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Scaling mathematics teachers' professional development in relation to technology – probing the fidelity of implementation through landmark activities

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This paper reports research into aspects of 'scaling' classroom access to technology within the context of an English teacher development project, 'Cornerstone Maths'. The aim of this multi-year project is to address issues of underuse of dynamic mathematical technologies by lower secondary students in classrooms through: specially designed web-based software; teacher and student materials; and professional development. The paper proposes the construct of a landmark question as a means to assess the degree of fidelity of the resulting classroom implementations at scale and reports emergent data on this theme.

Keywords: Mathematics, technology, teacher development, scaling, implementation fidelity.

INTRODUCTION

Despite multiple studies over many years that have concluded positive effects of student interaction with transformative digital technologies in mathematics education, teachers and schools find it difficult to integrate such resources within 'normal' mathematics lessons (Clark-Wilson, Robutti, & Sinclair, 2014; Gueudet, Pepin, & Trouche, 2012; Hoyles & Lagrange, 2009). By 'transformative technologies' we mean 'computational tools through which students and teachers (re-)express their mathematical understandings, which are themselves simultaneously externalised and shaped by the interactions with the tools' (Clark-Wilson, Hoyles, Noss, Vahey, & Roschelle, 2015). (For a more substantial elaboration of this, see Hoyles & Noss 2003). The reasons for this lack of engagement include: insufficient time and opportunity for sustained professional development; weak alignment with institutional practices; difficulties installing and maintaining software access; teachers' mathematical knowledge and beliefs, and insufficient access to teaching materials that exploit the affordances of well-designed technologies. The Cornerstone Maths (CM) project has been developed to respond to these concerns.

Cornerstone Maths began in 2009 as a design-based implementation study (DBIR, Kelly, 2004) that seeks to implement a replacement curriculum for hard to teach topics (linear functions, geometric similarity and algebraic expressions), which included professional development, and, research the resulting classroom implementations. This paper concerns the first curriculum unit on linear functions, which evolved from work in the USA. It is organised as a 'curriculum activity system' (Vahey, Knudsen, Rafanan, & Lara-Meloy, 2013) and comprises: web-based interactive software, teacher guide and student workbook [1] and face-to-face/at distance professional development support. Adaptation and pilot studies in England established the efficacy of the materials – a more expansive elaboration of the previous work is reported elsewhere (Clark-Wilson et al., 2015; Hoyles, Noss, Vahey, & Roschelle, 2013).

This paper extends this earlier work by elaborating a theoretical frame and methodological approach for research aiming at assessing the success of the professional development part of a large-scale intervention. Central to the approach is the question of how a teacher's classroom practice comes to align (or not) with the epistemic goals of the CM materials. We will limit this discussion to outcomes relating to classroom implementations of the CM curriculum unit on linear functions.

THEORISING ABOUT SCALING

We have drawn heavily on the work of Hung, Lim and Huang (2010) who, from the context of technology enhanced educational innovations within the Singaporean system, have defined the 'products' and 'processes' of scaling. By products, they mean the mainly quantitative measures such as the number of schools, teachers, and classrooms, the geographical reach and the (school-derived) measures of increased student attainment [2]. The processes describe the means through which such products are achieved, which will differ according to each project. For CM, the processes included the development of a localised PD offer led by a CM project lead who could provide ongoing peer support for teachers to embed CM within local of schemes of work.

However, whilst these products and processes indicate the extent of teachers' and schools' access to (and use of) the CM materials, they mask the more fundamental information about *how* the materials were implemented in classrooms and, crucial to our research interest, whether or not these implementations retain any fidelity to the design principles of the CM innovation. Existing literature on research into the enactment of the mathematics curriculum offers a range of methodologies to this end (Heck, Chval, Weiss, & Ziebarth, 2012 ; Polly & Hannafin, 2011). However, few studies have addressed how to research classroom implementations during large-scale projects involving hundreds of teachers over a timeline of years (Wylie, 2008).

Defining success at scale

Our earlier work (reported in Clark-Wilson et al., 2015, and summarised here) revealed a set of criteria or 'success indicators' at the level of an individual teacher's engagement with CM. These were:

1) Expression of satisfaction with the professional development and teaching materials;

2) Alignment between the professional development and teaching materials and their goals as a teacher;

3) Use of materials and the extent to which they create legitimate adaptations (which align to the design principles of the innovation);

4) Positive outcomes in their classroom;

5) Activity and engagement within the professional community and with the project team.

Ultimately, we were keen to uncover the extent to which teachers redefined powerful learning of their students in the light of the innovation. As our earlier work had concluded that legitimate adaptions [3] enhanced the epistemic value of the tool use (Hoyles et al., 2013), we viewed adaptation as an essential part of teachers' actions as they made sense of (and began to use) the CM materials. However, we were aware that some teachers could adapt the CM materials to produce 'lethal mutations', i.e., implement the materials in ways that are inconsistent or detrimental to the design principles such that they no longer retained their intended epistemic value. For example, an important design principle was for students to have some control of their interactions with the software. Consequently, a teacher who chose to always lead the use of the software from the whole-class display could jeopardise student autonomy in this respect.

As the project scaled to 113 schools (and over 200 teachers) it was evident that observation and interview was no longer a viable methodology. Therefore we chose teachers' self-reports to provide an insight into the teachers' perceptions of the epistemic value of the CM teaching materials and their associated classroom practices.

METHODOLOGICAL DESIGN

The CM unit on linear functions comprised 14 'Investigations', divided into sub-tasks, most of which required direct student interaction with the specially designed web-based software. In this paper, we focus on the first 7 investigations, which address the following mathematical ideas:

Representational:

> Equations, algebraic expressions, graphs and tables are forms of mathematical representation.

Motion can be represented on a graph of distance versus time.

On a position-time graph, multi-segment graphs can represent characters moving at different speeds.

Relational:

Linear equations can be derived using differences of position and time in a table or by using the y-intercept and speed/gradient of a graph.

Speed can be determined from different parts of graph and simulation.

Contextual

For equations of the form $y = mx$, in motion contexts, m is the speed of a moving object.

For equations of the form $y = mx + c$, in motion contexts, c is typically the starting point and m is the speed of a moving object.

Graphs of motion show characters' start position, speed (relative) and places and times where characters meet.

Landmark activities

The notion of a 'landmark' activity originates in the concept of cognitive breakdown, or a 'situation of non-obviousness' (Winograd & Flores, 1986, p. 165), in which established routines are 'replaced by conflict, disagreement or doubt' (Hoyles & Noss, 2002). This resonates with the role of 'contingent moments' within the development of mathematics teachers' knowledge and practice (Turner & Rowland, 2011). In the context of the technology-enhanced mathematics classroom, it is anticipated in the design that the technology would disrupt routine practices in a transformative sense, and that the ensuing breakdowns would provide insights into developing practices.

We define landmark activities as those which indicate a rethinking of the mathematics or an extension of previously held ideas – the 'aha' moments that show surprise – and provide evidence of students' developing appreciation of the underlying concept. Our challenge was to develop a methodological approach that enabled us to research *at scale* teachers' perceptions and use of previously identified landmark activities. There is a blurring as to whether such activities are landmarks for the teacher or for their students. They are derived in fact from the perspective of the teachers although, as will be seen later, teachers' perceptions are invariably influenced and substantiated by their students' responses to tasks, supported by day-to-day formative assessment practices. We recognize the temporal nature of landmark activities in that the teachers' initial selections of landmark activities resulting from their first teaching of the CM unit might evolve and, we conjecture, stabilise over time. At this point, we start from the assumption that, if teachers show awareness of landmark activities that align with the design principles, and foreground [4] them for their students, they have 'got it' with respect to the design principles of the unit.

The process of identification of landmark activities went through several stages. First, the research team (the authors of this paper) made their own selection from the student workbook. Then they discussed their selections and agreed a list of eight activities that were highly aligned to the design principles of the CM curriculum unit under discussion. The tasks included some that were mediated by the software and some that were paper-and-pencil tasks. This process was repeated face-to-face with a focus group of three teachers, selected as they had provided thoughtful reflections to the online surveys, who provided their rationale for their choices. We would have preferred that all teachers gave a wholly open-text response in justification for each landmark question. However, as hundreds of teacher would be responding to the questionnaire over a timeline of years, the project resources did not extend to the resulting qualitative data analysis process. The data gathered from the focus group of teachers, supplemented by responses from the Cornerstone Maths professional development team informed the development of a set of answer prompts that were used within the wider online survey. These prompts are given in Table 1 alongside the teachers' survey responses.

As part of the final questionnaire to teachers, administered after they had completed their first teaching of the CM unit, we asked teachers to report their three most memorable landmark questions and justify their choices by selecting one or more of the answer prompts and/or by selecting 'Other' and providing their own reason.

Rationale for choice of landmark question	% of total number of selections (n=601) [6]
Most students were engaged and motivated to complete the activity.	22
It provoked rich mathematical discussion.	46
Most students were able to record their explanations.	20
It revealed important misconceptions.	35
It revealed progress in understanding.	48
Other	8

Table 1: Summary of teachers' reasons for their identification of landmark questions

We conjecture that the teachers would be able to identify particular tasks in the CM materials that could be described as landmark with respect to students' mathematical learning and engagement. The teachers' justifications would be based on their: observations of their students engaging in the various CM activities (with and without the technology); questioning of students about their work (individually, in small groups and during whole-class teaching); and reviews of students' written responses in the workbooks.

FINDINGS AND DISCUSSION

Our initial analyses of 98 of the 111 [5] teachers' responses suggest that there are some trends emerging from the data that offer an insight into the teachers' perceptions and classroom practices with respect to landmark activities. Table 1 summarises the teachers' responses for all of their justifications of their chosen activities as landmark.

Almost half of the responses related to teachers' evaluation of their chosen landmark activities as being important for their role in: provoking rich mathematical discussion; revealing important misconceptions; and revealing progress in understanding. This suggests that the construct of a landmark activity is relatively well-defined.

The 'Other' responses, of which there were 31 comments that related to a particular landmark activity, could be classified as expanding on the particular: mathematical content (i.e., 'stationary= flat line'); mathematical process (i.e., 'it enabled the students to reflect on the connections between the graph, the table and the equation'); and highlighted the particular mathematical difficulties that the students had overcome (i.e., 'students found it difficult to fill in the table from the information given').

We highlight two contrasting findings that lead us to critique the validity of our approach with respect to our underlying aim to develop a methodology that might be appropriate for large-scale studies that seek to research implementation fidelity.

Firstly, we report on the frequency of teachers' alignments with one of our *a priori* landmark activities, supported by qualitative data provided by teachers for their choices. We focus on one landmark activity, as selected by 17 teachers (shown in Figure 1), taken from Investigation 3, which required students to interact with the software to respond to a series of questions that were designed to develop their understanding of the mathematical concepts.

This question was one of a series of sub-questions that required students to generate an appropriate graph by interacting with the software. The teachers' most common justifications for this choice of landmark question were: it provoked rich mathematical discussion (n=7); it revealed important misconceptions

D. Sketch a graph of a race in which

- The two team cars start at the same position,
- the two team cars travel the same amount of time, but
- Green Grass is faster than Blue Waters.

Don't forget to label your lines in the graph.

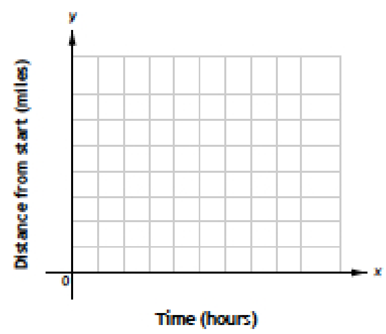

Figure 1: A landmark question from Investigation 3

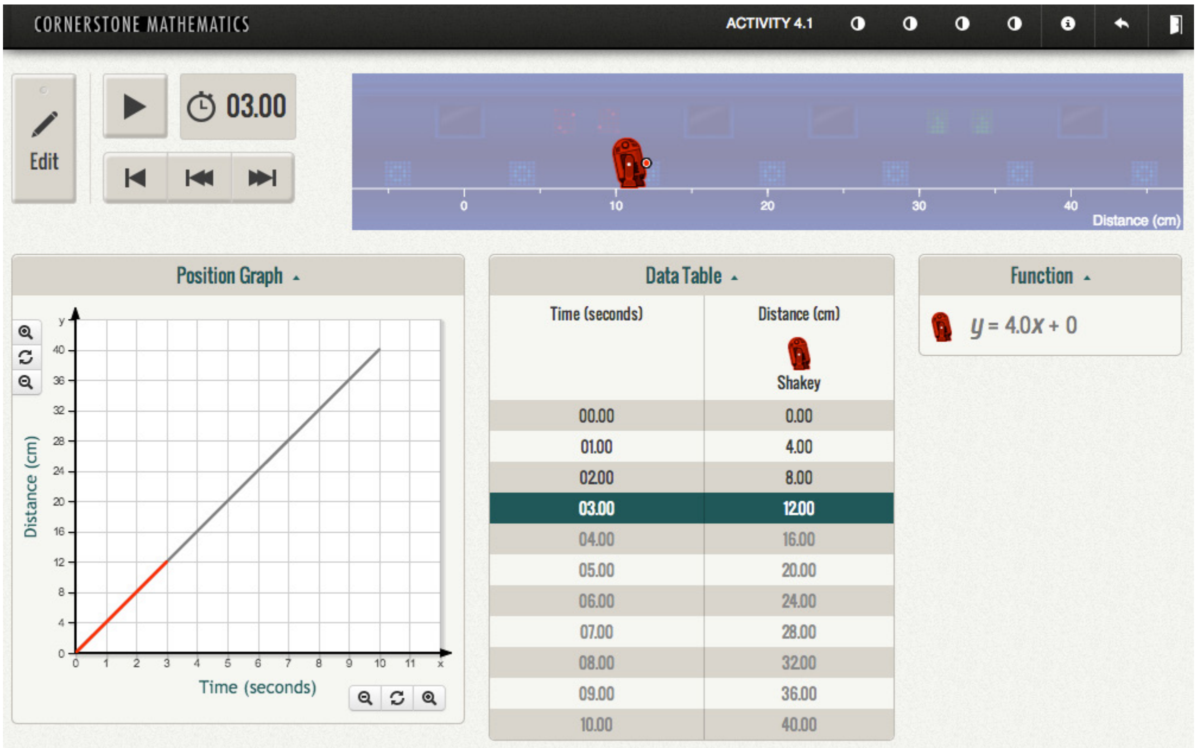

Figure 2: The accompanying software environment

(n=10); and it revealed progress in understanding (n=9). One teacher offered the additional comment,

> When answered together they showed immediately whether a pupil had understood the nature of the graphs, the different axes, the similarities and differences.

Another reported,

> I could easily see which students had a deep understanding of the concept specifically how the position and time were placed on the graph and the meaning of these axes.

By contrast, we were surprised by one landmark question that was identified by 28 teachers, as we had interpreted this activity as simply recording what students were seeing in the dynamic multiple representations and it did not, in itself, highlight any relational concepts. However, our teachers viewed it differently.

This question related to the software screen shown in Figure 2.

In the activity, the students were asked to edit the graph and play the resulting simulation in order to determine how time, position and speed were each represented in the graph, table and equation respectively. They were required to record a written response in their workbooks.

Fifteen of the teachers reported that this question had provoked rich mathematical discussion and fourteen stated that it had revealed important misconceptions on the part of their students.

One teacher justified her choice by saying,

> Because if students understand and can articulate the representation, then everything else follows.

CONCLUSION

Research on the successful scaling of educational innovations, with an emphasis on aspects that impact upon mathematics teacher development, is of primary importance given the funding constraints that many countries are experiencing (see Blömeke, Hoyles, & Rösken-Winter, 2015; Thompson & Wiliam, 2008). Furthermore, innovations that involve mathematical technologies are known to be slow to integrate and scale (Organisation for Economic Co-operation and Development, 2010).

The developing methodology reported in this paper offers a way to ascertain the fidelity of the resulting implementations with a large number of teachers. Although needing further elaboration, the construct of the landmark activity appears to resonate with teachers and their views captured in an online survey methodology with high response rates over time. Follow up interviews would certainly enrich the findings if this could be undertaken with some sample.

We will also explore how the observation of teachers' responses to landmark activities *during* the CM face-to-face professional development might shed further light on teachers' own knowledge development in our ongoing research.

The construct of landmark questions promises to be a productive way to probe teachers' interpretations of the CM unit of work and the mathematical outcomes for their students. Our ongoing work will seek to extend and validate the construct and its application within our studies.

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ENDNOTES

1. The student workbook is a consumable book that contains the task instructions. Students record their responses to interactions with the technology and other related questions in the workbook.

2. We conjecture that, whilst the efficacy of the Cornerstone Maths materials have been established by its pilot research projects, individual schools and teachers will seek to validate the materials to (re-)establish its efficacy within their institutional settings as an important component of the process of scaling.

3. We adopt the ideas of 'legal' and 'legitimate' mutations of an innovation to describe the extent to which classroom implementations adhere to its original design principles. This is not a bipolar scale.

4. As all teachers have access to the same set of teaching materials, they make individual decisions about which mathematical content and processes to emphasise (or foreground) in their teaching.

5. 111 teachers had completed their teaching of the CM curriculum unit by the end of September 2014.

6. Teachers could make multiple selections. This represents the total number of responses across the teachers' choices of three landmark questions.