Institution: University of Edinburgh		
Unit of Assessment: 23 (Education)		
Title of case study: Developing and implementing a new computing science curriculum in Scottish schools		
Period when the underpinning research was undertaken: 2016 – 2017		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Professor Judy Robertson	Chair in Digital Learning	2014 – present
Dr Andrew Manches	Senior Lecturer	2013 – present
Professor Helen Pain	Professor of Interactive Learning Environments	1983 – 2019
Period when the claimed impact occurred: 1 January 2016 – 31 July 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research from the University of Edinburgh's Centre for Digital Education contributed to enhancing digital literacy, particularly within the Scottish Curriculum for Excellence (CfE), informing curricular change and research-informed development of professional learning for teachers. This work now reaches 51,000 teachers and over 600,000 pupils in all 2,514 state primary and secondary schools across Scotland. To successfully embed digital literacy within the education system, the researchers:

1. advanced national curricular change by informing the revised CfE Technologies curriculum; and
2. enhanced teachers' capacity to support pupils' computer science learning by developing research-informed curriculum resources and professional learning opportunities to embed the curricular changes.

2. Underpinning research

In collaborative research across the University of Edinburgh's Moray House School of Education and Sport and the School of Informatics, Robertson, Manches and Pain have argued that children have a right to understand the strengths, limitations and potential risks of the technology which permeates their lives (3.1). This empirical research, led by Robertson, found that children often lack basic factual knowledge about how computer hardware and software work. The researchers also found that younger children tended to believe that computers have agency by wanting to help them carry out tasks, but overall the children participating in the study were divided and unsure when asked whether computers can think. These findings have important implications since children require basic knowledge of computer architecture to support them to reason realistically about possibilities and pitfalls of future technologies, including artificial intelligence.

In a subsequent paper (3.2), Robertson and colleagues from other institutions documented the theoretical perspective behind the curricular change which they influenced in computer science (CS), showing the importance of helping children understand how machines and languages are used to create artefacts (3.1), in addition to developing computational thinking skills. They described why efforts to make CS entirely focused on "computational thinking", in the absence of knowledge of "computers", are mistaken. They noted the importance of teaching young learners about computational thinking in everyday life, machine architecture, the semantics of programming languages, and building new software. The paper argued that learners require an understanding of three key aspects of CS education:

1) domains in which computers operate,
2) the computational mechanisms that make computers work, and
3) how to use the computational mechanisms to model aspects of the domains.

It is notable that computing curricula at school level in other countries typically focus only on aspect 3, often in the form of writing computer programs. Exploration of common computational processes such as searching or sorting which have many real world applications, or understanding how computers execute instructions in programming languages is often left until university-level courses. The research argues that, for computer science to take its intellectual place beside other sciences at school level, all three foundational concepts should be taught from an early age.

Because topics such as CS are typically new to teachers, it is important to support them through resource development and professional learning. CS, in common with other scientific disciplines, requires the understanding of deep concepts and subject-specific pedagogy as well as practical skills with the various technologies used to develop that understanding. Using a realist evaluation methodology, Robertson led the analysis of evidence gathered on the PLAN C project, a professional development programme designed to support secondary CS teachers at a time of substantial curricular change (3.3). The paper's particular focus is on the formation of a professional development network of several hundred teachers across Scotland. The researchers analysed evidence from a series of observations and teacher surveys over a two-year period with respect to the PLAN C programme theory in order to illustrate not only whether it worked as intended but why. Results indicated that the PLAN C design has been successful in increasing teachers' professional confidence and it appears to have catalysed a powerful change in attitudes to learning. The researchers' recommendations for teacher professional learning were to:

- encourage teachers to engage with pedagogical theories and emerging evidence from the current research literature;
- enable teachers to address gaps in their conceptual CS understanding;
- provide contexts where teachers are regularly able to engage in high-quality professional dialogue with peers in their subject (during which teachers should reflect on their classroom practice, question how their students' learning could be improved and share ideas with each other); and
- create an expectation that teachers will try out new teaching techniques regularly and reflect on these with their peers.

3. References to the research

3.1 Robertson, J., Manches, A., & Pain, H. (2017). "It's like a giant brain with a keyboard": Children's understandings about how computers work. *Childhood Education*, 93(4), 338-345, https://doi.org/10.1080/00094056.2017.1343589

3.2 Connor, R., Cutts, Q., & Robertson, J. (2017). Keeping the machinery in computing education. Communications of the ACM, 60(11), 26-28, https://doi.org/10.1145/3144174

3.3 Cutts, Q., Robertson, J., Donaldson, P. & O'Donnell, L. (2017). An evaluation of a professional learning network for computer science teachers, *Computer Science Education*, 27(1), 30-53, https://doi.org/10.1080/08993408.2017.1315958

4. Details of the impact

The research of Robertson and colleagues had impact in two main areas as detailed below.

1. **Advanced curricular change**

Based on her research and practice in supporting CS education, starting in August 2014 Robertson contributed to a group convened by the British Computer Society and Nesta to consider what skills and concepts primary children should learn within the field of computing and information and communications technology (ICT), and at what stage in the curriculum [5.1]. The group was convened by Kate Farrell, who is now Director of Curriculum on the Data Education in Schools project at the University of Edinburgh, with Robertson as a member. During these meetings, Robertson worked with Farrell, Cutts (University of Glasgow) and Connor (Strathclyde University) with input from Education Scotland staff to develop the ideas underpinning the three significant aspects of learning, which are reflected in the researchers' work (3.2).

In autumn 2016, Education Scotland invited Robertson and Farrell to join a working group revising the Technologies curriculum within the Curriculum for Excellence (CfE) [5.1], which supports over 51,000 teachers who work with over 600,000 learners in Scotland throughout their broad general education. Robertson, Farrell, Cutts and Connor collaborated to enhance the curriculum draft so that it aligned with the academic recommendations and research findings. These contributions have enhanced the curriculum in two important ways:

A) Drawing on the research (3.1, 3.2), the Technologies curriculum now includes CS as a distinct area of learning, supporting learners to develop CS knowledge and skills in a coherent line of progression [5.2].

B) This curriculum supports curriculum organisers to implement the research findings by including the three key aspects of CS education identified by the researchers (3.2) within a broader framework of "key concepts" [5.2]:

- The concept "Understanding the world through computational thinking" (TCH 0-13a to TCH 4-13b) corresponds to what the research refers to as "1) domains that can be modelled by computational mechanisms".
- The concept "Understanding and analysing computing technology" (TCH 0-14a to TCH 4-14c) corresponds to "2) computational mechanisms themselves".
- The concept "Designing building and testing computing solutions" (TCH 0-15a to TCH 4-15a) maps to "3) how to use the computational mechanisms to model aspects of the domains".

Describing the curricular change, one teacher said: *"The change in curriculum has been transformational in terms of Es and Os [curricular expectations and outcomes]. …This is very different from other curriculums. Many are very content led. This was future proofed"* [5.3].

Furthermore, a Policy Executive from the Scottish Government's Learning Directorate described Robertson's contributions to the curriculum change: *"The valuable work you undertook was significant in the wider aim of updating the curriculum to reflect the rapid and on-going changes in digital technology within our society"* [5.1]. He highlighted: *"We particularly valued the academic expertise you brought to the discussions and the collaboration with Computing at Schools Scotland and the Scottish Informatics and Computer Science Alliance to ensure that learners have the opportunity to use computational thinking as a means of developing capabilities in problem solving and computing science"*.

2. **Developed research-informed curriculum resources and professional learning opportunities to embed the curricular changes**

The Education Scotland Technologies working group acknowledged that the introduction of a specialist curricular area such as CS within broad general education was ambitious since it would require a steep learning curve for non-specialist teachers. Therefore, to support teachers in updating their practice, a group of academics led by Robertson and Farrell ran a series of professional learning events which were designed based on the research findings (3.3) including a successful conference to accompany the launch of the new curriculum and a series of "Coding and Cake" workshops on programming and data literacy. Robertson and University of Edinburgh colleague Linklater, in collaboration with Edinburgh City Council and sponsored by the technology company CGI, ran a year-long professional learning course in Computational Thinking for 14 Edinburgh-based primary teachers, piloting activities that met gaps in teachers' knowledge about CS. Participants commented that the workshops and course increased their confidence in CS skills and knowledge and provided them with effective CS teaching approaches that build on pupils' existing knowledge [5.3].

The University of Edinburgh team developed the Teach CS Primary Guide that explains the three key concepts of the revised curriculum informed by the research, providing various example activities for each curricular level and outcome. For example, to support children in the early years who are exploring computational thinking processes involved in everyday tasks and identifying patterns (organiser 1, outcome TCH 0-13a), teachers may use simple activities to help children sort toys by colour or shape, or identify the steps in everyday activities such as hand-washing. Sorting objects in the real world is conceptually similar to sorting information by attribute, which is fundamental to computer science. This Guide was distributed to all 2,019 primary schools in Scotland in 2017 and to 1,200 subscribers to the *Times Educational Supplement Scotland* in 2020.

The Guide and related professional learning workshops were independently evaluated in February 2020 [5.3]. The purpose of the evaluation was to gather evidence of the impact (if any) that (A) the Teach CS Guide has had on the confidence and competence (particularly understanding of CS concepts) of primary teachers who have engaged with it while teaching the new computing science strands of the Technologies section of the CfE and (B) gather views from teachers about how the change in curriculum has impacted their learners.

The independent evaluator stated: *"Without a doubt, use of the Teach CS Handbook* [Guide] *has increased the confidence of those teachers using it"*. For example, one teacher reflected on the benefits: "*although Es and Os are giving schoolteachers an understanding of what every child should understand in the curriculum, the document takes that and makes it much more manageable for teachers in schools"*. Another participant stated: *"If I hadn't been directed to the handbook, I wouldn't have changed my teaching. It made me see it in a different light"*. A different teacher said she regularly uses the Guide in shaping her teaching practices: "*I use it to select my activities when I'm teaching computing science. That is what I go to; it is my go-to thing, when I think 'what should I be teaching?'".* A primary teacher reflected on the different ways in which the Guide has enhanced colleagues' teaching practices, since it has proved beneficial in terms of making technical vocabulary accessible to teachers and illustrating how each curricular aspect can be taught. For example, "*it definitely helps older generation teachers who are not confident and also new teachers on 'how do I actually teach it'".*

A specialist in learning technologies for a Local Authority attended a short course run by Robertson and Farrell and, with permission from the researchers, subsequently created an open-source, interactive version of the Guide that facilitates connections across section areas. This online resource has been shared with over 500 primary teachers across their Local Authority. As a result, *"It has led to a change in the way we are producing resources"* because senior leaders have adopted the Guide's style for other curricular areas [5.3].

Teachers' enhanced practice as a result of the CS Guide and related resources has had a positive impact on pupils' learning. For example, the Guide supports teachers to explain CS concepts in more accessible ways for children, *"helping pupils understand the concepts"* and supporting teachers to *"know the children are making progress toward this outcome"* [5.3]. Furthermore, teachers reported that the resources and interactive activities in the Guide have sparked pupils' engagement and enjoyment of learning CS.

The evaluation report [5.3] concluded that:

> *"Use of the handbook led to increased confidence among teachers – interviewees and, often, their colleagues. The handbook led to clearer understanding of key concepts and thus to an increase in teachers' competence when teaching pupils about those concepts – to the benefit of pupils. The handbook has had an impact on teaching practices of individuals and also, through various planning processes and documents, on practices of colleagues."*

5. Sources to corroborate the impact

5.1 Testimonial from Policy Executive, Learning Directorate, Scottish Government, describing Robertson's contributions to the British Computer Society/Nesta working group and subsequent Education Scotland working group

5.2 Curriculum for Excellence: Technologies Experiences and Outcomes (see pp. 8-9), available at: https://education.gov.scot/Documents/Technologies-es-os.pdf

5.3 Impact Evaluation: Teach Computing Science Handbook, available at: https://schoolsonline.education.ed.ac.uk/wp-content/uploads/2020/06/Comp-Sci-Teach-CS-Handbook-Impact-Evaluation.pdf