Cornerstone Maths: Designing for Scale

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This paper builds on the outcomes of the Cornerstone Maths pilot study, a USA/UK collaboration, which is now in a phase of scaling to over 100 schools. We describe the vision for the project and its iterative design, both informed by a twenty-year history of research on dynamic digital technologies. The resulting intervention builds on our understanding of some of the constraints to the widespread use of dynamic digital technologies by pupils in mathematics, which relate to accessibility, teacher development, curriculum alignment and the need to support the instrumentation process for teachers. The accompanying research agenda is concerned with evaluating models for scaling that are mindful of the 'grain size' of analysis and the necessary re-alignment of the design principles of the innovation to take account of implementation imperatives.

Keywords: Cornerstone Maths, dynamic digital technology, geometric similarity, linear function, scaling, teacher development

Introduction

The *Cornerstone Maths* project seeks to exploit the dynamic and visual nature of digital technology (DT) to stimulate engagement with mathematical ways of thinking within key stage 3 by: focusing on the 'big mathematical ideas'; making links between key representations; and providing an environment for students to explore and solve problems within structured activities. The project is a collaboration between SRI International (USA) and the London Knowledge Lab (UK), funded by the Li Ka Shing Foundation. It builds on extensive work both in the USA (Hegedus & Roschelle, 2013; Kaput, 1994) and the UK and beyond (Hoyles & Lagrange, 2009; Noss & Hoyles, 1996).

The English project adopts a design-based research methodology, which is defined by Anderson and Shattock (2012) as research that is:

> designed by and for educators that seeks to increase the impact, transfer, and translation of education research into improved practice. In addition, it stresses the need for theory building and the development of design principles that guide, inform, and improve both practice and research in educational contexts (2012, p. 16).

The following phases of the project have been completed: Planning phase (Jun-Jul 2011); Unit 1 pilot phase (Jul – Dec 2011); and Unit 2 pilot phase (Jan – Jul 2012) (Hoyles, Kent, Noss, & Smart, 2012; Hoyles & Noss, 2013; Sturman & Cooper, 2012). The current work (phase 3) involves ongoing design cycles of the two existing (and two new) curriculum units with a small set of what we call 'design' schools (which are working intensively on trialling and honing the units) alongside scaling the project to include over one hundred 'focus' schools across the country which will teach the units when they are ready. We clarify the precise roles of the school below.

Cornerstone Mathematics: The Design Principles

The main features of Cornerstone Mathematics are:

- Co-development (by SRI and LKL teams) of replacement curriculum units with digital technologies to enhance the teaching and learning of core mathematical ideas that are hard to teach and learn. The implementation of these units of work is the subject of an intensive design-based research methodology.
- Co-development of teacher professional development materials and the provision of structures for professional learning and support for teachers in schools.
- A phased research process involving cycles of design-based research to inform and guide scaling.

There are four replacement units in development, covering the topics of linear functions, geometric similarity, algebraic generalisations; and ratio and proportion. Each unit comprises: web-based mathematics software, a teacher's guide, pupils' workbooks and online collaborative tasks. A unit of work is designed to require about 3-4 weeks of work. The activities within a given unit are all embedded within a 'realistic' context to motivate the learners and provide 'glue' for the separate activities. They incorporate both design principles for the use of software alongside a clear set of mathematical goals for each sub unit and the progression in the unit. For example, the overview of Unit 2 is shown in Figure 1.

Curriculum units – Unit 2 London Trending

Context: Produce the front cover for a digital magazine by creating mathematically similar images.

Design principles:

- dynamic measurements and comparisons
- structuring recording within tables
- link geometrical manipulation with tables and ratio

Big 'mathematical' ideas

- **Identifying the variants and invariants** in shapes that are mathematically similar, including identification of scale factor of enlargements.
- **Recognise the important one-to-one geometric correspondence of sides and vertices** within mathematically similar polygons.

Figure 1: Overview of Unit 2 on geometric similarity

Research methodology for scaling (Phase 3)

The current phase of the research involves two groups of schools; 'design' schools and 'focus' schools. The 'design' schools, of which there are between 5 and 7 for each Unit of work, are most closely involved with the project designers, researchers and CPD team. This contrasts with phase 1 of the project when, over an 18 month period, 18 teachers from 9 schools worked with 429 students across three year groups (Year 7 (aged 11-12): 179 (42%), Year 8: 227 (53%), Year 9: 23 (5%)). It is important to note that this constituted a diverse sample in terms of: contexts (social class, demographics, overall performance); prior student achievement in mathematics; and teacher experience and mathematical background.

Following the research with the design schools, revisions to the Cornerstone materials are made and 'focus' schools, are recruited, which although more distant from the core design process, will all participate in the ongoing research, and are preparing to teach the units to at least two classes. An outline of the focus and design schools' involvement is shown in Figure 2. The overarching aim of the research is to better understand the implications of designing a technology-based intervention for scaling. For example, we are currently redrafting the technology of our first and second units (based on SimCalc and Geogebra, respectively), to a web-based resource. There will be gains (ease of use, strength of mathematical focus) but also losses (fragmentation, possibly closing of exploratory pathways) and we are interested to know how these play out in the scaling process. No less important are the pragmatic considerations; for example, the nature of classroom access to technology is continually changing as schools reconsider modes of access to the technology to include the use of laptops, tablets etc.

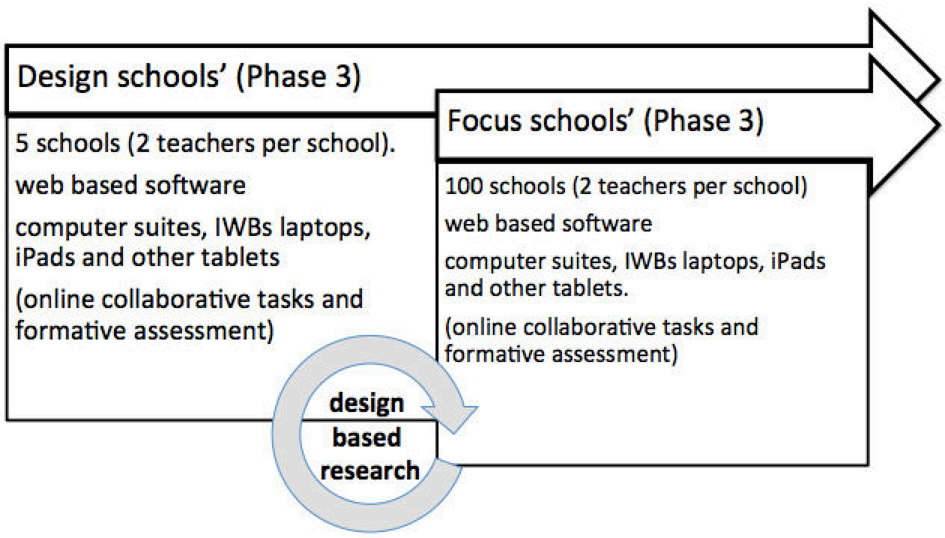

Figure 2 The research context.

These contexts result in two strands to the research, with methodologies appropriate to the differing grain sizes of analysis, as summarised in Table 1.

	Research aim	**Data collection technique**
Design schools	To improve the intervention through iterative changes to the software and materials, alongside the ongoing development of the software functionality.	Classroom observations and support visits (by CPD team). Teacher interviews. Online teacher surveys. Pupil interviews in groups (during phase 1, these were individual).
Focus schools	Identify the impact of scaling on the implementation and effects	Online teacher surveys. Lesson observations in sample

	of the intervention (and its design principles) with a view to tracing the evolution of the design decisions and principles during the process of scaling.	of classrooms. Observations of CPD sessions. Formative assessment tasks (analytics). (Student pre- and post-tests on request).

Table 1 The research questions and data collection methods

The iterative design research approach presents a number of challenges as the project scales, both with respect to the nature of the research questions that can be asked, the data that can be collected and the ways in which the wider group of teachers act as collaborators within the research process, an important feature of design-based research (Anderson & Shattuck, 2012). Alongside this, it is the implicit and explicit design principles of Cornerstone Mathematics, of which the participating teachers have varying levels of awareness, that underpin any value judgements about the quality of the subsequent implementations of the software and materials.

Scaling educational innovations – an emergent methodology

Although there are a number of references in the literature to the generic aspects of scaling educational innovations to large numbers of schools (Levin, 2008; Schneider & MacDonald, 2007a, 2007b), some of which involve the use of innovative digital technologies for science and mathematics (Organisation for Economic Co-operation and Development, 2010; Sinclair, Arzarello, Gaisman, & Lozano, 2009; Stylianides & Stylianides, 2013), this research domain lacks theories regarding more specific aspects of scaling the use of digital tools that are mathematically focused. This void can, in part, be explained by the need to collect 'large grain' data about many schools, teachers, classrooms and pupils alongside the 'finer grain' data about individual teachers' and pupils' experiences using the digital mathematical innovation (from which such theories regarding instrumentalisation and documentational genesis come into play (Gueudet & Trouche, 2009; Guin & Trouche, 1999)). Also these fine-grain data are more likely to provide the insights into the design decisions that teachers take when implementing the innovation at classroom level, which in turn will support the broader explanation of the impact of the technology at scale.

From the perspective of a country-based case study (Singapore) of educational technological innovations on a national scale, Hung, Lim & Huang (2010) offer a "locally oriented translation-scaling framework for extending technological innovations" where *translation-scaling* refers to the process of taking a research-proven innovation to scale through dissemination, implementation and diffusion. The authors argue that the outcomes of scaling should be considered from both a *product-oriented* and *process-oriented* perspective, where the *products* concern the numbers of schools, teachers, 'hubs' etc. and the *processes* refers to the actions and decisions taken in scaling the innovation. Table 2 illustrates this duality from the Cornerstone perspective.

Products	**Processes**
Number of schools involved	Development of a web based offer that embeds: software; curriculum materials; and formative assessment of students. Development of a hub-based offer of professional

	support that includes face-to-face and online PD. Development of online teacher community.
Number of participating teachers in each school	Development of subject leader. Development of peer-support for participating teachers.
Number of whole departments involved	Development of school-based PD. Support to embed Cornerstone Maths within local of schemes of work.
Geographical reach	Development of school and academy clusters, supported by Project team *leading to* Development of local hubs with local Cornerstone Maths project lead.
Wider use of the materials	Teachers' use of the materials beyond their original project commitment. (e.g. GCSE revision classes).
Improved student attainment	School-devised methods to evaluate students' outcomes

Table 2: Scaling Cornerstone Mathematics: Products and processes

Hung et al. (2010) argue that interventions are not processes to be replicated, but instead to be re-created/re-instantiated/re-enacted and that these instantiations and enactments take place in the milieu of the **products** of the innovation, namely artefacts and boundary objects. The boundary objects form the substrate from which the dialectical interactions between product, process and participant-practitioner are lived and therefore reified. Hung et al. also conjecture that mutations are necessary, desirable and helpful but some mutations are considered to be *lethal* when they are no longer consistent with the 'sound learning principles broadly specified rather than very specific design principles nearly consistent with the original design specifications of the research project'(Hung et al., 2010, p. 94).

We intend to explore further these ideas of boundary objects and seek to analyse dialogues between communities of teachers around them as an insight into the process of scaling at the level of the teacher.

Summary

The Cornerstone Mathematics project is in the process of scaling from its initial design phase to over 100 schools. The accompanying research agenda adopts a mixed methods approach in order to capture both large-grain and fine-grain data to enable conclusions to be drawn about the effectiveness of the innovation at scale, and of the scaling process itself. An important aspect of this methodology concerns the role that technology can play in both supporting the scaling effort as well as and enabling the analysis of large amounts of qualitative data, which could support a definition of a 'super-sized' design-based research methodology. More ambitiously, the project sets itself the aim of building theory about the products and processes involved in scaling educational innovations for school mathematics and the development of new methodologies.

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