



King's Research Portal

DOI:

[10.1145/3017680.3017749](https://doi.org/10.1145/3017680.3017749)

Document Version

Peer reviewed version

[Link to publication record in King's Research Portal](#)

Citation for published version (APA):

Sentance, S., Waite, J., Hodges, S., MacLeod, E., & Yeomans, L. E. (2017). "Creating Cool Stuff" - Pupils' experience of the BBC micro:bit. In *Proceedings of the 48th ACM Technical Symposium on Computer Science Education: SIGCSE 2017* <https://doi.org/10.1145/3017680.3017749>

Citing this paper

Please note that where the full-text provided on King's Research Portal is the Author Accepted Manuscript or Post-Print version this may differ from the final Published version. If citing, it is advised that you check and use the publisher's definitive version for pagination, volume/issue, and date of publication details. And where the final published version is provided on the Research Portal, if citing you are again advised to check the publisher's website for any subsequent corrections.

General rights

Copyright and moral rights for the publications made accessible in the Research Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognize and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the Research Portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the Research Portal

Take down policy

If you believe that this document breaches copyright please contact librarypure@kcl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

“Creating cool stuff” – Pupils’ experience of the BBC micro:bit

Sue Sentence
King’s College London
London, UK
sue.sentence@kcl.ac.uk

Jane Waite
King’s College London
London, UK
jane.waite@kcl.ac.uk

Steve Hodges
Microsoft Research
Cambridge, UK
steve.hodges@microsoft.com

Emily MacLeod
King’s College London
London, UK
emily.1.macleod@kcl.ac.uk

Lucy Yeomans
King’s College London
London, UK
lucy.yeomans@kcl.ac.uk

ABSTRACT

The recent introduction of computer science (CS) education into schools in many countries has led to a surge in interest in programming tools and approaches which make CS concepts and tasks engaging, motivating and accessible to all. There is renewed interest in supporting learning through physical computing, which has been shown to be motivational whilst offering opportunities for collaboration and creativity. Within this context the BBC recently led a collaborative venture in the UK to develop a portable and low-cost programmable device. The consortium funded and produced one million devices, enough for every 11-12 year-old in the UK. In this paper, we report on what we believe to be the first study to investigate the usability and affordances of the BBC micro:bit. We interviewed 15 teachers and 54 pupils in schools in England about their experiences with the device who were, in general, enthusiastic about the potential of the BBC micro:bit. We describe pupils’ experiences in terms of usability, creativity, the tangibility of the device and their learning of programming, and analyse their experiences in the context of previously reported benefits of physical computing.

CCS Concepts

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

Keywords

BBC micro:bit, creativity, K-12 computer science, physical computing, tangibility

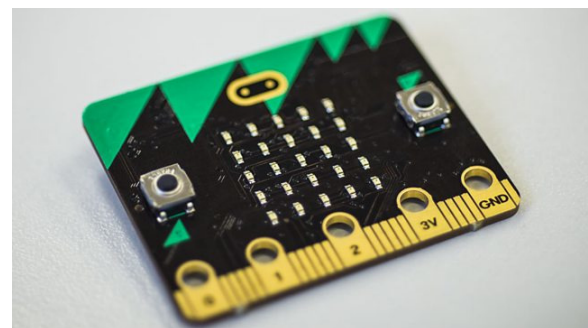


Figure 1: The BBC micro:bit

1. INTRODUCTION TO THE MICRO:BIT

The BBC micro:bit (see Figure 1) is a pocket-sized codeable physical computing device. It was designed to be visually appealing and tactile, affordable, easy to use, interactive and extensible. It has a built-in display, buttons, motion detection, temperature and light sensing, and it supports Bluetooth Low Energy (BLE) wireless communications [2]. 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 was part of the BBC’s UK-wide 2015 “Make it Digital” initiative which aimed to inspire young people to get creative with digital technologies and develop core skills in science, technology and engineering. A website which hosts the programming experiences along with a variety of micro:bit resources for teachers and students (see Figure 2) was developed in conjunction with the physical computing device itself.

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 [19]. The Computing curriculum replaced the ICT national curriculum in September 2014, promoting computational thinking and elevating the importance of programming [6].

In 2015 schools with 11-to-12 year olds (Grade 6) were



Figure 2: Official website with resources

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. A range of events were offered to train teachers. From March 2016, schools started to receive devices for teacher familiarisation and most schools received their full delivery between April and July 2016.

In total around 800,000 micro:bit devices were delivered to schools across the UK, generating widespread interest throughout the country and around the world [1].

The official website¹ supplied a range of small projects for students to develop in either Touch Develop, JavaScript, Python or a Block-based language. In addition teachers and others in the Computing community have devised a range of activities and resources that both extend the use of the micro:bit to use additional components and provide more structured lessons around the curriculum. The micro:bit was not provided with a set curriculum to follow and teachers have been free to use either the official website activities or their own or others' resources with the micro:bit.

The development of the BBC micro:bit and its subsequent distribution to children throughout the UK provides a well-timed opportunity to study the potential benefits of physical computing in the classroom and assess its impact on CS learning outcomes on an unprecedented scale.

2. PHYSICAL COMPUTING IN SCHOOL

The BBC micro:bit joins a set of well-established tangible, embedded 'microcomputer' devices used by students. These include the Arduino [3], the Scratch Pico Board² and Microsoft's .NET Gadgeteer [9], alongside newer products such as the Crumble³ and Codebug⁴. Whilst these devices have very different features they all offer a hybrid and extensible experience which cuts across hardware and software. The resulting process of 'creatively designing tangible interactive objects or systems using programmable hardware' is referred to as physical computing [15].

The advantages of physical computing and the experiences it delivers, particularly in a K-12 CS education context, can be drawn out from relevant research. Constructivist learning theory suggests that knowledge is actively constructed by the student [5]. Papert built on the constructivist concept

by introducing the term 'constructionism' [14] to indicate a combination of constructivism and hands-on construction. He argues that learning happens most readily in a context where the learner is consciously engaged in constructing a real, visible thing – whether it's a sandcastle on a beach or a theory of the universe [14]. This is evidenced by the Logo programming language and the robotic 'turtles' which became popular for engaging students with programming and computational thinking in the 1980s. Additionally, physical devices naturally support an exploratory 'bricolage' approach, as advocated by Stiller [18], whereby students learn by building on existing knowledge following a pedagogy of incremental problem-solving.

From the student's perspective, physical computing can be much more positive than a more traditional screen-based experience because of the focus on ideas, rather than restrictions [15]; students appreciate building real, tangible devices and report that physical computing platforms stimulate their creativity [9]. This in turn engenders a broader and deeper engagement in CS learning activities. Also, anecdotally girls are more engaged when exposed to physical computing, often enjoying coding an embedded device application as a means to an end. Crucially, girls have consistently described growing in confidence as a result of their exposure to physical computing [9]. Similarly, many of those who are currently underserved by CS education programs have responded positively to a CS education approach built on physical computing hardware [4, 16, 17].

In addition to technical skills they imbue, Marshall [12] and Horn et al. [10] both describe how tangible physical computing environments can have a very positive effect on collaborative and active learning, because students work together in a very visible way. Similarly, Hodges et al. [9] report that students with a diversity of skills and abilities support and learn from each other. Physical computing develops valuable inter-personal skills [9] and facilitates more natural and often more effective learning [12] and [10].

The benefits of physical computing in the classroom can be summarised as:

- **Motivation:** Increased motivation for students, including those from diverse backgrounds, because the learning experience and the outcome are visible not virtual. This is especially true when a programming task delivers a practical, meaningful product.
- **Tangibility:** The tangible nature of physical devices helps students make natural connections. Iteratively debugging and refining tangible systems helps to better understand programming concepts and the software development process. The fact that the output of the students' work can be seen and held can lead to an understanding described as 'concrete' [7].
- **Collaboration:** Working with devices often lends itself to group work – different roles include case design, hardware interfacing, algorithm design and user interaction. Groups of students can readily cooperate (or compete!) because of the physical nature of challenges and tasks.
- **Creativity:** Students naturally relate to the physical nature of the task, unleashing creativity in terms of what they build and thereby strengthening engagement with the task.

The benefits of physical computing are not limited to CS

¹<http://microbit.org> (enhanced since study)

²<http://www.picocricket.com/picoboard.com>

³<http://www.redfernelectronics.co.uk/crumble/>

⁴<http://www.codebug.org.uk/>

education. There are diverse connections to other STEM subjects, such as the simulation of behaviour in biology, the collection and analysis of measurements in physics, and logical mathematical operations [10]. It also connects to the arts and humanities, with application to topics ranging from interactive art pieces to geography and dance [8, 10].

With these four benefits of physical computing in mind, we present and analyse the results of an early study of students' use of the BBC micro:bit. In particular, we aim to understand the extent to which these elements are evident.

3. THE STUDY

3.1 Scope of the Study

Our study was designed to run immediately after the BBC micro:bit arrived in schools, to gather feedback from teachers and students about their initial experiences and perceptions of the BBC micro:bit, and thus inform any potential future developments. The overall research question for our study was 'What are the affordances of the BBC micro:bit in the classroom?' and was focused around four areas: (i) perceptions of the micro:bit; (ii) potential barriers to and facilitators of device usage; (iii) use of resources for the micro:bit; and (iv) use of the micro:bit across the broader curriculum.

In this paper we are focusing in particular on the perceptions of and responses from pupils. Other aspects of the study relating to teacher feedback will be reported elsewhere.

3.2 Study methodology

A qualitative approach was taken to capture the breadth of the pupils' engagement with the micro:bit by interviewing teachers and pupils about their experiences. More quantitative data collection may take place later on once the micro:bit has been used in a larger number of schools.

Face-to-face semi-structured interviews were conducted by four of the authors with teachers at 15 schools in England. In some cases, with the consent of teachers, students and their parents, these interviews were complemented by in-person focus groups with pupils. All the focus groups took place in school.

Each teacher interview lasted approximately 30-35 minutes whilst focus groups were a little shorter at 20-30 minutes each. Interviews were audio-recorded, transcribed by a commercial transcription service and all data was recorded and processed in accordance with the appropriate research and ethics standards and destroyed once transcription had taken place.

The data was analysed using QSR's NVivo qualitative data analysis software. Initial reading of the data revealed themes that were considered against expectations based on knowledge of the field. The data was then coded by two of the authors after reaching a coding consensus [11]. The coding scheme was then refined for a second round of coding with two different authors, following Mayring [13].

Key themes were identified from the data and are presented in the next section. Schools have been labelled A to O for this purpose.

3.3 Participants

The 15 schools were recruited by mailshots to teachers, advertisements on the UK's Computing At School (CAS)

Table 1: Profile of participating schools

Label	Single-sex or co-ed	Focus group size
School A	boys only	8 pupils
School B	girls only	8 pupils
School C	mixed	8 pupils
School D	mixed	7 pupils
School E	boys only	5 pupils
School F	mixed	3 pupils
School G	mixed	8 pupils
School H	mixed	7 pupils
School I	girls only	teacher only
School J	mixed	teacher only
School K	mixed	teacher only
School L	mixed	teacher only
School M	mixed	teacher only
School N	mixed	teacher only
School O	boys only	teacher only

website⁵ and via social media (see Table 1). In 8 schools a focus group of between 3 and 8 pupils was used to complement feedback directly from the teacher concerned.

Recruitment of schools took place when the micro:bits were expected to arrive.

The teachers in the study had a variety of experiences of Computing. Some were CAS Master Teachers who had been engaged with the micro:bit programme for some time and others were teachers who were both new to Computing and had just started using the micro:bits in school. There was a delay in delivery of the micro:bits so pupils had had between 2 and 12 lessons using them.

Projects developed by the students ranged from simple flashing messages, to designing a pedometer, and to creating a moving car using the micro:bit and other components.

4. FINDINGS

We report here on pupil responses, and evaluate the comments relating to (i) perceptions of the micro:bit and (ii) use of the micro:bit across the curriculum.

4.1 Perceptions of the micro:bit

From the eight focus groups in the study, four main themes emerged when the pupils discussed their experiences:

- ease of use of the micro:bit;
- tangibility and the concept of 'real';
- open-endedness and creativity; and
- programming skills.

We consider each of these separately below.

4.1.1 Ease of use

When asked what they liked about the micro:bit, the most common answer related to its ease of use:

"It's quite, like, easy to code. It's not really hard, so it's, like, you can create cool stuff without it being impossible." (Pupil, School B).

Comments referred to the labelling of the device in supporting the ease of use:

⁵<http://www.computingatschool.org.uk/>

“...if you’re not very good with technology, then you could have a look and see that it’s labelled everything very clearly, so if you want to do something you have everything in front of you and you just have to put it together to work.” (Pupil, School E).

Two teachers additionally remarked that students who normally struggled academically had enjoyed and learned from the micro:bit, echoing the low entry point of the micro:bit.

4.1.2 Tangibility

Pupils frequently used words such as ‘see’, ‘make’, ‘press’ and ‘shake’ etc. to describe their interaction with the micro:bit. Other comments related to the physical nature of the micro:bit—the physical elements like buttons, light sensors and the built-in display:

“I think it’s pretty good to be able to see, like, how much you can get out of a small device.” (Pupil, School E).

The mention of a “small device” by this pupil highlights a benefit of the device: its simplified nature constrains the domain in which students are working.

Other pupils mentioned the LEDs and different physical features:

“The options of what you could, like, actually make with it is so cool. Because you can do something that’s with LED lights or anything else really.” (Pupil, School B).

One of the most common suggestions about improvements for the micro:bit from the students was that it needed more LEDs, or colour LEDs, to extend what could be displayed:

“I think it would be nicer if there were more LED lights so you could make better animations, because there aren’t really that many you can use to make games and stuff.” (Pupil, School B).

Students also had some ideas for developing the micro:bit further as a device. One pupil suggested adding a joystick, and another a camera:

“I’d say that the micro:bit, they could add a joystick or something onto it because if you’re making games then you’ve got the two buttons, you can move left and right, there’s no real way to move up and down, so that would be good.” (Pupil, School C).

“Maybe you could have a few extra components which would increase its... increase its amount of uses; so for example you could maybe have a camera attachment which would allow to take photos and stuff.” (Pupil, School E).

Another illustrative comment focused on the ‘real’ element of seeing the output physically, compared with viewing output on a computer screen. This can be seen to relate to feedback given by a tangible device:

“Well I quite enjoyed the fact that we could actually program something with the benefit of seeing what we’re actually doing, like in the real world, instead of just on a computer screen. So that really like encourages me to work with it.” (Pupil, School E).

4.1.3 Opportunities for creativity

One of the benefits of physical computing is the opportunity it provides for students to be creative. Several pupil comments concern the open-endedness of the device; they felt they could create whatever they liked:

“There’s no real end to what you can make with the micro:bit, so you can use it to make whatever you want and there’s no sort of limits to it.” (Pupil, School C).

Having the opportunity to be creative can lead to a feeling of satisfaction from the completed product and also a sense of ownership and pride from the result:

“I quite like the micro:bit because when you program it and then play the game you get that feeling of ‘Wow, I’ve actually created this.’ ” (Pupil, School A).

Other pupils had some very creative ideas, including the following:

“You could attach it to a light sensor so it can tell you when you could turn out your lights if it’s got too much light.” (Pupil, School F).

Other students suggested connecting the micro:bit to a phone to turn music on, and connecting lots of micro:bits together to interact with each other, or form a large screen.

Being able to choose to make something of your own was mentioned by other pupils, highlighting the element of choice and autonomy as well as ownership of the process and the resulting device.

4.1.4 Learning programming skills

Enhancing an understanding of programming was a key motivator for the micro:bit. Students discussed the way that they had learned coding skills with the micro:bit:

“I learnt how to actually code because in primary school we didn’t do much with programming or computers except some sort of program with Scratch, but other than that we didn’t really do much. And now with the micro:bit I actually learnt how to program and make my own game.” (Pupil, School C).

The micro:bit can give a route into programming and using it can be a conduit to learning more advanced skills and concepts, which can be used either in the context of physical computing or in screen-based programming. Some students demonstrated that they were aware that the programming they were doing could lead on to more:

“If someone wants to get into coding, it’s quite an easy way to start because you can start off really easy, and it gets harder. And then you can move on to something else. ” (Pupil, School H).

At School H, the teacher has written his own MicroPython emulator, so may be a good role model for seeing what can be achieved with more extensive programming skills. In contrast, at School E, a student has picked up that the micro:bit can be used readily without a background in programming:

“I don’t think it’s particularly important to understand much about programming at all, most people could pick that up and put a simple code on it just by looking around the interface within a few minutes.” (Pupil, School E).

Some pupils highlighted the importance of understanding the code and what it does. In particular, this comment relates to pedagogical issues around the value of copying in contrast to having a good understanding of programming:

“Because you might be relying on someone showing you the code and then you just copying it out. But if you understand it, you can actually write it out yourself and think of other things.” (Pupil, School B).

Teachers’ perceptions of student response to the micro:bit were very positive, with few negative comments. When asked how their students felt about the micro:bit, most teachers used terms such as ‘anticipation’ and ‘excitement’ and ‘feeling special’. This latter term relates to how micro:bits were allocated to schools: the two key elements of the BBC’s initiative were that (i) pupils would own the micro:bits, rather than their schools, and that they could therefore take the devices home, and (ii) one year group (Grade 6) was singled out to receive the device for free.

4.2 Use of the micro:bit across the curriculum

There was considerable insight into the potential of the micro:bit across the curriculum, as well as in Computing lessons. One of the schools (School D) had organised for the BBC micro:bit to be used in other subject areas such as textiles and art. In textiles the micro:bit was programmed to light up and then sewed into clothes. Another school (School O) had arranged a ‘launch day’ which had taken up a whole day’s lessons for the entire year group, demonstrating the device’s impact across the curriculum.

Pupils were also able to see potential opportunities for the micro:bit across the broader curriculum:

“I think learning to code with micro:bits actually not just helps in coding but also the other things in STEM, so science, technology, engineering and maths. Because in coding, like, if you wanted to, for example, learn how to code a triangle then you need to be able to... learn, like, the angles.” (Pupil, School B).

The pupils had some specific, creative suggestions for using the micro:bit in particular subjects, for example in modern languages, and in physical education:

“It could help you with your languages. If say they added, like, a recorder onto it so it could record your voice and you put in the correct pronunciation... say for something French.” (Pupil, School B).

“In PE you could use the accelerometer and see how fast you can speed up when you’re running... You could put it in like a tennis ball, so when you hit it you could see how fast you actually hit it.” (Pupil, School H).

5. ANALYSIS

Returning to the four benefits of physical computing that were outlined in Section 2, we can reflect on the extent to which pupils’ experiences and learning are linked to motivation, tangibility, collaboration and creativity.

5.1 Motivation through physical computing

As can be seen above, the students’ comments about the micro:bit were very positive. Students were particularly enthusiastic about the ease of use of the micro:bit. Similarly, great enthusiasm was shown during focus groups as students voluntarily suggested cross-curricular uses and device improvements. This is very much in support of the view that physical computing motivates students. Many teachers commented on the motivating effect of working with the micro:bit:

“With the micro:bits, definitely an increase in motivation because they can see their code physically doing something.” (Teacher, School H).

5.2 Tangibility supports learning

That the device is tangible is obvious. The relevance here is the impact of touching, feeling and manipulating the device on learning. Students referred to the fact that they understood what was happening in the program more because they could physically see it. The most common suggestion for improvement for the device was to increase the size of the LED matrix; this indicates the significance of the display to students’ view of the device. Another aspect of tangibility is being able to do something physical with a micro:bit project, such as sewing it into clothes in textiles lessons (School D). Again our findings support the view from the literature that tangibility reinforces learning.

5.3 Opportunities for Collaboration

We did not directly ask either teachers or students about working collaboratively. However we found an interesting difference in practice amongst schools: A few schools were engaging in project-based learning and encouraged students to work in groups on open-ended challenges. However, since they had been given one device each, in most schools the students worked individually and did not refer to collaboration. The BBC’s approach may therefore have missed a previously-reported potential benefit of physical computing, namely to encourage collaboration. Of course, teachers will find ways to work around issues like this where the benefits of group work have been established.

5.4 Opportunities for Creativity

Our data includes examples of students being creative, mostly in terms of their ideas for using the micro:bit. The opportunity to create something that has a practical purpose—for a person such as the students themselves to use—seemed to motivate students and this in turn afforded students a more meaningful learning experience.

6. CONCLUSION

In this paper we presented initial perceptions of the BBC micro:bit in UK classrooms, couching our findings in terms of previous research in physical computing. We found that the micro:bit encourages students to work creatively; the novelty of the physical nature of the device is also a great motivator in the classroom. Additionally, data from our study suggests that the tangibility of the device is a key element in stimulating interest and supporting understanding. From our data we can see that children make a connection between learning to program and making digital products. This enables them to see the relevance of coding and CS more generally, and relate these to the real world.

It is too early to claim that simply using the micro:bit in the classroom provides students the benefits listed above. As with other physical computing devices, the micro:bit certainly has the potential to enhance learning in the four areas presented. In practice, whether it does or not is determined in large part by the way that teachers choose to use it: teaching style and the associated classroom activities. In our study there was a variation in practice, including the use of scaffolded learning, challenging the students and a focus on understanding the code.

Teachers in our study applied a range of different pedagogical approaches to incorporating the micro:bit in the curriculum. Our continuing research will analyse the relative effectiveness of specific approaches in terms of the resulting student motivation and understanding. In particular we plan to study potential barriers and facilitators to device usage. Of course—as always—a big factor in successful teaching outcomes is the quality of teaching.

We would also like to understand how well areas of the computing curriculum map to micro-bit related learning activities, and how this mapping can be supported by online resources and materials.

The BBC micro:bit initiative generated a high profile which caught the attention of schools, teachers and children. However, the initiative is not over. Many resources have been developed and micro:bits can now be purchased. The attraction of physical computing as a motivational strategy in the classroom is without doubt. With due attention to pedagogy and a focus on learning, the device has the potential to provide a generation of students with a compelling first exposure to coding, computational thinking and digital technology. We hope that other researchers will join us as we continue to promote, evaluate and report on the use of physical computing in the K-12 classroom.

7. ACKNOWLEDGMENTS

We are grateful to Clare Riley for her support and to Microsoft for funding this work.

8. REFERENCES

- [1] BBC to give away 1m Micro:bit computers to schoolchildren | Technology | The Guardian.
- [2] T. Ball, J. Protzenko, J. Bishop, M. Moskal, J. de Halleux, M. Braun, S. Hodges, and C. Riley. Microsoft touch develop and the bbc micro:bit. In *Proceedings of the 38th International Conference on Software Engineering Companion*, ICSE '16, pages 637–640, New York, NY, USA, 2016. ACM.
- [3] M. Banzi. *Getting Started with Arduino*. O'Reilly & Associates, Sebastopol, CA, 2. ed edition, 2011. OCLC: 844925524.
- [4] E. Barba and S. Chancellor. Tangible Media Approaches to Introductory Computer Science. pages 207–212. ACM Press, 2015.
- [5] M. Ben-Ari. Constructivism in computer science education. pages 257–261, 274308, 1998. ACM.
- [6] N. Brown, S. Sentance, T. Crick, and S. Humphreys. Restart: The Resurgence of Computer Science in UK Schools. *ACM Transactions of Computing Education*, 14(2), June 2014.
- [7] D. H. Clements. 'Concrete' manipulatives, concrete ideas. *Contemporary Issues in Early Childhood*, 1(1):45–60, 2000.
- [8] K. DesPortes, M. Spells, and B. DiSalvo. The MoveLab: Developing Congruence Between Students' Self-Concepts and Computing. pages 267–272. ACM Press, 2016.
- [9] S. Hodges, J. Scott, S. Sentance, C. Miller, N. Villar, S. Schwiderski-Grosche, K. Hammil, and S. Johnston. .NET Gadgeteer: a new platform for K-12 computer science education. In *Proceedings of the 44th ACM technical symposium on Computer science education*, pages 391–396. ACM, 2013.
- [10] M. S. Horn, R. J. Crouser, and M. U. Bers. Tangible interaction and learning: the case for a hybrid approach. *Personal and Ubiquitous Computing*, 16(4):379–389, Apr. 2012.
- [11] U. Kuckartz. *Qualitative text analysis: A guide to methods, practice and using software*. Sage, 2014.
- [12] P. Marshall. Do tangible interfaces enhance learning? page 163. ACM Press, 2007.
- [13] P. Mayring. Qualitative content analysis. *Forum of Qualitative Social Research*, 1(2), Jun 2000.
- [14] S. Papert and I. Harel. Situating constructionism. *Constructionism*, 36:1–11, 1991.
- [15] M. Przybylla and R. Romeike. Key Competences with Physical Computing. *KEYCIT 2014: key competencies in informatics and ICT*, 7:351, 2015.
- [16] S. Sentance and S. Schwiderski-Grosche. Challenge and creativity: using .NET gadgeteer in schools. In *Proceedings of the 7th Workshop in Primary and Secondary Computing Education*, pages 90–100. ACM, 2012.
- [17] G. S. Stager. Papert's prison fab lab: implications for the maker movement and education design. In *Proceedings of the 12th International Conference on Interaction Design and Children*, pages 487–490. ACM, 2013.
- [18] E. Stiller. Teaching programming using bricolage. *Journal of Computing Sciences in Colleges*, 24(6):35–42, 2009.
- [19] The Royal Society. Shut Down or Restart? The way forward for Computing in UK Schools. Technical report, 2012.