspect at a time. Both the PTD and PhC models suggest sharing the problem-solving approach with learners; the PHC model suggests decomposing a problem into parts – which could be seen to manage cognitive load [35].

Another pedagogical approach that can be adopted for physical computing is Use-Modify-Create [19], a teaching framework for supporting progression in learning to program. Here learners move along a continuum from using programs made by someone else to finally creating their own programs. Between these points learners modify work made by someone else so that the modified material becomes 'theirs'. Once students start to create their own programs they employ an iterative process of refine, test, and analyse. In a similar vein, Fuller et al [11] discuss a 2-dimensional learning taxonomy where students could reach the stage of creating their own projects via a number of routes but where both theoretical and practical understanding must be facilitated - this equally applies to physical computing.

Most of the approaches described above, even where the theoretical framework is not explicitly discussed, take what can be described as a constructivist standpoint [2]; in addition, the pedagogy adopted by teachers, particularly with a new kind of technology, may relate to teachers' beliefs and in particular, their expectancy of success [36], although a study of teacher beliefs is outside the scope of this paper.

There remains a need for empirical research to inform choices of what devices to use, appropriate pedagogical strategies, and the effectiveness of these approaches. In this study we were interested in the balance between open-ended projects and more structured activities that teachers used, and in particular, drawing on [11] and [19] to examine whether teachers were using a continuum of production from, at one end, following a tutorial, to at the other end, creating their own project, and the degree of scaffolding being incorporated into physical computing lessons.

3 THE STUDY

The study was designed around interviews and focus groups to gather in-depth feedback from teachers and students. Interviews were held with 15 teachers, and 8 focus groups took place totaling 54 students in Grades 6-8 (in England, these students are referred to as Years 7-9). Each interview lasted approximately 30-35 minutes and each focus group lasted 20-30 minutes. All interviews and focus groups took place face-to-face.

3.1 Data collection

Teachers were recruited by mailshots, advertisements within relevant communities and through the use of social media. There was significant interest, but with the delay of arrival of the micro:bits some of the teachers who had previously shown a willingness to participate had to withdraw as their micro:bits arrived too late to use in school. Micro:bits were originally due to be delivered to schools in October 2015; finally the devices were delivered to school from April to June 2016, towards the end of the school year. Due to this late arrival of hardware our sampling process was not representative.

Interviews were carried out by four researchers, after interview and focus group questions were identified and discussed by the group. Interviews were audio-recorded and transcribed by a commercial transcription service. Ethics procedures were strictly adhered to: consent was obtained from all participants, including parental consent for students. The interview schedule was piloted with one school prior to being used for all other interviews. Consent forms were used, and interview schedules used to ensure a common approach to questioning. Audio recordings were made, and audio data stored securely and destroyed once the transcription had taken place.

There were two different interview schedules. The first was for student focus groups and centred around five areas of questioning: (1) imagination and creativity, (2) learning and knowledge, (3) programming and the relationship to physical computing, (4) cross-curricular implications and (5) technology and the future. The teachers' interview schedule included questions around four themes: (1) general information about sessions with the microbit, (2) attitudes and motivation, (3) learning and skills and (4) connections to other subject areas.

3.2 Participants

The 15 participant teachers were varied in their experience, with one trainee and another early on in her career, and at the other extreme, four longstanding Computing At School (CAS) Master

Table 1: Schools included in research

School/Teacher	Mixed/boys/girls	Teacher
A/Amjad	boys	
B/Billy	girls	
C/Carlos	mixed school	MT
D/Dawn	mixed school	
E/Elizabeth	boys	New
F/Frans	mixed school	
G/Gerald	mixed school	
H/Harry	mixed school	MT
I/Isaac	girls	MT
J/Jane	mixed school	Trainee
K/Kamil	mixed school	
L/Luis	mixed school	
M/Morgan	mixed school	New
N/Nick	mixed school	MT
O/Oliver	boys	
Key:	MT = CAS Master Teacher	

Teachers[11]. Four teachers were from independent (private) schools, and there was a range of mixed and single-sex schools included (see Table 1).

The teachers and schools who participated had volunteered primarily because they were interested in using the micro:bit as early as possible; we had only sufficient volunteers to carry out the interviews and were not able to be selective. Nevertheless, the volunteer pool provided a range of experiences including use of the micro:bit in class and in extra-curricular activities.

Teachers follow a national curriculum for computing which, at this stage of education, includes the following two statements:

- *"Pupils should be taught to use 2 or more programming languages, at least one of which is textual, to solve a variety of computational problems; make appropriate use of data structures . . . ; design and develop modular programs that use procedures or functions"*
- *"Pupils should be taught to understand the hardware and software components that make up computer systems, and how they communicate with one another and with other systems"* [8]

These curriculum statements provide the context for the study and the concepts that the teachers were introducing with the use of the BBC micro:bit.

3.3 Data Analysis

The data was analysed within the QDA software NVivo to which all researchers had access. Initial reading of the data revealed themes that were considered against expectations based on knowledge of the field. This constitutes an inductive-deductive process; reading the data with an open mind about what can be understood from the conversations with teachers and students also draws on knowledge of key themes in physical computing in the literature.

Themes were constructed further through an inductive process of grouping student and teacher codes by looking for similarities and associations, following qualitative text analysis procedures [18, 21]. The overall objective at this point was to create main themes which would lead to a structure for reporting. After this initial analysis of the data, coded statements for each code and code group were reported and reviewed by the research team; common themes and patterns were identified, new codes created, and codes merged and split as required. This process was repeated iteratively to ensure rigour and reliability in the data analysis phase of the project. In the next section we detail the findings of the project.

4 FINDINGS

Teachers were free to carry out activities of their choice with the micro:bit, although officially-produced activities were available. Table 2 shows the amount and type of activity carried out by each teacher at the time of the interview. There was considerable variation in the reported use of micro:bits in class amongst the teachers we interviewed.

Students' perceptions of the micro:bit have been reported elsewhere [30] and we report here primarily findings from the teacher interviews. From this data there were particular themes emerging from the thematic analysis: most common were themes around teachers' emotional response to the micro:bit, pedagogical issues, tangibility of the device, differentiation, logistical issues, wider skills being developed and cross-curricular opportunities. We report on the data in relation to five areas:

- Classroom activities
- Teaching with the micro:bit
- Student engagement
- Learning outcomes and assessment
- Practical issues

4.1 Classroom activities

Teachers used a variety of classroom activities. For example, Carlos developed his own teaching scheme based on algorithmic thinking, followed by a project, and Dawn used the official micro:bit website accompanied by a series of differentiated worksheets that she developed. Seven teachers created completely new resources, while the other eight teachers used resources from either the official website or other resources made available. Six teachers used additional components which can be added on to the micro:bit, and six teachers used additional components such as speakers which can be connected to the micro:bit. Some teachers worked hard at developing activities which emphasised the physicality of the applications and use additional components, such as attached sensors using crocodile clips, to enhance the functionality of the micro:bit:

> *"We've done things like the temperature sensors, . . . a virtual pet which would respond to different stimuli, and that people would have to interact with . . . which will smile when it's happy. And then after a random time, it might get hungry, and you might need to press a button to feed it. Or, if the environment is too cold or too hot, it can show a grumpy face."* (Carlos)

One of the four CAS Master Teachers in our sample created his own 6-week teaching sequence:

[11] Computing At School (CAS) Master Teachers (MT) are expert teachers, selected for their depth of experience and aptitude for training and supporting their colleagues [28]

Table 2: Summary of teachers and activities

Teacher	Class/Club	Website	Other	Own resources	Add-ons	Sessions
Amjad	Class	Yes	No	No	Yes	7-8 lessons
Billy	Class	Yes	No	No	No	6-7 lessons
Carlos	Class	Yes	No	Yes	Yes	5-6 lessons
Dawn	Class	Yes	No	Yes	No	3-5 lessons
Elizabeth	Class	No	Yes	Yes	No	5 lessons
Frans	Club	Yes	No	No	No	8 sessions in after-school clubs
Gerald	Club	Yes	No	No	No	Series of lunchtime clubs
Harry	Class	Yes	No	Yes	No	4 lessons with year 7
Isaac	Class	No	Yes	Yes	Yes	6 lessons
Jane	Class	Yes	No	No	No	12-14 lessons
Kamil	Class	No	Yes	No	Yes	4–12 lessons
Luis	Class	No	Yes	Yes	No	5-7 lessons with 8 groups of year 7
Morgan	Class	Yes	No	No	No	2 lessons
Nick	Class	No	No	Yes	Yes	5 lessons
Oliver	Class	Yes	Yes	No	Yes	Launch day + lessons

> *"We've got a scheme of work with six lessons and I've been through five lessons of that with my Year 7s … it's been very positive, a good experience for all, [students are] very enthusiastic.… [I have created] a set of simple things that we work through, introducing them to basic programming concepts … then building up to them programming music and playing with crocodile clips on the earphones."* (Nick).

Another school had assembled a kit of additional components to use with the micro:bit that they felt would assist other teachers:

> *"An inventing kit, and it's got a motor driver, IC microchipped 2X DC electric motors. One electronic prototyping board, on 30cm black tinned wire, a yellow wire, a red wire, a battery holder, and a pulley. And some crimp sockets as well for the connections … Little, kind of goodie box."* (Carlos).

Another teacher has developed an online environment with tasks alongside the micro:bit for his students to use:

> *"I created it myself, but I use it for the kids. And it is really quite effective. It gives a lot of quick feedback … there's a big picture of the micro:bit on the left hand side. And then on the right hand side there's like tasks, so there's different activities … you've got an access section, where you've got the tasks. Each one given a task to do: a piece of collaborative writing, some explanation about what's happening."* (Luis).

Harry described how he built a simulator for Micro Python on his own website for his students to use; this was then shared with other teachers and used widely:

> *"[the tool is] publicly accessible online… you see it on your screen, you can share it, you can run it, you can see the error messages … I wouldn't say it's the perfect resource but it's certainly made the process of developing Python easier for students."* (Harry).

Other teachers were less confident about developing their own activities and materials. Six teachers focused on the ready-made tutorials provided on the official website, which were small exercises followed by challenges.

> *"Mostly we have used the BBC website … It has got demo and then activity and challenges. And if the boys are good, then they moved on to the next activity. But we always start with one activity and then move on to the next … "* (Amjad).

4.2 Teaching with the micro:bit

In this section, we look at the approaches taken by teachers and how they supported students' learning. Here a teacher describes an activity around programming a micro:bit to teach the concept of sequence in programming:

> *I jumbled it up and then take the lines of code that I've given them. Put it into microbit and see if they actually get I've lost my phone, bit of a wait, then see a sad face … So it's trying to relate right from the word go to everyday life and something they would recognise so it actually made sense.* (Isaac)

Here we can see that the teacher is relating the task to real life (losing a phone) and also scaffolding the exercises so that student have to work with jumbled up lines of code and sort them into an order that works. This helps to keep the students' motivation. The same teacher described a task where the students had to research a visit to a museum via public transport and then devised programs for the micro:bit to assist the journey, for example, a buzzer by the train doors, and LEDs flashing to say the name of the next stop. In this way the micro:bit was being used in a way that the children could see its usefulness as a device, as well as a tool for learning to program.

There were teachers who allowed students to use their imagination and explore the capabilities of the micro:bit. In this type of teaching, students were set goals to work towards, then got on with activities on their own, or in pairs or groups:

> *"I give them all the information, all the goals, and then they direct themselves. I give them feedback along the way. I think that could also be quite a nice way to take things forward with this. So, by them being armed with a wealth of resources, and the motivation for, ah, this is what I want to achieve."* (Carlos)

Some, but not all, teachers are very aware of differentiation and have adapted resources to ensure that their students are all supported appropriately:

> *"First lesson we all did the same task differentiated and then from lessons onward I've taken activities, had a look at them myself; which are the easiest ones, which are the harder ones and I've split them into which are the ones the students then do and can attempt."* (Dawn).

4.3 Student engagement

Every teacher interviewed mentioned that the children enjoyed using the micro:bits, often with a high degree of enthusiasm or excitement. Positive emotions were coded under different themes, including anticipation, ease of programming, and making something work. Eight teachers mentioned anticipation, six ease of programming and 10 the importance of getting something to work.

Amjad described the fact that the students were *"really excited and feel quite cherished that they've been chosen"*. Along the same theme, Carlos reported that his students were *"jumping for joy"* when the micro:bits arrived. Another teacher linked enthusiasm with motivation, and went on to associate this with learning:

> *"They're on fire with it, you know, of the four classes we teach between us I don't have any problem with motivation ... It was incredible the enthusiasm that it engendered. And we've seen all these fads for kids and I just hope that from the fad we'll get some real learning and we'll get some traction."* (Oliver)

More than one teacher also highlighted the fact that the device had been well received by less able students:

> *"In terms of a classroom then, what we've found so far, is that it really has motivated most of less able students to have an interest in computers, you know, in programming."* (Frans).

The teacher at School A, an independent boys' school, also suggested that the device may not be so appealing to the gifted and talented (G&T) children because it is not as high tech as other devices or is not seen as robust. This sentiment of the device not being 'exciting' for all pupils was echoed by Jane who reported that two students opted not to take them home because they felt that they had exhausted the potential of the micro:bit already. Another teacher felt that the increased motivation and interest might wane with time:

> *"We've had a few kids who really took it to heart early and are now very good at it... Their interest in that will be transient."*(Kamil).

The notion of *physicality and tangibility* came up very frequently in our analysis of the teacher interview data.

> *"So there's an incentive built into physical devices so it builds on that sort of experience I had before that physical devices do encourage and engage students to actually solve a problem. They [Students] make a problem and if it's their problem they solve it."* (Isaac).

Overall, having a physical and tangible device is seen as having great learning benefits for students, with 12 out of 15 teachers commenting on this feature:

> *"They really liked it because they, and particularly with a project like the compass which is a very physical, tactile kind of activity, they could see the benefit of doing it and what it meant."* (Morgan).

In one interview, the teacher talked solely about the technology or motivation, including some critical comments about the appeal of a small relatively low-tech device to younger children:

> *I mean I think it's cute but I could easily see why you know a 4K mobile phone screen is going to hold more appeal than regular LEDs ... I think there is merit in that but I could see how people would understandably go where's the screen?* (Kamil)

Primarily comments around engagement were positive, with only a few concerns. These included practical difficulties connecting the device to the physical configuration, hardware problems, the process of debugging, tutorials being too easy, and difficulty seeing the practical application of the device.

4.4 Students and learning

Although focusing on the teachers' perspectives we can see that some of the students' comments on what they had learned reflected the pedagogical approach taken at their school. In particular, we noted two differences in the student feedback about their learning: firstly, the limits of the device in terms of what they could learn from it and secondly the usefulness of the activities they were engaged in. Taking the first area, in one school the students seemed to feel there was a limit to the amount they could learn from the micro:bit:

> *"... the limitations in the software, so you can keep it going for like 10 minutes and less ... it's very limited the coding.* (Student, School D) "

This is in direct contrast to a student in another school:

> *"I like how you can do like anything on the Micro Bit ... there's no end to it"* (Student, School C)

There were several other comments from students around the open-ended nature of the device and how they could continue to learn with it. The other area in which the comments were quite different from different groups were about the activities the students reflected that they were engaged in. A student from school B commented that they were following the tutorials but had not really understood much about what they were doing by following the on-screen, step-by-step tutorial, and was able to suggest better activities that they could be engaged in:

> *" the games on the [BBC] website ... they'll give step by step kind of format or guide. But that's not exactly very challenging and you don't really learn much from it. Whereas if they did a hints for you to do trial and error, and find the results for yourself, that would be one, more rewarding,*

> *plus you've learnt something from the experience."* (Student, School B)

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We found that this was a drawback of the official resources. However the teachers did not all reflect this in their interviews. In contrast, another student, at school C, where the students had been given open-ended projects, felt that they would be able to create something new:

> *"And now with the Micro Bit I actually learnt how to program and make my own game."* (Student, School C)

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4.5 Learning and assessment

Teachers were specifically asked about the learning outcomes relating to the work on the micro:bit and about assessment practices to measure learning. Generally the responses across all 15 teachers were unspecific in relation to these two areas: the focus was on the challenge and motivation as opposed to fitting into particular learning outcomes in the curriculum.

> *"They know a little bit more about, more confident with describing what an algorithm is. They can say what debugging is. They understand the concept of what an input is, and what an output is, and how they're different. I think in two lessons that's probably it."* (Morgan)

There are two possible reasons for this. One is that the devices arrived towards the end of the year when the full year's work would have all been already prepared; lessons with the micro:bit may have been seen as an entertaining diversion, or consolidation, of other work on computer programming. The second reason may be that at the time of the interviews the teachers had not been teaching with the micro:bit enough to develop frameworks for learning and assessment: they were themselves still exploring what the micro:bit had to offer to the curriculum. In subsequent observations since the project completed we have seen more teaching around specific learning outcomes. One exception to this was Nick, a teacher who developed a series of lessons with objectives around development of programming concepts (described in Section 4.1).

Most teachers had little to say on assessment. Some teachers reported that the students had carried out peer assessments or small quizzes to assess their knowledge at the end of each lesson, but none of the teachers had yet done any more formal assessment of learning based on micro:bit lessons at the time of our study.

4.6 Practical issues

There are practical issues with physical devices in the classroom. Dealing with the practical day to day handling of the micro:bits were mentioned by several teachers, sometimes with differing views.

> *"The downside of it being physical is that, it's a bit of a faff sometimes to either distribute them at the start of each lesson and then to collect them back "* (Harry)

Amjad, Frans and Isaac agreed with some of these concerns:

> *"And that housekeeping is just too much. Yes, when I gave the micro:bit to them, I actually wrote their initial and the department in the corner, but then again, who is going to look after the cable? "* (Amjad)

Overall the practical issues were not extensive and teachers found a variety of solutions to store and distribute the micro:bits efficiently in lessons. Issues relating to school computing infrastructure not allowing USB connections did not directly relate to the micro:bit but may have slowed down implementation.

5 DISCUSSION

Returning to the research questions identified in Section 1.2, we firstly wanted to consider how the micro:bit has been adopted in computing classrooms and how this has implications for physical computing in general.

The high profile initiative and launch led to widespread excitement, including in the media. However implementing the micro:bit in the classroom depended to some extent to the confidence and expertise of the teacher. Exercises provided on the official website at the time of the study involved following instructions in a step-by-step way, without any deviation. Apart from the issue of not allowing any independent learning, activities such as this may increase cognitive load as they require a lot of reading and processing of instructions. In addition students may not be able to explain their learning when they are following step-by-step tutorials. At the early stage of our study, it is likely that teachers who followed this path had not yet fully explored the full possibilities of the micro:bit.

Teachers adopted particular strategies in their teaching. One teacher, Harry, described a way of teaching that was a version of 'Use-Modify-Create' [19]. The focus was on reading code and asking children to modify the code. This strategy was reflected in the comments of his students:

> *"...but it's a lot easier if you can see an example of something else and then be like, oh, I need to adapt that to do what I want to do. "* (Student, School H).

Another teacher, Dawn, supplemented the website activities with worksheets around the tutorials requiring students to write an explanation of each tutorial completed. However, her students felt limited by the capabilities of the micro:bit.

> *"...and I don't like how there's like a limit that you can't do more, you can only like do simple games and like shapes and like sometimes you can't do more than just shapes and sentences. "* (Student, School D)

These examples demonstrate the range of ways of teaching with physical computing and the potential impact on the student experience. However, this study has shown that the BBC micro:bit and similar devices do have the potential to engage many students; all teachers we interviewed reported that children found it motivating to use.

In this initiative, the micro:bit was positioned as a pupils' device, for children to take home and own. Teachers were not given their own set. One teacher complained that they had not been consulted and included in the development of the product, roll-out and resources. Giving a device to pupils is meritorious but the support and engagement of teachers is also a key factor.

Some teachers seemed to lack confidence in adopting a new technology - it is probable that they may find it difficult to both implement a new product in this area and also to assess the quality of materials that are being presented. The resources provided with the micro:bit have been developed further since the study was carried out but it is clear that more guidance on differentiation and assessment would be useful for any physical computing work. It is important that teachers who are prepared, either by means of familiarity or with high-quality resources and training to use physical computing. Teachers who have not had sufficient preparation may:

- be unable to trouble-shoot if students have difficulties
- have an over-reliance on step-by-step tutorials and worksheets and not be able to critique ready-made resources
- benefit from a roll-out that allows plenty of time for a development of a scheme of work (preferably before the beginning of a school year).
- need reassurance about logistics and technical support so that lessons can run smoothly

There are many logistical and technological hurdles that may present themselves but an understanding of pedagogical approaches that apply to physical computing would be useful in both pre-service and in-service teacher training.

Overall, the initiative was successful in that it brought physical computing into many more classrooms where teachers would not necessarily have chosen to adopt it - the research undertaken here was early in the initiative and further research is needed to investigate more long-term impact.

6 TEACHER TYPES: INSPIRERS, PROVIDERS AND CONSUMERS

In this section we address the second research question around the different styles of teachers and subsequent experiences for students in physical computing.

The arrival of the micro:bit has brought opportunities to teachers and to pupils. There are new and interesting activities to do in lessons which give teachers and pupils the opportunity to be creative. Teachers can risk new ways of working that they have not been able to do before. Teachers who have experience of physical computing may see the opportunity to create new material that they can share or promote. However confidence with physical computing is a key driver of the approach taken in lessons. Some teachers in our study have engaged fully with the micro:bit launch and can see its potential. They have spent much of their own time developing resources, encouraging other staff and running events. Other teachers are not as sure of the long-term viability of the project so have used them in class or in a club but with constraints of time, energy or skill. The teachers who have embraced the micro:bit most fully in the curriculum are mostly teachers very experienced with Computing: confident in their Computing teaching and not anxious about the challenges of physical computing. These confident teachers may:

- Embrace new developments; are not overwhelmed by logistical difficulty
- Critically evaluate resources; adapt or create new ones where they are not sufficient
- Develop activities that encourage problem-solving
- Encourage students to work creatively and independently on projects

There is thus a correlation between the confidence of teachers and their ability to inspire children with physical computing. Looking at practice across teachers, we have been able to identify three different approaches to teaching with physical computing:

(1) **Inspirers**: Teachers using a range of open-ended activities and taking risks; relating this to pedagogical beliefs
(2) **Providers**: Teachers using structured approaches to learning programming using the device; relating to pedagogical beliefs
(3) **Consumers**: Teachers making use of short, ready-made exercises to motivate and engage; no explicit reference to programming pedagogy

Each type is described below.

6.1 Inspirers

The inspirers in our study demonstrated some or all of these characteristics in that they:

- created open-ended resources for pupils to use
- shared resources amongst the wider community
- linked the use of physical computing to real-world contexts
- encouraged independent learning
- were willing to take risks with lessons that might not work

The teachers we identified as innovators were those who created original lessons or activities and had particularly strong views on how the students could benefit from physical computing. They were primarily the most experienced and confident teachers, willing to take risks. They were in favour of a more exploratory approach to working with the devices [31, 34]. The teachers we identified as being innovators were Harry, Carlos, Isaac and Oliver: these teachers are excited by the possibilities they can see for children to be independent, forward-thinking, creators:

> *"How are you going to make the world a better place with your micro:bit? Or how are you going to make your world a better place?"* (Oliver)

As an example, Isaac created projects that would help students relate the use of the micro:bit to real-world contexts such as travelling by train and he had strong views about why he particularly believes that physical computing can add a lot to the teaching of CS:

> *"'Well I wasn't going to go in doing sort of that boring paper and screen lesson. I'm really interested in physical computing and because I can't see a lot of difference between typing an essay in history and programming a page or coding a page in HTML on the screen. It's just keys on the screen... Once you actually start putting it in physical items it becomes manifested differently - into something you can't do with your laptop, or your tablet or your phone ... "* (Isaac)

Isaac creates all his own lesson material, and pupils do not follow tutorials. The lessons are problem-based, around real-world scenarios. He provides challenge through pupils asking to build upon their solutions. Isaac is an example of a very experienced computing teacher, highly skilled in physical computing. In addition, there were some strong references to pedagogy by these teachers. For example, as mentioned earlier, Harry described a strategy of a) run the code, then b) try to debug incorrect code and c) then try to write your own code, which is very similar to the Use-Modify-Create approach [19], which can be applied readily to physical computing lessons.

6.2 Providers

The providers in our study demonstrated some or all of these characteristics in that they:

- created structured resources for pupils to use
- transferred approaches to teaching programming to the physical computing context
- (perhaps) shared resources amongst the wider community
- were focused on learning outcomes
- took account of differentiation

These teachers are excited about physical computing and want to build their own resources to support their own students. What they produce is based on their experience and what has worked for them in their classroom previously. They think deeply about how the children can best learn and their beliefs are embedded in the resources they developed. From our data we could see that Nick, Dawn, Elizabeth and Luis talked about these aspects in their interviews. For some, like Dawn, the approach is very structured:

> *"Yes, so what I tend to do is we do especially when we're doing challenges they have to screenshot their code, put it onto a document and then they explain it."* (Dawn)

Dawn was particularly focused on differentiating her lessons using handouts that children could access at different levels when working with the micro:bit. Luis has a different approach: he is developing his own website with resources for children to use, and his pedagogical approach comes through in the resources he is developing:

> *"We use a student-led approach, where they complete one or more tasks, which will be: following the tutorial; following instructions; following a video; following text; copying code, using their muscle memory, in many respects to actually get something that works. And then have a challenge, where they actually have to then put that into practice. And it goes: task, challenge, task, challenge, task, challenge."* (Luis)

These teachers used more of a blended approach in their pedagogical strategy in delivering lessons with physical computing - some adopting ideas similar to those suggested in [12] for teaching programming.

6.3 Consumers

In our study the 'consumers' demonstrated some or all of these characteristics:

- Used existing resources provided by the BBC and others
- Offered micro:bit lessons as an add-on to the normal curriculum lessons
- Did not voluntarily discuss pedagogy in their interview
- Focused on technological and logistical issues

These teachers were also keen to explore the use of the micro:bit but some were slightly sceptical of the technology and wanted resources to use that would enable the students to use it in lessons. They were more likely to be critical of the device and engagement in lessons than try to find an improved approach to teaching it. From our data we could see that Billy, Kamil, Morgan, Amjad, Jane, Frans and Gerald fell into this category.

> *"So it gives you . . . It tells you what, where you have to type in next and when you go to type it, it flicks around a little bit, even on a PC, until you get used to that, it's quite tough but some of them found it really easy because they've been using similar programmes in their junior school."* (Billy)

Kamil was quite sceptical of the resources that he used from the official website, but had the expectation that these would be provided, and was also slightly sceptical about the appeal of the device:

> *"They've enjoyed the creation of the projects which are there, but my problem is are they going to remember it for themselves and can they actually use it for themselves and create something new?"* (Kamil)

Data were obtained over a short period of time when the device had just been introduced into the classroom. The teachers reported on strategies that they were using at that time; this is a snapshot of classroom experience during that time period. A further research activity would be to revisit the teachers to ascertain if their teaching practice with regards to physical computing had changed with more experience and exposure.

This group of teachers may have been more wary of the technology, or too busy to devote much time to it. However the variety of reactions to new physical computing devices has several implications which will be discussed in the next section.

7 PHYSICAL COMPUTING IN THE CLASSROOM: RECOMMENDATIONS

The introduction of a new physical computing device into the curriculum gives many opportunities for engaging and effective teaching. In this study data from teachers leads us to recommendations around the way in which such initiatives can be managed. This will be relevant to other countries seeking to launch a new device in school. Key recommendations for physical computing initiatives in school are that:

- Teachers need preparation time to be able to embed devices into the curriculum and time for training, planning and curriculum development.
- Efforts should be made to consult with "expert" teachers who can develop teaching materials demonstrating strong pedagogical approaches.
- Attention should be given to the provision of resources that span a period of weeks, have supporting assessment activities, and are linked to the curriculum: this will be preferable to the provision of many short un-sequenced activities.
- Teachers should be provided with professional learning opportunities around physical computing in the classroom.

These recommendations would be appropriate for any physical computing device.

In addition to subject knowledge and familiarity with the technology, an understanding of pedagogical approaches that apply to physical computing would be useful to both pre-service and in-service teachers. This can be achieved through professional learning opportunities that involve developing resources, using physical computing in an exploratory way to build projects, and sharing resources within a community of teachers using physical computing.

8 CONCLUSION

The BBC micro:bit initiative is an exciting development bringing physical computing to classrooms across the UK. The device has many positive usability features including a tangible nature that engenders active engagement with technology, support of many programming languages, and opportunity for incorporation in real world projects.

In this qualitative study, the opinions and experiences of a number of teachers with relation to the micro:bit have been gathered, reported and analysed. In addressing the research questions set out in Section 1.2, we have reported on a range of practice in the classroom with relation to physical computing; more research is needed to better understand differentiation, progression and assessment. In addition we have drawn out from the data characteristics of three types of teaching approaches: inspirers, providers and consumers; this analysis should help those engaging with professional learning initiatives with teachers of physical computing, and teachers wishing to create effective learning opportunities in the physical computing classroom.

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