In this forum we celebrate research that helps to successfully bring the benefits of computing technologies to children, older adults, people with disabilities, and other populations that are often ignored in the design of mass-marketed products.
— Juan Pablo Hourcade, Editor

From the BBC Micro to micro:bit and Beyond: A British Innovation

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Many British people remember fondly the BBC Micro from their childhood in the 1980s. They spent hours playing video games like *Frogger* and *Pac-Man* while also learning to program using the BASIC language. The computer's colorful graphics and chunky keyboard, with a row of orange function keys at the top, made it distinctive, accessible, and user friendly. It inspired a generation to learn about computing, programming, digital music, and video games.

In the 1970s, the microcomputer revolution was changing working life. Television programs like the BBC's 1978 *Horizon* special *Now the Chips Are Down*, were highlighting the critical need to skill up the U.K. workforce. Backed by the U.K. government, the BBC produced three television documentaries and a highly influential report. As a result, the BBC's Continuing Education department decided to start a computer literacy project based on television programs, courses, supporting books and software, a network for teachers and learners, and the licensed production of its own microcomputer. Working with the BBC R&D, the department developed a specification for a machine and contacted a range of companies to bid for the contract to develop it. The response from one company, Acorn Computers, stood out above the rest and the BBC Micro was born (Figure 1). Its remarkable legacy lives on:

Not only did the computer literacy project help transform the culture of computing in Britain, making computing acceptable and bringing it into many British homes, it also had positive repercussions for the U.K. high-tech sector. The impact of Acorn can be seen directly in high-tech companies such as ARM, and indirectly in the serial entrepreneurs, strong social networks, and inspiration to others that were, in part, created by Acorn [1].

THE CODING CHALLENGE FOR THE 21ST CENTURY

Roll on 30 years and a new problem was emerging. Two influential reports [2,3] stressed the same thing: There were not enough U.K. students taking university computer science courses and not enough working people skilled in computer technologies. This had happened because schools had stopped teaching children about computers and how to code them. The conclusion of both reports was that there was an urgent need to re-skill the nation's children.

The BBC's Learning department realized there was a similar but different challenge and tasked its Innovation team with finding a new solution. The team talked to experts, teachers, and children and, critically, built and hacked things: for example, novel coding platforms, TV-responsive robots, mobile phones, smartphone apps, and haptic gloves. After all this activity, the team concluded that the aim should be to start young people making and building, especially around the Internet of Things (IoT), and support the development of a new generation of tech pioneers, turning the consumers of technology into its creators. They decided the essential ingredient to help this transformation was a small piece of enabling hardware—a cheap, accessible, fun, and easy way to start coding and making that was physical in nature, that children could hold in their hands, and that was low-cost enough to be given away.

Around the same time, University College London's computer science department was scaling up its own outreach activities. This involved creating a computing device, the Engduino, intended to teach coding in and outside of schools and that would be given to students for them to continue using on their own. The project's focus, like the BBC effort, was to promote coding in the context of the IoT by using a device built on top of the Arduino platform. Part of its unique design was to embed 16 multicolored lights on the PCB, along with various sensors, infrared communication, and a built-in battery. Its attractive, all-in-one design was meant to be easy to use and appealing to complete beginners in programming and electronics. It

Insights

- Forty years later, the BBC reinvented the Micro in the form of the micro:bit, which aims to make coding fun and accessible to all.
- UCL's computer science department collaborated with the BBC to help shape an innovative IoT toolkit, inspiring the next generation of children to code, make, and create future technologies.

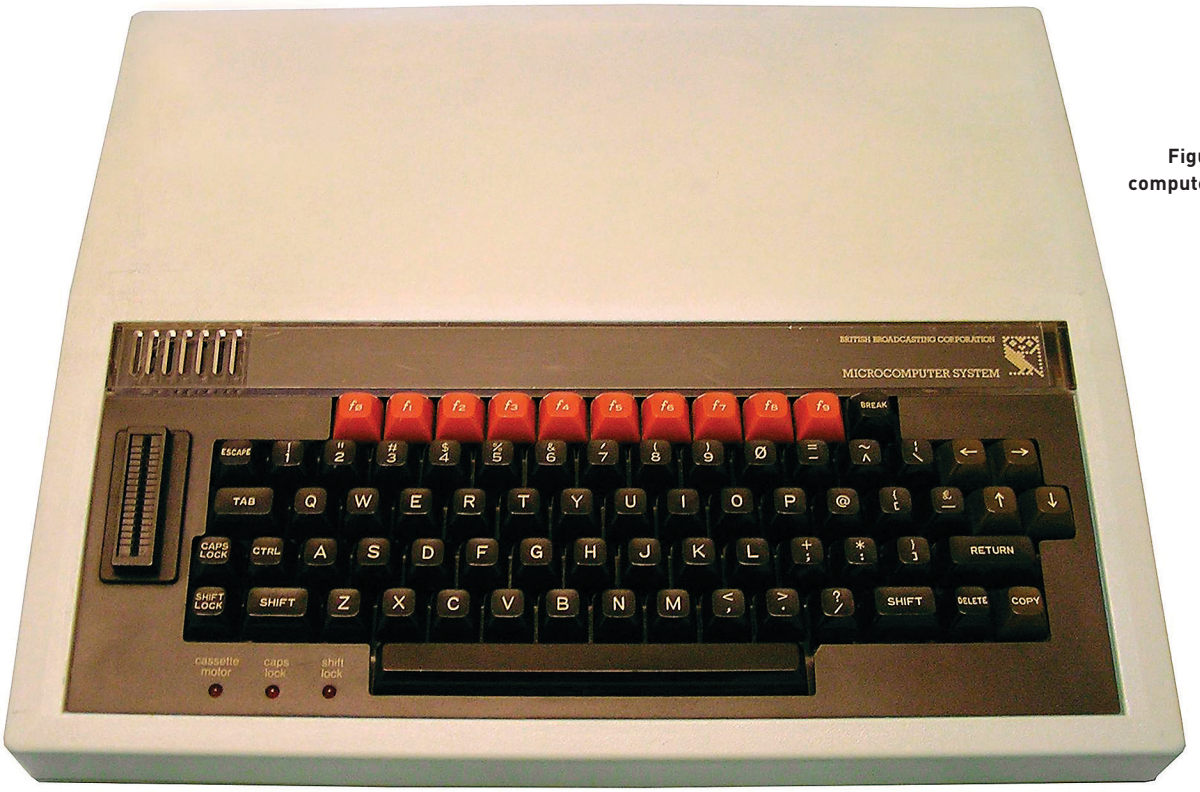

Figure 1. A BBC Micro computer from the 1980s.

received very positive reviews from the teachers and students. The students learned about Arduino-C programming, sensors, and communication, and with this knowledge designed, built, and created a diversity of projects. For example, the children created spelling games and emoticons and recorded their heart rates using the device. Everyone wanted to get their hands on one.

Then, serendipitously, Yvonne Rogers, a professor at UCL, and the late Katy Jones, an executive producer at the BBC's Learning Zone, met by chance by the swimming pool while on holiday. Their mutual ideas and inspiration about how to help children learn resulted in UCL and the BBC joining forces. A meeting of minds ensued as they discussed how the Engduino could be further developed along the lines of what the BBC had in mind: to get children excited about coding and creating.

A number of other universities and companies had also been presented with the BBC IoT device challenge. The UCL team addressed the challenge from an interaction design perspective. Over a period of a few months, they ran a series of design workshops with Nic Marquardt (physical computing), Venus Shum (electronic engineering), Yvonne Rogers (educational technology and HCI), Howard Baker (part of the BBC Learning team working on micro:bit), and Matt Davies (an independent UX consultant). Through many brainstorming sessions, they came up with a universally accessible, gender-neutral sensing/actuation device that could support social- and discovery-based explorations of electronics and coding while introducing computing concepts that could be readily linked to children's everyday life. The importance of the user journey, from the moment children would receive the kit to what they would do with it afterward, was sketched, prototyped, laser-cut and redesigned. As part of this process, the kit was thoroughly tested to get the right form factor and engineering, and to find the right making activities that would inspire children to learn to code and create.

Out of this collaborative process, the MakeMe cube was born (Figure 2). It was presented as a simple flat-pack construction kit, comprising six pieces, intended for assembly into a cube. When shaken, it would change color depending on the speed and the direction of the shaking motion. The ultimate challenge was to shake the cube into a multicolored light show. Each piece made up a side of the cube; one side had a PCB embedded in it, another an accelerometer, another a battery, and another an LED. The other two sides were left blank. The idea was that by first snapping the pieces out and then working out how to put them together to make the cube, children would learn about the properties of each component and the mapping between sensors and actuators.

The UCL team ran several workshops with the MakeMe kit in schools and at outreach events for children and teenagers between the ages of 6 and 16. The feedback was overwhelmingly favorable. Moreover, it was found that the process of making the cube significantly improved young children's learning and performance [4]. The MakeMe cube was pitched to the BBC, which was suitably impressed by its design and the findings. Several hundred were then built and distributed to both children and adults at workshops and science festivals in the U.K., and at the Exploratorium in San Francisco. Further workshops were held at the BBC's own CBBC days for children, generating much joy and excitement.

The MakeMe cube, alongside the other university and industry researchers' prototypes, provided

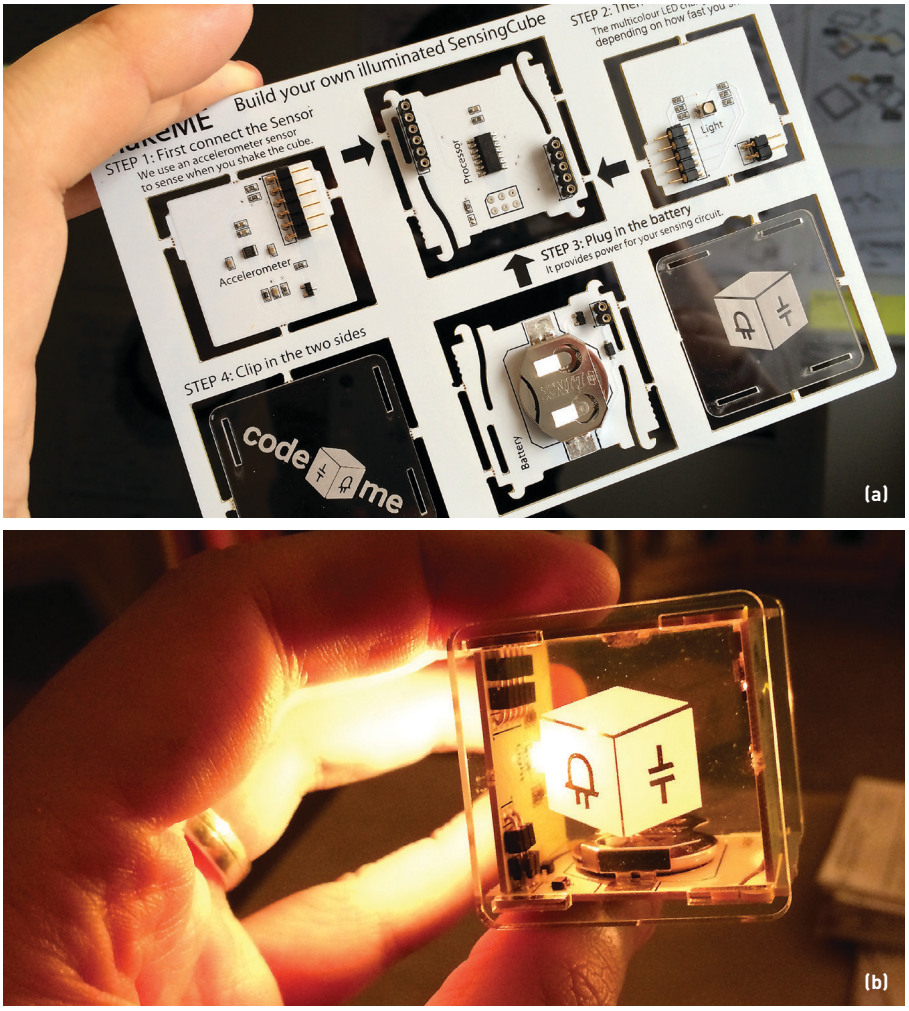

Figure 2. The MakeMe construction kit (a) before and (b) after assembly.

much food for thought for the BBC Innovation team and for the BBC R&D team they had approached to help them create their own smart little BBC board and a simple-to-use coding website. The team tested the new system with children at BBC events and in classrooms with teachers; the response was remarkable. Children, parents, and teachers were amazed at how easy the BBC device was to program and thrilled at the things they could make it do with a few easy instructions. The team and BBC Learning realized they were onto something special.

2016: THE ARRIVAL OF THE MICRO:BIT IN SCHOOLS AND SETTING UP A FOUNDATION

In October 2013, the new BBC Director General announced that 2015 would be a yearlong educational campaign to get the nation coding and creating in the digital realm. BBC Learning took its device to the new Make It Digital team, who requested a groundbreaking proposition. BBC Learning's response was to suggest giving away 1 million of the little boards to every 11- and 12-year-old child in the U.K. through their schools. The campaign team agreed and asked BBC Learning to make it happen.

In late 2014, the BBC circulated an invitation for companies and organizations to partner with the BBC on a public-service project to get the children of the U.K. coding. The response was stunning. Hundreds of companies and university teams put in their proposals. By early 2015, 29 partners had signed up and a new, completely redesigned BBC micro:bit board was in development. Throughout the rest of 2015 and the early part of 2016, the BBC and its partners worked through the complications of developing and getting a brand-new concept to market. By early summer 2016, delivery of the BBC micro:bits to

Figure 3. Students Jessica and Leila from West Ashtead Primary School in London coding animations on their micro:bits to make a story book.

schools had begun (Figure 3); by the end of the summer, most of the devices had successfully arrived.

UCL RESEARCH: FROM MAKEME TO THE MAGIC CUBES

Following the productive collaboration with the BBC, the UCL team continued its own research agenda, investigating more extensively how to teach the IoT to young children. They began working on a second cube, SenseMe, that was designed to have more sensing and actuating functionality with scope for on-board coding. These innovations would enable the exploration and measurement of many aspects of the world. Following the same design philosophy of MakeMe, the sides of the cube provide different components of a computing device, but with a much more powerful microcontroller, more sensors, and Bluetooth radio.

The team switched their efforts to conceptualize the coding, making, and creating activities in terms of an overarching framework called digital fluency. This represents the core set of skills necessary to empower people to see themselves as creators and shapers of modern technology, rather than just its consumers. Whereas the initial research with Engduino and MakeMe demonstrated how children learn to code, make, and create together, UCL's current research is pushing the envelope further by exploring how extending these activities and more can enable children to develop what we call the Four Cs of digital fluency: computational, critical, connected, and creative thinking.

The kit got a new name: Magic Cubes. The environmental and personal sensors, in addition to being colorful and engaging actuators, are intended to enable children to explore the world of data in everyday contexts. By connecting several cubes together, children can design their own Internet of Things applications, discover mechanisms for ensuring privacy and security, and explore abstract systems-thinking concepts, such as interdependence and emergent system behaviors [5]. Further testing in classroom settings has shown that the tangible and personally meaningful nature of these activities can facilitate thinking about the abstract world of complex computational concepts, motivating children to think independently about the real-world implications of modern technology and inspiring higher levels of engagement and creativity. The Magic Cubes are also proving a hit in special school settings, for children with autism and learning difficulties.

NEXT STEPS

It had always been the ambition of the BBC to hand the micro:bit over to a foundation to handle the micro:bit legacy. On the October 19, 2016, the Microbit Educational Foundation was launched in London. The aim of this nonprofit is to continue the micro:bit experience in the U.K. and roll it out to Europe, and then the world, to inspire a global generation of young inventors. (For more information, see www.microbit.org.) The micro:bit and Magic Cubes are two of a number of promising projects that are providing new ways for preparing children (and adults) to code, create, and invent the future using IoT toolkits in innovative ways.

In memory of Katy Jones, who died suddenly on April 24, 2015 at age 51.

Endnotes

1. Blyth, B. Computing for the masses? Constructing a British culture of computing in the home. In *Reflections on the History of Computing: Preserving Memories and Sharing Stories* A. Tatnall, ed. Springer, Heidelberg, 2012, 231–242.
2. Livingstone, I. and Hope, A. Next Gen. NESTA Report. 2011; http://www.nesta.org.uk/publications/next-gen
3. Furber, F. Shut down or restart? Royal Society Report. 2012; http://royalsociety.org/topics-policy/projects/computing-in-schools/report
4. Johnson, R, Shum, V., Rogers, Y., and Marquardt, N. Make or shake: An empirical study of the value of making in learning about computing technology. *Proc. IDC'16*. ACM, 2016, 440–451.
5. Lechelt, Z., Rogers, Y., Marquardt, N., and Shum, V. ConnectUs: A new toolkit for teaching about the Internet of Things. *Proc. CHI EA'16*. ACM, 2016, 3711–3714.

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DOI: 10.1145/3029601