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Key Factors for Successfully Embedding a Programming Approach to the Primary Maths Curriculum at Scale

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The ScratchMaths (SM) intervention was designed in response to changes in the primary curriculum in England to incorporate mandatory computer science - aiming to exploit this change in the interests of mathematics learning. In this paper we describe SM and its critical components for implementation with fidelity. We present preliminary case studies of two high-fidelity schools, which point to variation in fidelity of implementation. We conclude with a derivation of quantifiable measures for the identification of high, middle- and low-fidelity schools (O'Donnell, 2008).

Keywords: Primary mathematics, computer science, teacher professional development, coding, programme evaluation.

Introduction

In 2014 in England, the previous information and communications technology (ICT) primary curriculum was replaced by a new computing curriculum specifying mandatory content (but no pedagogical guidance) for the teaching of computer programming to all pupils (Department for Education, 2013). Some factors that contributed to Logo and other early programming initiatives not fulfilling their potential have been described in earlier work (Benton, Hoyles, Kalas, & Noss, 2016), a key factor being identified by Noss and Hoyles (1996) as the importance of fostering a sense of teacher understanding and ownership of any programming innovation.

There have been significant technological developments since this early teaching of computer programming, with a number of block-based languages such as Scratch now freely available and widely used. These environments have helped to address some of the difficulties of mastering programming syntax, but there remains the challenge of ensuring that teachers first appreciate why they are introducing programming as part of mathematics - and then have opportunities to develop appropriate skills to teach programming.

The ScratchMaths (SM) 2-year intervention¹ aimed to develop the mathematical knowledge of pupils (aged 9-11 years) through programming. The SM approach was to select and design activities around core computational ideas that would then be used as vehicles to explore specific mathematical concepts and promote mathematical reasoning. For example, the concept of variable is developed by enabling pupils to first explore the *Answer* block, initially on its own, but then in association with its companion block *Ask* in the context of a short script that draws polygons. Pupils encounter the limitations of the *Answer* block when confronted by a situation that needs the answer to contain two different values simultaneously, stimulating a need to introduce the new idea of **Variable**. This approach enables parts of computing to be taught within, or as a supplement, to mathematics lessons.

SM initially adopted a design research methodology to produce pupil and teacher materials along with professional development (PD) to support the teachers to exploit the powerful ideas of computational thinking as a way to engage pupils in mathematical thinking (see Benton, Hoyles, Kalas, & Noss, 2017 for a detailed account of the design of the study). SM is also being independently evaluated by another university through a randomized control trial (RCT, see Education Endowment Fund, 2016 for the detailed research design of the RCT). The first year's content (Y5 in England) focuses primarily on the computing curriculum and developing pupils' programming skills. In the second year (Y6), pupils utilise these programming skills to explore key mathematical ideas within the primary mathematics curriculum (place value, polygons and ratio and proportion). 111 English primary schools (6300 pupils) were recruited to the project by open invitation through networks such as the National Association for Advisers in Computing Education (NAACE) and regional information events. The schools were randomly assigned to the control and treatment groups at the school level. Schools did not pay to participate in the project and the

¹ <https://www.ucl.ac.uk/ioe/research/projects/scratchmaths>

teaching materials are freely available from the ScratchMaths website under creative commons licensing (www.ucl.ac.uk/scratchmaths).

The primary research question for the RCT conducted by the external evaluators was “What has been the effect of the intervention on the development of pupils’ mathematical skills as measured by a randomised control trial?” However, in parallel to this the authors of this paper sought to research how the curriculum materials were used by teachers to seek to understand its effects. The research reported here concerns the latter study.

Theoretical background of ScratchMaths and its pedagogical design

The SM design was framed by constructionist theory whereby pupils would engage with the mathematical ideas by building programs to explore them. (See Noss & Hoyles, 2017). This constructionist approach was operationalized in a pedagogical approach structured by five key ideas, called the ‘5Es framework’ derived from the theoretical underpinning of constructionism (Papert, 1980) and described in Noss & Hoyles (2017), see also Benton et al. (2016). These five unordered constructs are:

Explore: Pupils learn from computer feedback. Pupils should have opportunities to explore different ways of dealing with constraints and ambiguity as well as investigating their own and others’ ideas and debugging different types of errors. Through this exploration pupils should be encouraged to take control of their own learning and understand the reasons behind different outcomes.

Explain: Pupils use different modes of communication to articulate learning and the reasoning behind choices of approach. Pupils should have opportunities to explain their own ideas as well as answer and discuss reflective questions from the teacher and peers. Pupils should be encouraged to use the programming language as a ‘tool to think with’ and to support explanations of key mathematical ideas.

Envisage: Pupils predict outcomes of their own and others’ programs with specific goals prior to testing out on the computer. Pupils should be given opportunities to consider program goals and the outcomes of different strategies before conducting their own exploration in Scratch. This should be balanced with activities which allow discovery through exploration.

Exchange: Pupils develop ideas through interacting and comparing with others. Pupils should have opportunities to share and build on others’ ideas as well as being encouraged to both justify their own solutions and understand another’s perspective on a problem.

bridgE: Pupils make links between contexts beyond the Scratch programming environment and the mathematics domain by explicit re-contextualization and reconstruction within the language of mathematics.

Our overall aim in developing this framework was to chart a course for pupils in which they could begin to express mathematical ideas in Scratch and to provide guidance for teachers on the pedagogical strategies (which the English National Curriculum does not stipulate) that could lead to successful implementation of the SM intervention.

Professional Development

Prior to teaching each year of the SM intervention, teachers were offered two full days of professional development, spaced a few months apart. During these sessions, the teachers were introduced to Scratch and the SM curriculum content. The 5Es framework guided the design of these highly interactive sessions, with teachers given the opportunity to participate in activities that incorporated exemplars of these different pedagogical strategies. After experiencing for themselves the pedagogical approach, as modelled by the PD leaders, teachers were also explicitly introduced to the approach and the definitions of each of the constructs.

Curriculum Materials

The learning objectives of all activities within the SM curriculum are focused towards one or more of the 5Es. The connection with the different constructs is made explicit within the teacher materials, with a range of activities such as Scratch-based tasks that require pupils to explore within the Scratch environment and then subsequently explain and exchange their programs with the rest of the class as well as ‘unplugged’ tasks (away from the computer) which require pupils to envisage outcomes of particular programs and bridge to their existing mathematical knowledge to calculate the correct inputs.

Findings

Measurable constructs for the fidelity of ScratchMaths

Fidelity of implementation within an education context has been defined as “the determination of how well an intervention is implemented in comparison with the original program design during an efficacy and/or effectiveness study” (O’Donnell, 2008). Using the criteria of program differentiation, the SM team evolved some critical components for implementation with fidelity of the SM intervention, leading to the derivation of quantifiable measures for the identification of high-, middle- and low- fidelity implementation. There is a tension between a high-fidelity implementation of the original designed intervention and the potential for the intervention to be adaptable and flexible enough to fit within a range of contexts, which could lead to higher rates of adoption and sustainability (O’Donnell, 2008). Therefore, finding an appropriate measure of fidelity that identifies the critical components of an intervention that must remain unchanged but allows for appropriation to local context was important.

The fidelity of implementation was defined in terms of five school-level measures as: days of professional development attended; availability of computer technology; curriculum coverage; the amount of time spent teaching SM and the sequence of progression followed through the materials. The criteria are given in Table 1.

| Fidelity criteria | High | Medium | Low |
|----------------------------------|---|--|--|
| Days of professional development | Y5 and Y6 teachers each attended at least two days of PD. | Y5 and Y6 teachers each attended at least one day of PD. | Y5 and/or Y6 teacher had limited PD from a more experienced person away from the |

| | | | |
|------------------------|--|--|--|
| | | | organised sessions. |
| Technology | Computers running Scratch 2.0 online or offline. Minimum 2:1 pupil to computer ratio. | <i>No classification</i> | Computers running Scratch 2.0 online or offline. Minimum 3:1 pupil to computer ratio. |
| SM curriculum coverage | Pupils taught at least some of the core activities across 5 different modules. | Pupils taught at least some of the core activities across 4 different modules. | Pupils taught at least some of the core activities across 3 or fewer different modules. |
| Curriculum time | Time spent teaching SM is at least 20 hours in Year 5 and at least 12 hours in Year 6. | Time spent teaching SM is at least 12 hours in each year. | Time spent teaching SM is fewer than 12 hours per year. |
| Progression | The order of modules and order of activities are mostly followed in general. | The order of modules and order of investigations are mostly followed in general. | The order of modules is mostly followed in general. |

Table 1: The ScratchMaths fidelity criteria

All schools participating in the trial received online surveys to complete at the end of the 2015-16 and 2016-17 school years to collect information about SM implementation. 28 of the 55 ‘treatment schools’ provided data to both surveys and are included in our analysis presented below. Whilst a more complete set of research data would have increased the validity and reliability of our findings, we could only work with the data that we received. Indeed, it is a finding that, despite their initial enthusiasm to participate in the project, with institutional participation agreed by the headteacher, approximately half of the schools did not respond to project communications. Hence the survey results of these 28 schools, alongside data triangulation by follow-up communications and school visits, were then used to classify the schools according to their fidelity.

School level fidelity

The spread of fidelity scores for the 28 schools is shown in Figure 1.

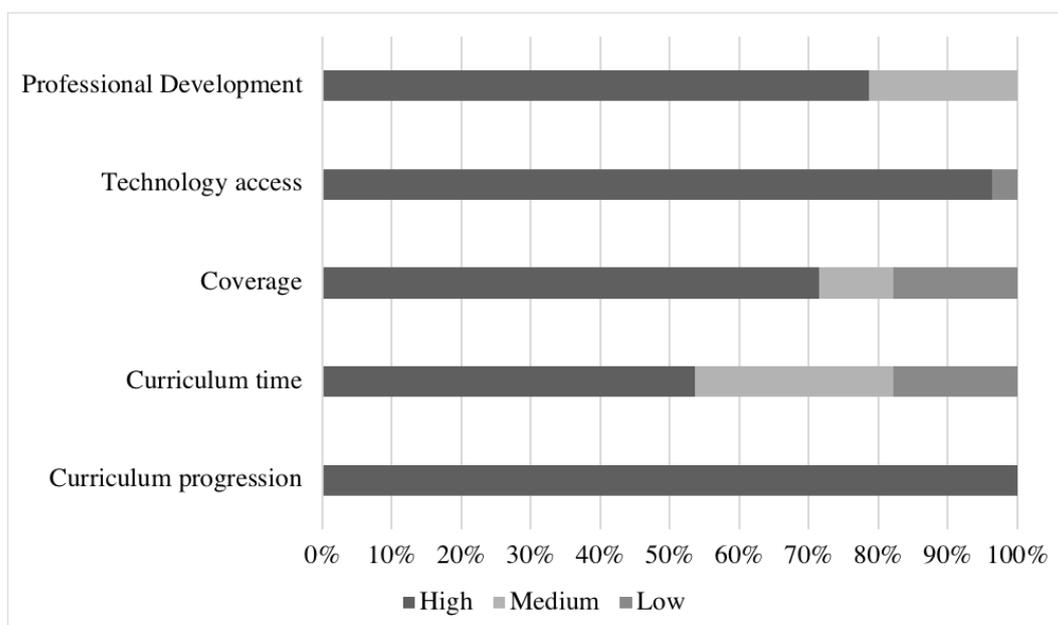


Figure 1: Spread of fidelity measures (n=28 schools)

Probing the survey and interview data further revealed a number of findings.

Professional development: The school-level fidelity measure reveals high commitment to the PD. However, probing the data further revealed that 43% of schools were hampered by internal staff changes and teacher movement in and out of the schools (teacher ‘churn’). So, in fact the teachers who were trained did not necessarily match with the actual classes being taught SM.

Technology access: Only one school was unable to provide the pupil:computer ratio of at least 2:1, which resonates with recent OECD data on the high levels of computer access in UK schools (OECD, 2015).

Coverage: Three quarters of the schools reported that they had struggled to cover the SM curriculum. This was particularly evident in Y6 where the demands of the high-stakes National tests are great, with the result that a huge proportion of class time was spent ‘teaching to the test’ and associated revision activities.

Curriculum time: The allocation of curriculum time was challenging for about half of the schools, again more evident in Y6 due to pressures of the National test.

Curriculum progression: All of the schools were high fidelity in that they followed the order of the teaching modules and the activities within them. (In lower fidelity schools, teachers reported that they varied the sequencing or skipped activities).

This analysis identified 15 schools that were high fidelity for all five criteria. From this group, an opportunity sample of 2 schools was selected for follow-up visits and semi-structured interviews with teachers and headteachers during the 2017-18 school year, focusing on three general questions to elicit respondent’s experiences and perceptions of the SM curriculum: How and why they got involved in the SM project? How they implemented SM, and what were their impressions of SM? Both schools were in the same geographical (rural) area about one mile apart. The resulting data

was used firstly, to triangulate the fidelity judgement for each school and secondly, it was coded in relation to the 5 Es as a means to establish a deeper understanding of the quality of the implementation. Arriving at a school level judgement for a project that had spanned two years proved to be complex due to the differing experiences, perceptions and memories of the people involved.

The demographic information for the two schools is given in Table 2.

| School | Number of pupils on roll | Scaled score in mathematics (100 = National expected score) | School progress in maths score ² | % of pupils eligible for free school meals (Measure of socio-economic status) |
|----------|--------------------------|---|---|---|
| School A | 420 | 102 | Average (-0.9) | 28.9% |
| School B | 424 | 101 | Below average (-3.1) | 3.6% |

Table 2: Overview of the schools³

Although similar in overall size, the pupil demographic and attainment measures were notably different; one might have expected School A to achieve rather lower progress given the social background of the pupils. This difference is highlighted in School B's lower 'progress score', a comparative measure of pupil progress in similar schools. Both schools taught the SM curriculum in the teaching time allocated for the teaching of computing and none of the teachers in either school also taught mathematics to the same pupils. We now highlight aspects of the quality of delivery that were discernible from the research data, to provide deeper insight in relation to school-level implementations.

School A was confirmed as a high-fidelity school as it became clear that the two teachers involved (Peter and Carol) had worked in a highly collaborative way and had both embraced the SM curriculum, dedicating their planning and preparation time to becoming familiar with all of the pupil activities in advance of the lessons, as highlighted by the following response:

Peter: You couldn't just pick it up and follow it, and then expect the children to understand. And, then we thought, 'Well, if we have got to spend this amount of time getting our heads around it, it is a big ask for the children to do it in the same time'.

² A government-defined measure of school progress with respect to pupils' mathematical outcomes at age 11. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/560969/Primary_school_accountability_summary.pdf

³ 2017 data taken from <https://www.compare-school-performance.service.gov.uk>

Concerning the 5Es, Carol referred to the ways in which she encouraged children to *Explain*,

Carol: Once they got it, we kind of said, ‘Well, try to show the person next to you, if they haven’t,’ and then sometimes, if they showed them one little bit, they were alright then...

Peter highlighted how the pupils *Exchanged* their ideas,

Peter: And, I make a point at the end of sessions now, I leave 15 minutes before the end so that anyone who has done what I have asked them to do, essentially gets to share their work. And, they absolutely love it, whether they have not quite got it, or they have done more... .. I put it up on the big screen for them.

In addition, School A had made the SM materials locally accessible and created files of exemplar student work, which had supported alignment between the two teachers’ pedagogic approaches.

The overall fidelity criteria for school B was also confirmed to be high as the two teachers described how one of them (David) had taught the Y5 curriculum to both classes and the second teacher (Tim) had done the same in Y6. During interview, Tim described his pedagogic approach thus,

Tim: We sort of gave them the option to explore the bits and for them to ... trying to link it to the real world, to explain the steps behind it... why they have done what they have done, why they think it is may be more efficient or whatever. And as I say, I think we did the envisioning with a lot of the debugging ones [activities].

David commented on his use of the unplugged activities, highlighting how he encouraged pupils to *Envisage*, *Explain* and *Exchange* their ideas,

David: I would put up, for example, one of the algorithms and I say, “Well, what would this algorithm do if we clicked on it,” and they would talk it through with a partner and then... I could pop one up on the board and say, “Right, what would this do?” And, “If we changed this bit, how would that change the outcomes?” and things like that.

Final comments

It is hard to assess in such a large-scale study how far the implementation of SM was faithful to the designers' goals (Fullan, 2001). Many of these goals were generic, and we make no claim to originality on this score. For example, teacher 'churn' was both ubiquitous and destructive - quite frequently SM teachers had not engaged fully with the PD. However, where we saw specific variation in fidelity, it tended to be related to the particularities of attempting a novel and demanding curriculum based on a somewhat daunting field of knowledge – programming – where teachers had little or no background. In such circumstances, the curtailment of teaching time due to the pressures of national testing was a strong impediment.

Clearly, some factors supported SM implementation: local access to the resources, exemplar student work and pre-written computer models. The excellent collaborative practice of School A that enabled them to overcome the challenges is noteworthy and echoed in other high-fidelity schools.

We noted little teacher adaptation at this first stage of implementation, but with more fluency and familiarity with the SM approach, this is likely to grow, leading, we conjecture to less emphasis on 'curriculum coverage' and more time to explore the mathematical ideas.

Acknowledgment

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