Institution: Lancaster University		
Unit of Assessment: 11 Computer Science and Informatics		
Title of case study: The BBC micro:bit: Lancaster University inspires children around the world to become digital pioneers		
Period when the underpinning research was undertaken: January 2003 - present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Joe Finney	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 2001 - present
Period when the claimed impact occurred: 2013-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Computer Science researchers from Lancaster University have applied software composition research and embedded systems design to create a lightweight operating system (runtime) that **runs on over 5 million micro:bit devices** currently being **used by an estimated 25 million students and teachers worldwide**.

The micro:bit began in 2014 as a project by the BBC; the aim being to create a pocket-sized, inexpensive, computing device that would encourage a broader range of children to engage in digital creativity and coding. Lancaster University (as **the only academic partner** to be invited in to the micro:bit consortium of 28 organisations including Samsung, Microsoft, Arm and many more) created the runtime that allows the programming of the micro:bit device and enables the wider micro:bit ecosystem [3.1]. In 2016 the Micro:bit Educational Foundation was created and in that same year **1 million units were deployed to every year 7 child student in UK**, free of charge. Statistics from the online programming editors regularly record 1 million user sessions per month, indicating that, on average, **a child or teacher starts work on a micro:bit program somewhere in the world every 2.5 seconds, 24 hours a day.** The micro:bit has now built a global following and is **available in over 70 countries and 17 languages**.

Lancaster University remains central to the development of micro:bit and is one of 3 members on Hardware Advisory Committee for micro:bit version 2. The new model adds a speaker and microphone, as well as artificial intelligence and machine-learning capabilities. In supporting this first hardware feature update to the micro:bit device since launch in 2015 Lancaster University continues to support the simplification of physical computing for computer science education, making it more widely available and useable for students and educators.

2. Underpinning research (indicative maximum 500 words)

Prof Finney led Lancaster's role as a founding product partner of the BBC micro:bit alongside ARM, BBC, Microsoft and Samsung [5.4b]. Building on the university's strong ongoing relationship with BBC, and Finney's responsibility for Computing at Schools and outreach at the time, Lancaster was well placed to bid for inclusion in the consortium. Lancaster became the only academic partner and went on to make a foundational contribution of the runtime system software, enabling the entire micro:bit ecosystem.

The design of the runtime builds on Prof Finney's extensive record of accomplishment and body of research in the field of mobile and embedded computing. This includes the innovative layer breaking internal communications architecture inspired by cross-layer communication support he developed in NEMO (EPSRC grant no. EP/C014677/1) which trialled easy to use embedded sensor devices that fused low level hardware layer data normally only internal to operating systems with higher level application context descriptors [3.5]; and the Firefly project that created ultra-low footprint computing hardware small enough to be effectively integrated into a single LED [3.3]. The design also draws on Finney's experience with embedded protocol stack innovation in the industrially funded Mobile IPv6 testbed and EPSRC NP++ (internet working protocol, EPSRC Grant no. EP/D033489/1) projects that resulted in integration of next-generation mobile internet protocols into Microsoft operating systems, the EPSRC NEMO project (EPSRC grant no. EP/C014677/1) that developed and trialed easy to use, intelligent contextual monitoring devices in industrial contexts [3.5] and the Firefly project that innovated ultra-low footprint computing hardware small enough to be effectively integrated into a single LED [3.3].

Building upon this body of knowledge in 2015, Prof Finney undertook the research and development of the unique lightweight operating system for the micro:bit that would prove to be crucial to the project's success. The roles of the other product partners were hardware design (ARM), project management (BBC), programming languages and editors (Microsoft), and mobile applications development (Samsung), respectively. An additional 25 organizations, including Barclays, Cisco, IET, Element14 and Wellcome Trust provided additional non-technical contributions to the project (financial, educational, manufacturing and logistics).

The consortium's aim was to create a pocket-sized, inexpensive, inclusive, low barrier to entry computing device designed specifically to inspire children to learn to code and to promote and support computer science and technology education. The micro:bit consists of 32-bit ARM Cortex CPU, LED matrix display, and a range of internal sensor to detect acceleration, magnetic fields, light levels, temperature and touch sensitive user inputs. Bluetooth and USB connectivity allows the micro:bit to be programmed in high level languages including Scratch, Microsoft MakeCode Blocks, JavaScript, Python in addition to C/C++.

Historically, software development for embedded systems has been highly specialist, requiring knowledge of low-level programming languages, complex toolchains, and specialist hardware, firmware, device drivers and applications. This research identified and characterized the semantic gap between the capabilities of low-cost, resource-constrained devices, like the micro:bit, that are normally programmed at a low-level (languages such as C/C++) and the needs of inexperienced developers who require high-level languages such as visual programming metaphors to succeed. This project in many ways heralded the emerging trend in zero-code / low-code development we see today.

Democratising access to embedded systems technologies required a new type of platform to support high-level programming abstractions that are easy to learn, and simple abstractions to make interacting with the underlying hardware easy, consistent and as uniform as possible. Prof Finney went on to design, develop and evaluate the micro:bit Device Abstraction Layer (DAL), a platform that bridges this semantic gap [3.3] [3.4].

The micro:bit DAL adopts a novel architecture that leverages static compilation of high-level languages with an efficient C++ runtime that provides the fundamental building blocks expected by such high-level languages, including multi-threading, asynchronous event-based communication and memory safety. The micro:bit DAL is specifically designed to run in extremely low memory footprint devices, as little as 8 KB RAM. It provides an abstraction layer allowing a choice of several high-level programming languages, and when partnered with Microsoft's visual blocks and Typescript editor (MakeCode) gives a user experience as easy as MIT's Scratch to use. Despite this, measurements indicate the micro:bit platform has 50x higher performance in CPU benchmarks than state-of-the-art high-level languages designed to operate on similar small footprint devices (micropython, espruino).

The DAL has four main underlying innovations described in [3.3,3.4] that make this possible in small footprint devices:

1) A layer breaking internal communications architecture based on a unified eventing subsystem that provides all components a mechanism to map asynchronous hardware and software events to event handlers.
2) A non-preemptive fibre scheduler that enables support for concurrency while minimizing the need for resource locking primitives (no primitives required above the DAL layer).
3) A common managed type system to enable simple memory management based on reference counting.
4) A stream processing framework based on a composable, receiver-driven component model.

Key to the impact beyond micro:bit, the DAL (now further developed for multiple embedded hardware variations and known as CODAL) was released as open-source software in 2016 along with the entire micro-bit software code stack [3.1] [3.7]. The underlying technical innovations and performance evaluation of the platform are published in [3.3] [3.4].

3. References to the research (indicative maximum of six references)

3.1 micro:bit-dal open source repository: https://github.com/lancaster-university/microbit-dal

3.2 Austin, J., Baker, H., Ball, T., Devine, J., **Finney, J.**, de Halleux, P., Hodges, S., Moskal, M & Stockdale, G 2020, 'The BBC micro:bit – from the UK to the World', *Communications of the ACM*, vol. 63, no. 3, pp. 62-69. https://doi.org/10.1145/3368856
3.3. Devine, J., **Finney, J.**, Moskal, M., de Halleux, P., Ball, T. & Hodges, S. 2018, MakeCode and CODAL: Intuitive and Efficient Embedded Systems Programming for Education. *in LCTES 2018 Proceedings of the 19th ACM SIGPLAN/SIGBED International Conference on Languages, Compilers, and Tools for Embedded Systems. ACM*, *New York,* pp. 19-30. https://doi.org/10.1145/3211332.3211335
3.4. Devine, J., **Finney, J.**, de Halleux, P., Moskal, M., Ball, T. & Hodges, S., 2019, MakeCode and CODAL: Intuitive and efficient embedded systems programming for education', *Journal of Systems Architecture*, vol. 98, pp. 468-483. https://doi.org/10.1016/j.sysarc.2019.05.005
3.5. Efstratiou, C., Davies, N., Kortuem, G., **Finney, J.**, Hooper, R., & Lowton, M. 2007, Experiences of designing and deploying intelligent sensor nodes to monitor hand-arm vibrations in the field. in *Proceedings of the 5th international conference on Mobile systems, applications and services*. pp. 127 - 138, ACM Mobisys 2007: 5th international conference on Mobile systems, applications and services, San Juan, Puerto Rico, 11/06/07. https://doi.org/10.1145/1247660.1247677
3.6. Hodges, S., Sentance, S., **Finney, J**. & Ball, T. 2020, 'Physical computing: A key element of modern computer science education', IEEE Computer, vol. 53, no. 4, pp. 20-30. https://doi.org/10.1109/MC.2019.2935058

3.7 CODAL open-source repositories:
https://github.com/lancaster-university/codal
https://github.com/lancaster-university/codal-core
https://github.com/lancaster-university/codal-nrf52
https://github.com/lancaster-university/codal-microbit-v2

4. Details of the impact (indicative maximum 750 words)

The breadth and depth of the impact of the micro:bit is significant; with the pocket-sized computer having helped to inspire more than **25 million students and teachers** to learn digital creativity and computing skills to date. BBC Director General, Tim Davie, said: *"From the very beginning the BBC's purpose has been to inform, educate and entertain – qualities which are all reflected in the micro:bit project. Since its launch through our 'Make it Digital' campaign, it has helped transform digital skills and learning. I have no doubt the updated and upgraded [V2] micro:bit will drive further innovation and creativity, both in the UK and around the world."* The following text outlines the scale of impact nationally and internationally, and the depth of the impact upon educational and industry practice.

4.1 Impacts on education, gender diversity and public understanding, following the launch of micro:bit

The micro:bit created direct educational and social impacts immediately after it was launched on 22nd March 2016, when it was used to open the London Stock Exchange. On the same day, a micro:bit was delivered free of charge to every year 7 student in England and Wales, every year 8 student in Northern Ireland and every S1 student in Scotland. **1 million devices** were given away in total, with **an estimated monetary value of GBP10 million**.

Quantitative and qualitative data highlights the educational impact of the UK micro:bit rollout. **Over 2 million micro:bit programs were written by schoolchildren and their teachers in the first six months.** As was hoped, exemplar programs included creative, interdisciplinary, team-based projects that introduced students to solving real-world problems. Pupils at Rishworth School who developed a micro:bit based thermal sensor to log changes in temperature. The equipment was attached to a helium balloon and was launched 32km high to record temperatures in the stratosphere [5.1]. Six students at London's Highgate School used the device to help people with autism recognize the emotional states of others by projecting emojis on micro:bit badges [5.1]. Hundreds of children used micro:bits to instrument the performance of their rocket powered entries to the Bloodhound SSC "race to the line" initiative. [5.1]

An independent commercial survey of 405 UK school children and their teachers (undertaken by Discovery Research Group) concluded that 86% of students said the micro:bit made Computer

Science more interesting, **70% more girls said they would choose computing as a school subject after using the micro:bit and 85% of teachers agree it has made ICT/Computer Science more enjoyable for their students.** [5.2a and b]

Public understanding was also impacted through the accompanying media campaign, headed by the BBC. The initial launch was covered by BBC News, The Guardian, Reuters and Bloomberg, among many other major outlets, with a combined readership of over 26 million people [5.3]. Extensive media coverage with household celebrities raised awareness of the importance of computer science and the micro:bit. This included Ronan Keating, who appeared with the device on billboards, and Dara O'Briain, who discussed the device on the Radio 2 breakfast show with Sara Cox. It was embedded and showcased in television shows including Strictly Come Dancing, The One Show (22nd March) and The Voice where it was used to help select the finalist. National 'Make It Digital Roadshows' took place in ten cities around the UK in the summer of 2015, with a combined footfall of approximately 100,000 people [3.2]. Public lectures were also delivered at UK and international educational conferences (Ravensbourne London, 19th Nov 2015 and Newcastle University, 6th July 2017, Lancaster University, 4th April 2017 and Barrow, 23rd November 2017), the Bluetooth SIG (online seminar, 2 June 2016), and the Microsoft Faculty Summit 2016 (July 13th, 2016, Redmond US). All of which, has contributed to the national and international rollout of the product and its wide-ranging successes to date.

4.2 micro:bit and its impact on education – nationally and internationally
In September 2016, the micro:bit began to extend its UK centric impacts to the rest of the world as the Micro:bit Educational Foundation (MEF) was established - a UK-based not for profit organization founded by the project partners (including Lancaster University). The micro:bit has since grown to a truly global scale. The micro:bit is now commercially available **in over 70 countries**, **17 languages**, and at the time of writing, **over 5 million micro:bits** have been distributed globally, **with an estimated 25 million teachers and students** around the world using the micro:bit, and in the words of the CEO of the Micro:bit Educational foundation: *"Lancaster University were a core partner in the development of the micro:bit runtime and the software editors. They also collaborated on specific aspects of the project with the BBC to deliver enhanced learning to students specifically working with Wellcome and the Bloodhound Project. It is safe to say that the project would not have been the success it was without the core role that the team at Lancaster University played."* [5.4b]. During school term times, **over 1 million unique micro:bit sessions per month are typically recorded on the Microsoft MakeCode editor alone** [5.4a]. MEF has also been the recipient of eight awards, including the Ed Tech Company of the Year at the UK Business Tech Awards in November 2020 and European winner of the MIT Inclusive Innovation Challenge 2018 [5.8b].

As the impact of the UK micro:bit rollout was recognised further strategic national and international scale deployments took place. At the time of writing: more than 20,000 micro:bits are on offer in thousands of UK libraries, supporting children and families in disadvantaged areas across the country [5.5]; 64,287 micro:bits have been provided to students in Denmark across 1,447 schools as part of the ultra:bit programme [5.5]; 100,000 micro:bits were distributed to KidsCode Jeunesse (a bilingual national non-profit organization helping build long-term sustainable digital skill communities for Canadian children) to support the country's government funded CanCode initiative in every province and territory across the country [5.6a]; The Icelandic government delivered a micro:bit to every 11/12 year old child in Iceland [5.6b]; The Croatian Academic and Research Network received 45,000 micro:bits for a national rollout to each Year 6 child in Croatia [5.6c]; Singapore's Ministry of Education supported a national campaign to roll out more than 100,000 micro:bits in the country as part of its Digital Maker Programme [5.6d]. The British Council also adopted the micro:bit to support further international strategic initiatives including an aim to reach 1 million children, 22,500 teachers and 4,500 schools in the western Balkans by 2021 [5.7]. They also provide free access to the micro:bit for 175,000 children in Bangladesh through its Libraries Unlimited programme in the same timescale [5.8a].

The micro:bit is also used extensively to support education, outreach and research activities at leading HEIs in the UK and worldwide. Examples include Oxford's Bare Metal micro:bit [5.9], UCL's Computer Science induction [5.10], MIT's Scratch Extension [5.11a and b], Manchester's project Malawi [5.12] and the Laboratory for Playful computation at UC Boulder [5.13].

4.3 micro:bit enables a product ecosystem

The success of the micro:bit has prompted the creation of a global ecosystem of related products and accessories that both enrich educational experiences and bring commercial benefits to industry. There are **257 registered hardware product accessories for the micro:bit spanning 62 companies** [5.14]. Over twelve books about the micro:bit have been published by third party authors. The CODAL/MakeCode software now also supports approximately thirty physical computing devices beyond the micro:bit, including products from industry leaders such as Adafruit, SparkFun, Arduino and the emerging MakeCode Arcade platform [5.4a], [5.15a and b]. Micro:bit also created impact through the enabling of further research projects including the GBP103,480 IoT4Kids project (EPSRC Grant no. EP/N023234/1 and EP/N02334X/1) and the GBP204,411 Energy in Schools project (UK BEIS funded).

4.4 The release of version 2 and the future of micro:bit

Lancaster continues to support and grow the legacy of the micro:bit as an active founding partner of the Micro:bit Educational Foundation, where it continues to lead on the CODAL device software, serve on the hardware advisory committee, and collaborate to support the micro:bit ecosystem as it evolves [5.4b]. In October 2020, the foundation announced the release of the micro:bit v2 [5.16]. This upgrade is designed to extend the scope of the micro:bit to also enable the foundations of machine learning and AI to be introduced to the next generation of computer scientists around the world.

5. Sources to corroborate the impact

5.1. Seven outstanding micro:bit projects: BBC News Article (March 2016)
5.2. [a] Discovery Research Group report; [b] King's College London Independent Evaluation of micro:bit. Both demonstrating efficacy of micro:bit.
5.3 Media appendix with further detail of all known press pieces and reach (full report can be provided upon request).
5.4 Testimonials: [a] Partner Researcher at Microsoft Research – demonstrating impact of Finney's research on Microsoft's work on improving digital literacy among school-age children (January 2021); [b] CEO of Micro:bit Educational Foundation – demonstrating Joe Finney's contribution to the micro:bit project (February 2021).
5.5 Micro:bits around the world - the pocket-sized computer transforming the world.
5.6 Media sources relating to international adoption: [a] Canada (February 2018) [b] Iceland (September 2017) [c] Croatia (December 2018) [d] Singapore (October 2017)
5.7 British Council use of micro:bit in Balkans initiative (2018).
5.8 Sources from microbit.org website: [a] Case study: Transforming libraries into hubs of digital innovation in Bangladesh [b] Awards: various awards at UK Business Tech Awards 2020
5.9 Web resources for micro:bit use as part of Oxford University's Bare Metal outreach and educational project (accessed December 2020).
5.10 Letter from UCL Computer Science Head of Department to first-year undergraduate students directing them to micro:bit educational resources (2016).
5.11 [a] Web link, guide and [b] testimonial relating to use of micro:bit on MIT's scratch project website.
5.12 Web link and statement confirming donation of micro:bits by Lancaster University and micro:bit Foundation for Manchester University's Malawi project (June 2017).
5.13 Educational resources and tutorials relating to micro:bit as part of University of Colorado 'Playful Computation' programme (accessed January 2021)
5.14 Micro:bit - Accessory Guide - Micro:bit Educational Foundation 2020 (January 2020)
5.15 MakeCode website: [a] Repository of products developed and [b] list of educational services/projects (accessed December 2020)
5.16 Press release outlining Lancaster University's contribution to micro:bit v2 development and rollout (October 2020)