Developing instructional and pedagogical design for the Cambridge Mathematics Education Project: A Design-based research approach

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This paper details how the Design-based research (DBR) methodology is being used to support a sub-component of the Cambridge Mathematics Education Project (CMEP). It is set in the context of on-going research taking place at the University of Cambridge's Faculty of Education. This involves the development of instructional and pedagogical design to support and enhance mathematics education. An introduction to both DBR and CMEP is provided while details of the developed research strategy are outlined. This is followed by an overview of data collection activities completed to-date and planned activities.

Keywords: Design-based research; A-level, post-16; development; instructional design; pedagogical design; teaching resources; CMEP

Introduction

This paper outlines the approach for the development of instructional and pedagogical design, using Design-based research (DBR) methodology (Brown, 1992), in the context of the Cambridge Mathematics Education Project (CMEP). CMEP aims to enhance and support Advanced Level (A-level)[1] mathematics education through the creation of rich tasks for teaching A-level mathematics (CMEP, 2015).

Background

The Cambridge Mathematics Education Project (CMEP)

Funded by the Department for Education for an initial period until March 2016, the aims of CMEP are to (CMEP, 2015): *(1)* identify the main themes and big ideas that permeate pre-university mathematics and lead into further study and industry; *(2)* consider how [A-level] mathematics can inspire and benefit students moving from school into university and the work-place beyond; *(3)* create innovative and carefully constructed materials around the themes and big ideas; *(4)* consider the most effective ways of helping students to understand the mathematics; *(5)* ensure that the materials are engaging and accessible to a wide range of students and teachers; *(6)* provide support to mathematics teachers to help them to use the materials effectively.

To help support and inspire teachers, CMEP is developing a range of innovative resources that will be made freely accessible[2]. The learning needs of students, and the associated issues facing teachers, have been considered from the outset and the project has worked closely with practitioners to gain feedback and input (Feng & Kimber, 2014). In order for CMEP tasks and pedagogy to become embedded into teachers' practice, however, it is necessary to develop a deeper

[1] The post-compulsory (post-16) two-year course comprising AS and A2 taken in England, Wales and
[2] On a purpose built-website available at www.maths.cam.ac.uk/about/community/cmep/

understanding of what is an effective pedagogy for a CMEP task. Consideration of the issues faced by teachers when adopting such pedagogy, including how they can plan to use CMEP tasks effectively, is also required. To meet these aims, a sub-component of CMEP is being undertaken by researchers from the University of Cambridge Faculty of Education. This involves the use of DBR to develop support materials to help teachers to use CMEP tasks. Detailed teacher notes and video clips are being created to assist teachers by offering models of how tasks can be used and how students may respond.

Design-based research (DBR)

DBR[3] is a systematic approach that aims to improve educational practices through the development of 'products'; iterative cycles of design and revision; testing in 'real' educational settings; data collection; analysis and evaluation; re-design and adaptation (Anderson & Shattuck, 2012; DBRC, 2003). Based on collaboration between researchers and practitioners, DBR leads to design principles and theories (Wang & Hannafin, 2005). Examples of DBR interventions include activities, assessments and other innovations (Anderson & Shattuck, 2012). DBR is flexible (Wang & Hannafin, 2005) and strength lies in the methodology's adaptability (Herrington et al., 2007).

The process begins with an assessment of the local context and is informed by relevant literature/theory (Anderson & Shattuck, 2012). Once an intervention has been developed, the next phase encompasses the implementation and evaluation of the proposed solution(s) (Herrington et al., 2007). Interventions are assessed using multiple methods for data collection (Anderson & Shattuck, 2012) while multiple iterative cycles of design and testing, conducted in real-world settings, are undertaken (Wang & Hannafin, 2005). These are offset by periods of review, reflection and re-design (Herrington, McKenney, Reeves & Oliver, 2007). The process involves collaboration between practitioners and researchers (DBRC, 2003) because DBR acknowledges that teachers are often too busy and underprepared to conduct rigorous research while researchers often lack knowledge of local circumstances (Anderson & Shattuck, 2012). During formative evaluation, iterative cycles of development, implementation, and study allow information about how a particular intervention is (un)successful to be collected (DBRC, 2003). The intention of DBR is to enquire broadly into the nature of a complex system and to advance theory (ibid). The knowledge claim of DBR, which sets it apart from other approaches (e.g. action research), takes the form of design principles, that is, evidence-based heuristics capable of informing future development and implementation (Herrington et al., 2007). This explains why designs work, and suggests how they might be adapted to new circumstances (Cobb, Confrey, Lehrer & Schauble, 2003), in a manner that can improve practice and research (Anderson & Shattuck, 2012).

Research Design

Rationale for adopting a DBR approach

Our motivation for using DBR is driven by the fact that it facilitates the collection of rich information that is capable of being used to assess, inform and improve practice (Anderson & Shattuck, 2012). Use of the methodology was considered appropriate

[3] For a more detailed introduction to DBR consult the following special issues: *Journal of the Learning Sciences 13*(1); *Educational Researcher 32*(1); and *Educational Psychologist 39*(4).

due to: the innovative nature of CMEP resources (designed to encourage ambitious teaching of A-level mathematics); the importance that DBR places on the development of theory and design principles (which will inform other initiatives in addition to CMEP); it allowing the research team to deepen their understanding of how teachers utilise developed support materials.

Using DBR in the context of CMEP

Our use of DBR has dual aims: *(1)* To iteratively develop and evaluate teacher support materials to help teachers to use CMEP tasks effectively; *(2)* To develop a set of recommendations for pedagogical and CPD design.

CMEP tasks

CMEP offers a variety of tasks (which have been classified by 'resource type'). DBR has taken place to develop support materials for four of the longer CMEP tasks. These tasks are of two resource types: 'A package of problems' (a set of problems that have been designed and should be thought of as a single entity) or 'Many-ways problems' (which draw students' attention to the thought that there might be several ways to tackle a problem, or to represent an idea). Two of the tasks for which materials have been developed – 'Discriminating' and 'Two-way functions' – are online[4].

Teacher support materials

Influenced by the design of existing formative assessment lessons (MAP, 2013), the support materials place the main CMEP task in the context of a sequence of preliminary, main and follow-up tasks. The preliminary task is used as formative assessment (to remind students of certain ideas/skills and to give the teacher an opportunity to assess students' familiarity or confidence) while the follow-up offers a chance for students to revisit or develop ideas from the main task. CMEP resources are flexible and it is expected that teachers will use these differently. Our concern is in supporting teachers to see how they can use the resources effectively and, therefore, support materials include a suggestion of how to use the task (including task-specific suggestions of how to facilitate student pair/group work, ways to introduce the problem and how to encourage the sharing of ideas through discussion). In addition, support materials detail learning opportunities that may arise while mathematical behaviour to look out for, and teacher responses/questions, are suggested.

Our DBR strategy

Working with schools in England, research has been conducted in collaboration with six teachers (and this number is planned to increase). Data collection takes place before, during and after lessons including: pre- and post-teacher interviews; observation of classroom practice through video*;* in-class dialogue (teacher-student and student-student); student surveys and a focus group*;* anecdotal evidence (e.g. lesson plans). Analysis of collected data feeds into the development of lesson support materials, which go on to be used by other teachers. This analysis strategy involves looking at how the suggested way of using the task was followed by the teacher. Clarification of the suggestions provided, or further details of the purpose of specific activities, are offered by the research team (where necessary). Common issues or

[4] See nrich.maths.org/11264 and nrich.maths.org/11301 respectively.

misconceptions, including teacher responses to these, are considered. Student responses to the task are also monitored including mathematical behaviour that might be of interest to other teachers. Where the teacher uses the suggested reflection questions, the nature of the discussion is monitored and questions amended in response to this. The format and content of implemented support materials was initially suggested by teachers at the CMEP partner schools and has been subsequently refined through the iterative research cycles. Some elements of these designs are transferrable between tasks, while others are task-specific.

Due to the practicalities of A-level courses, and the commitments of those involved, it is not possible for a teacher to use a particular task (and associated materials) repeatedly. As a result, additional teachers (often in other schools and potentially when using different tasks) implement revised teacher support materials to satisfy the requirement for multiple iterations. This helps to overcome a drawback traditionally associated with DBR, specifically that substantial time is needed (Herrington et al., 2007). Despite this distinctive characteristic, our design satisfies criteria for "good" DBR as (DBRC, 2003): design and theory development are intertwined; development and research takes place through continuous cycles of design, enactment, analysis and redesign; research takes place in authentic settings; appropriate research methods are used; a set of principles and recommendations for pedagogical and CPD design will (ultimately) be generated. Use of multiple sources of data helps to ensure empirically grounded claims (Cobb et al., 2003) while validity is addressed by the partnerships and iteration characteristic of DBR as this results in alignment of theory, design, practice and measurement over time (DBRC, 2003).

Summary and next steps

This paper reports an approach for the development of instructional and pedagogical design through the use of DBR. Situated in the context of A-level mathematics, specifically the CMEP project, teacher support materials will continue to be iteratively developed and evaluated. DBR is a systematic methodology that has particular promise for exploring novel educational approaches, supporting the development of contextualised theory and in constructing cumulative design knowledge. Our flexible interpretation and implementation of DBR has empowered us to take of a number of research affordances. Detailed teacher notes and video clips are being developed to assist teachers by offering models of how CMEP tasks can be used and how students might respond. In addition, a more widely usable set of principles and recommendations for pedagogical and CPD design will be generated. Materials developed through the use of DBR aim is to support teachers who may find using CMEP tasks challenging given the nature of the tasks require a different way of acting. It is intended that these materials will be housed on the CMEP project site.

Teachers have welcomed the format of the sequence of tasks and the level of detail, although some reported that their colleagues may not have time to read the documents. There is a tension between presenting details of different responses, so that the notes will support a wide range of teachers, and providing brief notes that communicate only the essential details of the main task. Teachers have asked for details such as prerequisites to be included and for the format of the documents to be the same for all tasks. The tab structure of resources on the CMEP site can be used to structure the teacher notes to suit the needs of different teachers and, therefore, the format of the notes will be developed in future cycles in consultation with teachers.

One possible output is a template to help teachers to prepare to use CMEP tasks in a way that reflects the project philosophy.

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