Programming and Mathematics
Insights from research in England

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NCCE online seminar June 2020
Inspiration…….

Eric Schmidt
Chief Executive of Google visited England 2011

“I was flabbergasted to learn that today Computer Science isn't even taught as standard in UK schools”

“Your IT curriculum focuses on teaching how to use software, but gives no insight into how it's made”.

Royal Society reports
• Shut Down or Restart 2012
• After the Reboot: Computing Education in Schools 2017

From slaves of technology to its master
From consumers to creators
New statutory primary National Computing Curriculum 2014 in England for pupils age 6 to 16 years

Key aspect: pupils should **design, build & debug programs**

National Centre for Computing Education (NCCE)

[https://teachcomputing.org](https://teachcomputing.org)

How does **programming** fit with the rest of the curriculum?
My background

1. Mathematics and mathematics education

2. Inspired by constructionism; vision of Seymour Papert around the potential of Logo programming

3. Involvement in
   - Logo: 50+ years of research (with Richard Noss)
   - Huge conferences at MIT 1984/5
   - Logo Maths movement

1. Learning effective when making an artefact that is **personally** or **socially meaningful**; can be **shared** with others; **reflected upon, debugged** (see for example Kafai & Resnick, 1996)

2. Importance of
   - **powerful ideas** embedded in well-designed constructionist activity
   - **personal meaning** and **emotional connection**...
What does it mean to program & why program?

To understand how something works
- build
- trace
- debug
- share.....
UCL ScratchMaths project 2014-20......

SM developed a 2-year curriculum with teacher and pupil materials for 9-11-year-olds in England
• aligned to the National Computing and National Mathematics primary curricula
• supports the teaching of carefully selected core ideas of computer programming alongside specific fundamental mathematical concepts

We acknowledge the generous funding of the Education Endowment Foundation
UCL ScratchMaths project 2014-20…ctd

• supported schools in addressing computing curriculum using specially devised materials in Scratch

• supported mathematical learning by teaching some of the mathematics involved through programming in Scratch
Computational Thinking alongside Mathematical Thinking

Computational thinking

Mathematical Thinking
Computational thinking

• seeing a problem and its solution at many levels of detail (abstraction)
• thinking about tasks as a series of logical steps (algorithms)
• understanding that solving a large problem can involve breaking it down into a set of smaller problems (decomposition)
• appreciating that a new problem is likely to be related to other problems the learner has already solved (pattern recognition)
• realising that a solution to a problem can be made in ways that can solve a range of related problems (generalisation)
Phases of UCL ScratchMaths

Phase 1. Iterative Design
- computer tools
- materials tried with small number schools/teachers
- professional development for the teachers

Phase 2. Implementation at scale
- > 100 schools across country
- PD in regional ‘hubs’
- formative evaluation

Phase 3. Summative evaluation
- teacher reflections, survey, interviews, curriculum coverage, fidelity
- student outcomes by RCT (external)

impact & dissemination
replications/ adaptations in different contexts or countries
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UCL ScratchMaths project team

Interdisciplinary team led by

- Professor Dame Celia Hoyles (Mathematics) & Professor Richard Noss (Mathematics) UCL Knowledge Lab
- Professor Ivan Kalas, (Computing) Comenius University, Bratislava, Slovakia
- Dr Laura Benton (Computing) & Piers Saunders, (Mathematics) UCL Knowledge Lab
- Prof Dave Pratt (Mathematics) UCL Institute of Education
Phase 1. Iterative Design

4 design schools

• Intensive work with teachers over two years: design workshops, observations

• Trials in design schools

Evolved *principles to guide design* of

• *pedagogical framework*

• *instructional sequence* (9-11 year students, Year 5 and Year 6) & *professional development framework*

• *curriculum materials* for Years 5 & 6
Outcome 1. Pedagogical framework (5Es)

Explore: Investigate, try things out yourself, debug in reaction to feedback

Envisage: Have a goal in mind, predict outcome of program before trying

Explain: Explain what you have done, articulate reasons behind your approach to yourself & others

Exchange: Collaborate & share, try to see a problem from another’s perspective as well as defend your own approach and compare with others.

bridge: Make explicit links to the mathematics curriculum
Outcome 2: Two-year instructional sequence & Professional Development

SM Year 1
- Teacher support
- Year 5
  - 9/10 yrs
- Computational Thinking
  -(Implicit maths)

SM Year 2
- Teacher support
- Year 6
  - 10/11 yrs
- Mathematical Thinking
  -(explicit maths)
2 days of Professional development per year
• orienting day
• use in school (online support, visits, gap task)
• reflections & further orientation

–NOTE: At the end of Year 6 all students in England take a high-stakes National Mathematics Test, Key Stage 2 test
Year 5 (9-10 yrs) – Computing focus (20+ hours)

Outcome 3. student & teacher curriculum & support materials

Year 6 (10-11 yrs) – Mathematics focus (20+ hours)

Freely available through UCL website http://www.ucl.ac.uk/scratchmaths
Outcome 3. Student & teacher curriculum & support materials (ctd)

• Teacher materials for each module:
  • Detailed description of each activity
  • Starter projects
  • Additional support including example scripts
  • Unplugged pupil worksheets
  • Suggested discussion points

• End of module assessments
• SmartBoard presentations for all activities
• Supporting videos
• Reference posters
• Additional challenges
—blended learning

• on- and off- computer
• different modes of classroom interaction to support E’s
Module descriptions

Module 2: Beetle Geometry

Introduction to Module 2

Module 2 is focused around creating different drawings using the pen tool including numerals, patterns, polygons as well as entire scenes. This module could potentially be linked with several different areas of the Key Stage 2 curriculum including history, science, and geography.

History: Romans and Morse Code

The first investigation looks at drawing Roman numerals which could link to history projects around the Roman empire.

The third investigation requires pupils to create Morse code messages, which could link to work on the history of communication.

Geography: The Natural World

The final project in this module is creating different scenes found in nature including forests and beaches. This investigation could be linked in with geography topics exploring different elements of the natural world.

Key Vocabulary and Concepts Covered by Module 2

Scenes: Pen, colour, backdrop, pre-defined blocks, pick random, repeat block, define block

- Pen down, pen up blocks
- Pen colour blocks
- Pen shade blocks
- Pen size blocks
- Backdrop
- Pre-defined blocks
- Pick random
- Repeat block
- Define block

Computing: Initialisation, expressions, debugging, sequence, repetition, logical reasoning, algorithm, definition

Mathematics: Roman numerals, perimeter, regular and irregular polygons, multiplication and division, angles, rotation, positive and negative numbers, coordinates

Images by Helene Guerber (Story of the Romans) [Public Domain], via Wikimedia Commons; (Borch3kawki~commonswiki) (Amanita muscaria 01) [Public Domain], via Wikimedia Commons; "Praia da Redinha Natal" by Patrick - Patrick - Canon PowerShot A200.. Licensed under CC 3.0 via Wikimedia Commons; https://commons.wikimedia.org/wiki/File:Praia_da_Redinha_Natal.jpg#/media/File:Praia_da_Redinha_Natal.jpg
Computer tools: Scratch or ScratchMaths 😊
What looks different?

Module 1. Tiles

Module 2. the Beetle
A Scratch Program

1. define polygon
2. repeat number of sides
3. move side length steps
4. turn 360 / number of sides degrees
Unplugged: Predictions

Read each of the scripts. Draw and/or explain in words the picture that it will create.
Module 2: Investigation 3
Activity 2.3.2 – Unplugged: Picture Predictions

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Module 2: Investigation 3
Activity 2.3.2 – Unplugged: Picture Predictions

- Read each of the scripts. Draw and/or explain in words the picture that it will create.

1. dear
   - set pen color to
   - set pen size to 10
   - repeat 24
     - dot
     - move 20 steps
     - turn 15 degrees

2. dear
   - set random pen size
   - repeat 24
     - dot
     - move 20 steps
     - turn 15 degrees

3. dear
   - set random pen size
   - repeat 24
     - set random pen size
     - dot
     - move 20 steps
     - turn 15 degrees

4. dear
   - set pen color to
   - repeat 24
     - set random pen size
     - dot
     - move 20 steps
     - turn 15 degrees

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1. A circle with red dots
2. A circle with red dots
3. A question mark
4. A question mark
Module 2: Investigation 3
Activity 2.3.2 – Unplugged: Picture Predictions

☐ Read each of the scripts. Draw and/or explain in words the picture that it will create.

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   set pen color to
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   set random pen size
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   dot
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4. dear
   set pen color to
   set random pen size
   repeat 24
   dot
   move 20 steps
   turn 15 degrees

Images of drawn circles with varying dot patterns.
Polygon Fireworks
Three Phases of UCL ScratchMaths

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impact & dissemination
replications/adaptations in different contexts or countries
Phase 2: Implementation at scale

- 7 regional hubs and local coordinators (maths and/or computing PD leads)
- 110 English primary schools with 2,986 students
- PD in each region by UCL team along with hub lead and ongoing support
- Independent evaluator appointed in April 2015 for Phase 3
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Phase 3: Summative evaluation

Teacher reflections
survey, interviews

fidelity: professional development, technology access, coverage, curriculum time, curriculum progression

Students outcomes (independent evaluator)

• randomised control trial methodology (RCT)
  treatment and control groups with schools matched according to 2 standard measures
    • socio-economic status using proxy measure of eligibility for free schools meals
    • prior attainment as measured by national standardised mathematics assessment at age 8 years
  • Computational thinking test scores for Year 5 students, test designed, administered & scores analysed by evaluator
  • National Key Stage 2 Maths test for Year 6 students
Findings from RCT evaluation of impact of ScratchMaths

• Positive & significant impact on Computational Thinking skills in Yr 5
• Particularly evident among disadvantaged pupils ..those who had or currently have free school meals
• No difference between girls and boys
• No evidence of impact on the national Key Stage 2 Maths test

“ScratchMaths is an affordable way to cover aspects of the primary computing curriculum in maths lessons without any adverse effect on core maths outcomes”

The evaluation report can be found at
• https://educationendowmentfoundation.org.uk/projects-and-evaluation/projects/scratch-maths/
• The student and teacher materials are freely available from the UCL website http://www.ucl.ac.uk/scratchmaths (creative commons license)
Why these findings?

- **Positive & significant impact** on Y5 Computational Thinking skills
- Particularly evident among disadvantaged pupils ..those who had or currently have free school meals
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Fidelity
very high in Year 5 ..dramatic drop in Year 6

• ? negative impact of the high-stakes testing in mathematics at the end of Year 6

• Huge variation in pedagogy
  *computing was new; maths is scary.*
• Lethal mutations 😞
• Need to return later: 3 to 4 years …..
Three Phases of UCL ScratchMaths

UCL ScratchMaths materials upgraded to Scratch 3

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Absolutely loved ScratchMaths, it was so fun learning all about coding and was something I looked forward to every Monday. I enjoy having to find the problem when it goes wrong and then making the code much better. I find it really cool that you can program a computer to do something like turning a certain amount of degrees or moving a certain amount of steps.

ScratchMaths was difficult at first but once I learnt the basics all I wanted to do is learn ScratchMaths.

Led by Elena Prieto-Rodriguez & Kathryn Holmes
Dr. Hongliang Ma, Professor in Educational Technology, Shaanxi Normal University

• designed ScratchMaths learning materials aligned to the Chinese Math Curriculum Standard for grade four students
UCL Scratchmaths in Spain

• The Spanish Ministry of Education translated ScratchMaths curriculum into Spanish and updated the materials to Scratch 3.0.

• Implemented an online teacher training course using the SM curriculum (Dec 2018-Jan 2019) with 310 teachers across Spain taking part (about 4000 students)

• From February-May 2019 the teachers implemented the activities with their students

• Evaluated the impact computational thinking and maths skills through pre/post tests.
Final report of "Escuela de Pensamiento Computacional" (School for computational thinking) part of which concerned the impact of the Scratch maths was published in Dec 2020.

Google translate says:

"....

the results show that it is possible to include programming activities in 5th grade in the area of mathematics, so that students not only learn to program and engage in computational thinking, but also improve the development of their mathematical competence greater than their colleagues who have worked in this same area using other types of activities and resources not related to programming."
personal thoughts on limitations of our project

- **Assessment** of student outcomes: mathematics & computing
- **Assessment** of teacher outcomes
  - understanding of computational concepts; e.g. in Scratch: multiple sprites, parallel processes, sending & receiving messages, sensing collisions…….
  - competence & confidence in teaching them (self-efficacy)
- **and another subject focus ...?**
- **Assessment** of actual practices in classroom? fidelity measures, gender interactions?
- Commitment to **professional development** for teachers
Need more fine-tuned and nuanced quantitative student outcomes?

All those teaching UCL ScratchMaths have engaged with the PD...... Impossible...... 😞
More general reflections...

- **On pedagogy**: multiple representations
- **Other subject domains**: is there anything special about maths and computing/programming?
- **Transitions**: upwards and downwards?
- **Teacher confidence**
- **Affective component**
- **School component**...Support of senior management?
A great chance for mathematics and computing

“Magic in front of my eyes”

Glimpse of the classroom case studies
Thank you