CAMBRIDGE Mathematics

Methodology

Research-informed design: a summary

Others in this series

- Building the research base: a summary
- Formative evaluation: a summary
- Ontology: a summary

Author

Dominika Majewska

Representing the work of

Lynn Fortin, Tabitha Gould, Rachael Horsman, Ellen Jameson, Vinay Kathotia, Ray Knight, Lynne McClure, Darren Macey, Dominika Majewska, Nicky Rushton, Lucy Rycroft-Smith and Ben Stevens.

Cambridge University Press | University of Cambridge Faculty of Mathematics | University of Cambridge Faculty of Education | Cambridge Assessment

Summary

- Design refers to the process of creating tools, objects and processes that may contribute to a field
- We are engaged in research-informed design of the Cambridge Mathematics Framework, with the aim of contributing to education by producing a tool that can help to address identified problems in mathematics curriculum design rather than developing a new theory
- The research which informs our design is multidisciplinary and interdisciplinary
- We record links between theories, design features and uses to help us develop and refine the design
- The Framework is stored as a network within a graph database, which allows for flexibility and interconnectedness, as writers can simultaneously edit content and see changes made by others
- The potential uses of the Framework and its content are tested and refined through pilot implementation

Introduction – what is our design approach?

This paper discusses the rationale for our design approach and the inputs, outputs, methods and processes it includes. The design methods used by Cambridge Mathematics are positioned within educational design methodology and are connected to other elements of the Cambridge Mathematics Framework project, such as our approaches to research, formative evaluation, ontology development and the fundamental goals presented in A Manifesto for Cambridge Mathematics (McClure, 2015).

In education, design refers to a process used to create tools, objects and processes which contribute to the field. Design projects often share the following components:

- *Design goals* describe what aspects of the problem the design is intended to address.
- *Design principles* describe approaches to meeting particular design goals which will then be implemented in the design.
- *Inputs* might be influences, references, prior knowledge, existing information or initial discussions – or, they might be outputs from formative evaluation or a previous design process.

- *Outputs* might be components of the overall design, components of formative evaluation, design principles, or agreed design practices.

- *Processes* may be developed for the purpose of an investigation or design or evaluation.

As educational designers aim to bring about positive change, the design process is usually:

- Collaborative – therefore includes those whose professional experience is embedded in the context of the problem (and the solution),

- Responsive – can be corrected on the basis of formative evaluation as the design progresses, particularly as the design reaches the point where it can be implemented with users,

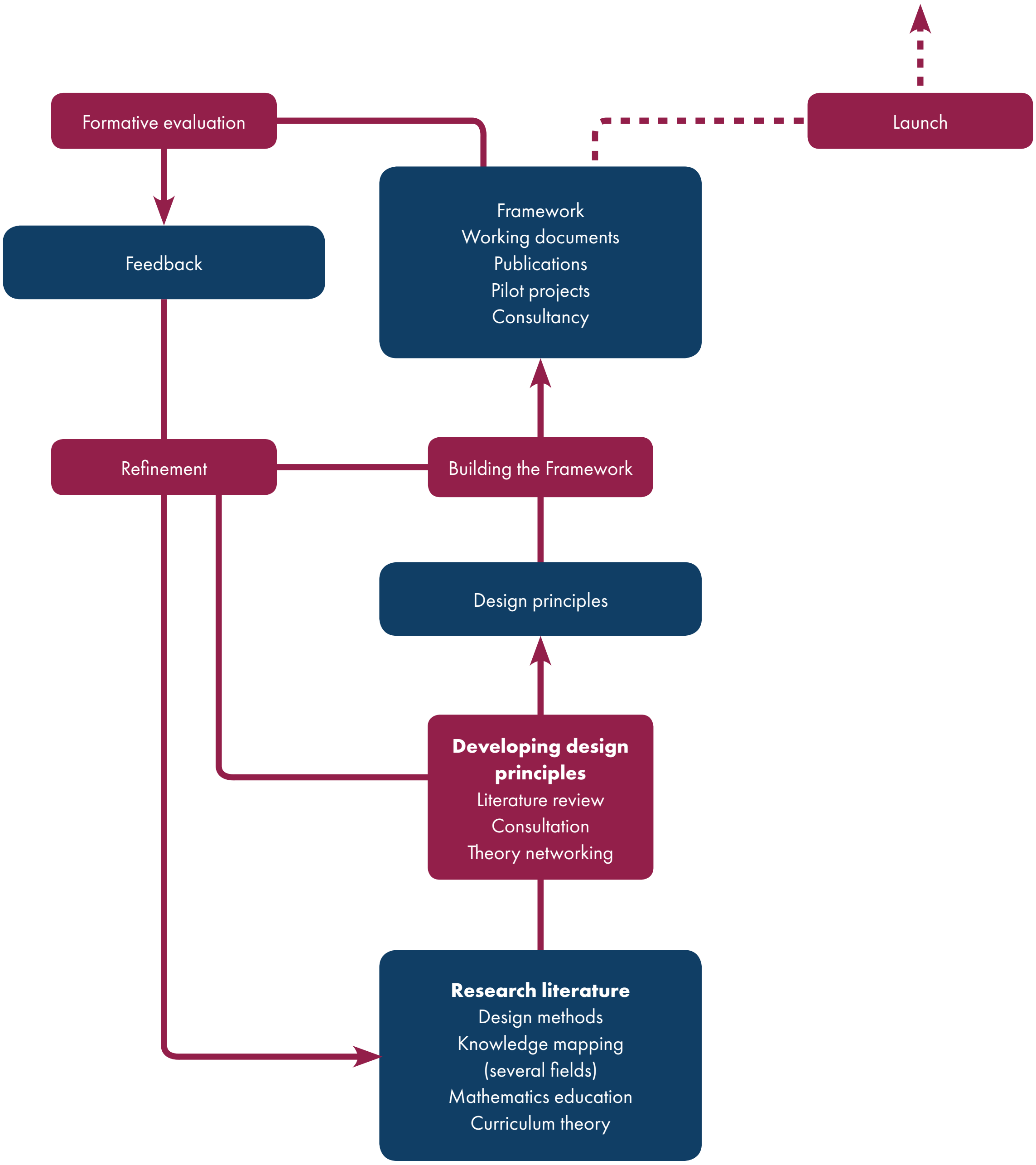
- Iterative – because once a design is evaluated in some way, the data may suggest it should be refined, and

- Theoretically grounded (in the case of design research) – so that the design can be informed by theories built on prior empirical work and can contribute to theory (McKenney & Reeves, 2012).

Research may inform changes to the components of a design over time, so that they are better- aligned with their purpose. This happens through *design cycles* (McKenney & Reeves, 2012). Figure 1 shows research among the elements of the cycles which have informed our design trajectory so far.

Figure 1 on next page

Figure 1: Cycles in the Cambridge Mathematics Framework design trajectory (inputs and outputs in blue, categories of processes in red)



Design projects in education may be categorised as research-informed design or design research. These orientations have many aspects in common: they may be informed by existing theory and data; may involve certain attitudes, values, methods and outcomes; may gather data to inform iterative refinement of a design or may contribute design principles, which bridge theory and design in a way that could be useful for other design projects. The distinction is in the use of research and the purpose for design choices. In research-informed design, design choices incorporate influences from existing research and are shaped mainly by the contribution to some form of practice in education. In design research, the design choices taken must support theory-building, bridging theory and practice through design in a way that could be useful for other design projects (McKenney & Reeves, 2012).

The Cambridge Mathematics project primarily uses research-informed design, as our aim is to contribute to education by producing a tool that can help to address identified problems in mathematics curriculum design and enactment rather than to develop a theory. We apply existing research and empirical data to our design and incorporate other traits that have been associated with design research (McKenney & Reeves, 2012):

- We analyse our design and formative feedback from evaluation according to frameworks found through literature reviews.
- We formally document our aims, goals, research influences, methods and results.
- We seek to learn from other design efforts with similar goals and/or contexts.

How did we develop our problem context, design goals and design principles?

Problem context

The design of this project began with the research that led to the writing of A Manifesto for Cambridge Mathematics. The document lays out background knowledge of the problem context from the professional experiences of the director and Cambridge University partners, and senior curriculum designers and researchers whose work has had impact at national and international levels.

Design goals

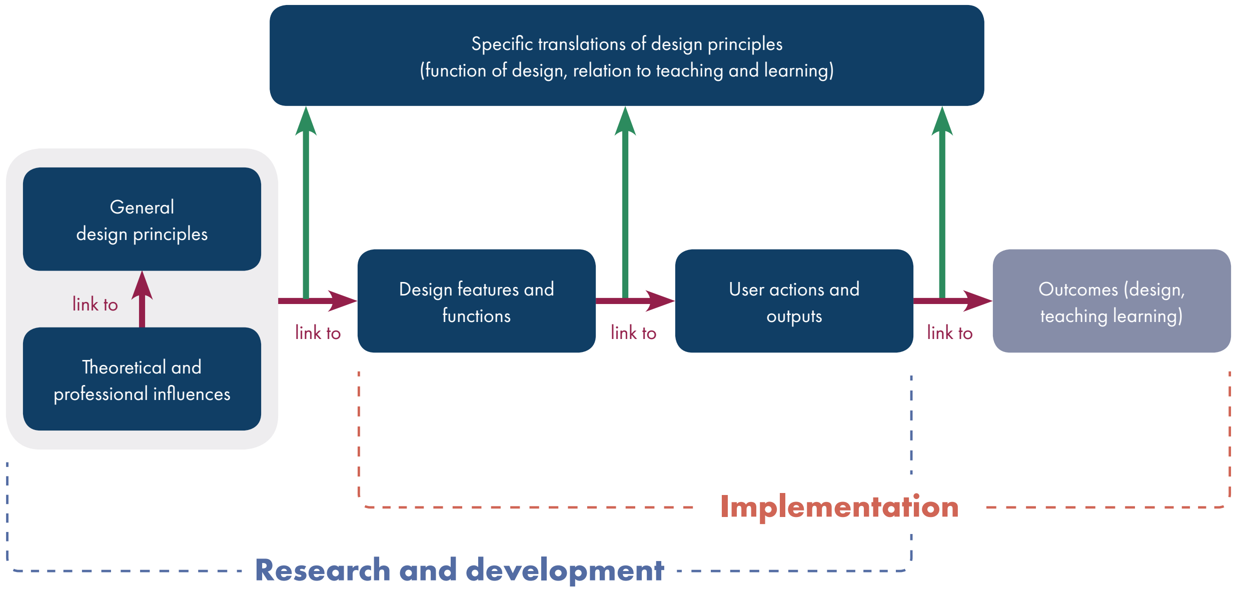
Design goals are developed from an understanding of the problem context and the scope of the design project. Our initial design goals were presented before design work began. As the goals came from discussions of the amount and variety of existing practical experience with the problem, the goals themselves have not changed. Our immediate design solutions for matching scope and resources have evolved as we have developed and implemented our design processes.

CAMBRIDGE Mathematics

Design principles

Once design goals are defined, it is important to establish how the design will meet those goals (Sandoval, 2004). Design principles guide the choices made about design features and the functions those features should support (McKenney & Reeves, 2012). Design principles also make a design process more transparent by giving justification for specific design choices and features. They may be changed and improved, prioritised or deprioritised as a project develops. In the Cambridge Mathematics Framework project, the ability to trace theoretical influences to specific design features enables us to improve the design and design principles in an informed way. For instance, we can pinpoint which assumptions should be revisited when something changes or what additional research and evaluation should be conducted to support refinement (see Figure 2).

Figure 2: Components of our feature-specific logic models (adapted for our process from Sandoval, 2014)



How do we develop the rationale for specific design choices?

Sandoval (2004) suggests that conjecture mapping can help designers to reflect on the logic of their design and can provide guidance for refining the design if needed. The Cambridge Mathematics team has adapted the idea of conjecture mapping in their pilot case studies to create feature-specific logic models for analysing specific aspects of Framework design.

CAMBRIDGE
√Mathematics

How do we manage what influences our design?

Our research base draws on research from a range of areas other than mathematics education, including Learning Sciences, Computer Supported Collaborative Learning (CSCL), Computer Supported Collaborative Working (CSCW), Information Science (IS), Human Computer Interaction (HCI), User Experience (UX) and qualitative methods in the social sciences. We write Research Summaries to explain how theory and evidence from research have influenced our work.

Research and practices developed to study specific phenomena are often simplified (Artigue & Mariotti, 2014) and so it is important to consider multiple theories when thinking about our design. Since the Cambridge Mathematics Framework will eventually include teacher education content, tasks, and assessments, we have considered literature related to these and networked the embedded theories. These include for example, theories about pedagogical subject knowledge, knowledge perspectives and boundary objects.

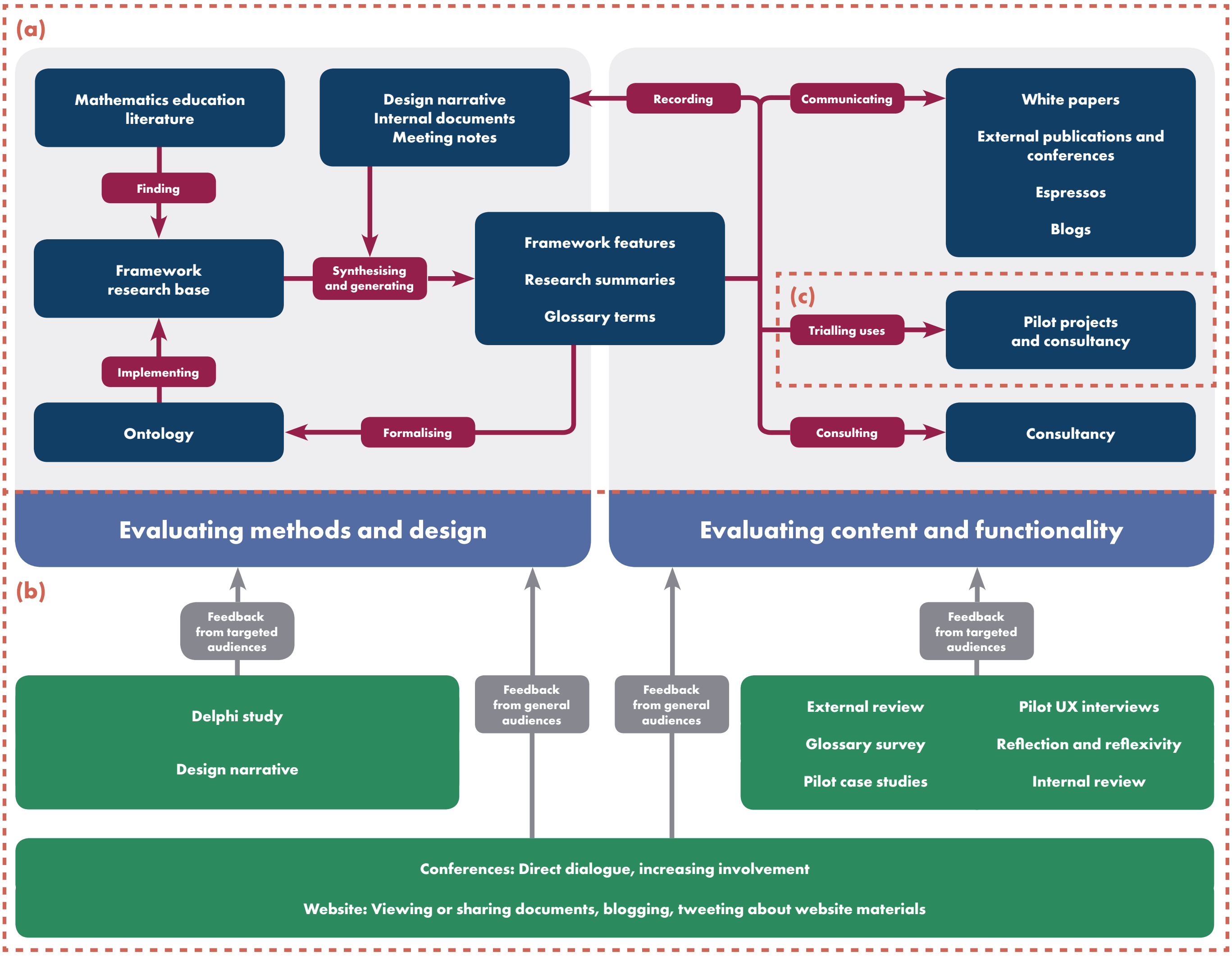
Our design is influenced by grand frame theories (e.g. activity theory), intermediate frame theories (e.g. Swan's task design framework (Swan, 2014)), and domain-specific theories (e.g. the theory of geometric reasoning (Clements & Battista, 1992)).

The processes we engage in are cyclical: as we continue our literature reviews and receive feedback on current work we continue to integrate additional theories and practices when appropriate. We bring ideas from individual reading to team meetings, try ways of incorporating them in design and discuss the results. We write up our literature reviews in Framework-embedded Research Summaries for topic-specific areas, in Espressos and blogs, in reports, conference papers, and publications for our overall design and methodology and in our survey and interview methods for formative evaluation. Finally, we use techniques such as adapted conjecture mapping to record links between theories, design features and emerging uses. To assess whether our theoretical influences and justifications, and their links to our design, are valid, we review them through various formative evaluations of Research Summaries and related Framework content (see Methodology: Formative evaluation (Jameson, 2019) for more detail).

Building the Framework

The extended design: a summary of Framework components and design processes

Figure 3: Components of the Framework design process showing (a) the extended design, (b) formative evaluation and (c) pilot implementations



How do we integrate design principles?

As the design cycles continue over time, our understanding of the bigger picture and our priorities for the design develop. Table 1 shows that the design principles we identified at the start of the project have developed and been added to over time.

Table 1: Design principles integrated at different stages of design

Initial	Access to mathematics for all students Collaboration and consultation Support for a coherent programme Evidence-based
Added	Research-informed (adapted from evidence-based) Transparency Connectivity Early experiences
Recently emerged	Flexibility

How do we use consultations and discussions in our design?

The Cambridge Mathematics team has developed different structures for different levels of group discussion and knowledge building:

- Individual members of the design team interact with discussions in the mathematics education literature.
- The team meets to discuss specific and general design issues and to develop outputs for discussion with audiences.
- Targeted audiences are recruited for more extensive involvement in structured discussions about the design process.
- General audiences come into contact with our work by engaging in specific outputs. This allow us to anticipate some necessary Framework design decisions for different audiences. More information on how we incorporate feedback from different audiences into our design can be found in Methodology: Formative evaluation.

Table 2: Examples of forms of internal discussion

Meeting/discussion type	Frequency
Making connections between topic areas	Weekly
Maintaining the research base	Weekly
Ongoing pilot case studies	Weekly to monthly
Big questions (un-agreed design priorities or emerging potential structural elements)	Monthly
Internal review (reliability of ontology implementation)	Weekly
Review functionality (can we do what we need to do, are new features or changes to features needed?)	Monthly
Feedback on draft publications	Monthly

How have we developed our ontology?

The development of our ontology mirrors the more general design process. In each cycle we assess whether the ontology helps us to support the design principles we have chosen. For the rationale and method behind the development of our ontology, see Ontology: Structure and meaning in the Cambridge Mathematics Framework (Jameson et al., 2019).

What tools do we use?

The Framework is stored as a network within a graph database managed by *Neo4j* – an industry-standard graph database management system (GDBMS). Building on this we developed the *CMF Nexus* platform to address two problems:

1. The problem of sharing, integrating and discussing the most up-to-date versions of Framework content.
2. The problem of storing all the content and connections necessary to form a coherent map of important mathematical ideas, and being able to filter it to get information out as needed.

Framework content is written by multiple people whose work is both simultaneous and interconnected. To facilitate this, CMF Nexus has been developed as a system for collaborative writing, querying and visualisation. It serves as an interface for the Framework database, which can be accessed by multiple users simultaneously. It gives all authors access to the most recently saved versions of any author's Framework content, while allowing them to record snapshots of previous states of the Framework. It enables the generation of particular maps for specific purposes to guide the focus of group discussion.

This allows the Framework to act as a shared knowledge representation in design discussions as everything produced on CMF Nexus can be shared for discussion with the team and/or wider audiences. Team discussions result in shared representations of understanding in many forms such as Research Summaries, ontology features or connections between authors' work.

Using the Framework

Table 3: Categories of potential users and uses of the Framework

Category of potential users	Category of uses	Scope of use
Curriculum committees	Curriculum goals, design, comparison and revision	Broad; multiple domains, entire range of content
Policymakers	Comparison and revision of current policies; policy advice	
Instructional designers	Designing or revising resources, activities, textbooks, schemes of work	Intermediate; switching between levels of detail for particular subsets of the Framework
Teacher educators	Designing and delivering teacher education programs; continuing professional development	Intermediate to detailed; switching between a horizon perspective, waypoints and student actions for very small subsets of the Framework
Teachers	Certification; professional development; lesson planning	
Assessment designers	Designing, developing or revising assessments to match the curriculum	
Researchers	Investigating existing literature regarding mathematics learning; developing new ideas and theories; enhancing current understanding	Detailed; working with themes, waypoints, student actions and research nodes for small subsets of the Framework

We focus on identifying and supporting a set of core uses, some of which may be important for all users and some of which may be specific for some user types. For instance, all users may benefit from seeing where a topic fits across the network as a whole, but curriculum designers may need a different window onto that information than teachers would need. This core set of uses is tested and added to our pilot cases.

Formative evaluation and feedback in the design cycle

We gather feedback from individuals representing potential users of the Framework and the research communities on whose work we draw to develop Framework content. This allows us to expand our circle of participants in design and include important perspectives into our knowledge-building discussions.

Conclusion

From developing our design problem, goals and principles to building, evaluating and refining the Framework, each component of the design process described in this paper involves decision-making, which is informed by a number of factors and considerations. We hope that providing this perspective will contribute to the resources other designers can draw on for similar projects. Other papers in our Methodology series elaborate on some of the ideas introduced here.

References

Artigue, M., & Mariotti, M. A. (2014). Networking theoretical frames: The ReMath enterprise. *Educational Studies in Mathematics, 85*(3), 329–355.

Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. A. Grouws (Ed.), *Handbook of Research on Mathematics Teaching and Learning* (pp. 420–464). New York: Macmillan.

Jameson, E. (2019). *Methodology: Formative Evaluation*. Retrieved from Cambridge Mathematics website: https://www.cambridgemaths.org/research/framework-documentation/view/methodology-formative-evaluation/

Jameson, E., Horsman, R., Macey, D., Gould, T., Rushton, N., Rycroft-Smith, L., … McClure, L. (2019). *Ontology: Structure and meaning in the Cambridge Mathematics Framework*. Cambridge, UK: Cambridge Mathematics.

McClure, L. (2015). *A Manifesto for Cambridge Mathematics*. Retrieved from Cambridge Mathematics website: https://www.cambridgemaths.org/Images/cambridge-mathematics-manifesto.pdf

McKenney, S., & Reeves, T. C. (2012). *Conducting Educational Design Research*. Routledge.

Sandoval, W. A. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist, 39*(4), 213–223.

Swan, M. (2014). Designing tasks and lessons that develop conceptual understanding, strategic competence and critical awareness. *Tarefas Matemáticas: Livro de Atas Do Encontro de Investigação Em Educação Matemática*, 9–28.

Cambridge University Press | University of Cambridge Faculty of Mathematics | University of Cambridge Faculty of Education | Cambridge Assessment