RESEARCH PAPER

Methodological Choices Made When Using Design Based Research to Explore Mathematics Education: An Updated Analysis

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Design based research (DBR) has become a popular methodology for exploring various aspects of mathematics education due to its focus on theoretical development and practical implementation. Drawing on a recent meta-study into trends in mathematically focused DBR studies, this paper explores how this method is being used in comparison to its original goals. Findings indicate that most studies presenting as DBR are essentially isolated case studies exploring individual teaching interventions lacking the iterative development needed to meet the intentions of DBR. Reasons for the current state of research are suggested along with a potential research architecture for mathematics education.

Design based research (DBR) is a methodological genre with similarities to many overlapping research methodologies such as design experiments, educational design research and design-based implementation research. When exploring education issues, these approaches attempt to iteratively build on theoretical understanding of learning and teaching whilst also establishing effective practical implementations. This richer and more contextual view of education has led to increased adoption of DBR throughout the education research community—particularly in investigations relating to mathematics—but the complexity of its ideals has led to greatly varying interpretations. As such it is important to examine the current practical application of DBR in order to identify whether the original conception of DBR is aligned with its actual implementation.

In arguably the first significant review of DBR to be published, Anderson and Shattuck (2012) where still quite tentative as to whether the methodology was meeting its promised benefits in the decade after it first came to prominence (e.g., Barab & Squire, 2004; Sandoval & Bell, 2004). A particular concern raised by Anderson and Shattuck was that DBR was not supporting the widespread adoption or scaling of tested innovations. Their analysis demonstrated the early adoption of the methodology was only resulting in "small improvements to the design, introduction, and testing of sustaining technologies and practices in classroom or distance education contexts" (Anderson & Shattuck, 2012, p. 24) but not in sustained or scalable change.

The purpose of this paper—and another we have published with a focus on how DBR tends to be used for different kinds of *theoretical* development in different parts of the world (Fowler et al., 2022)—is to report how the methodology has matured after another decade of use. To do so, we present the results of a meta-study making use of tools emerging from the "digital" social sciences to visualise trends in the literature with respect to the *methodological* choices made in DBR in mathematics education research. The questions guiding this meta-study were:

- *How is DBR being used to improve outcomes in mathematics education?*
- *How has the use of DBR in mathematics education research changed over time?*
- *To what extent are DBR studies in mathematics education meeting the goals of the early advocates of DBR?*

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The key finding we report here is that Anderson and Shattuck's (2012) conclusion of "cautious optimism" is still appropriate. In many ways the research being undertaken under the DBR banner has grown stronger, but there remains only scant evidence that the method is supporting real-world change any more than traditional research methodologies. Our findings suggest, though, that we may need to look not at the conduct of individual projects but rather at our research infrastructure if DBR is to fulfill its early promise.

Method of Review

This paper reports on the maturing nature of DBR methodology and adds an additional 56 papers (15% increase) to our original meta-study (Fowler et al., 2022). This is notable as these more recent papers do show maturation in the methodology. Similar in some ways to a scoping review, meta-studies are a largely qualitative research methodology that can help generate new understandings by treating the research literature itself as the source of data—becoming essentially "research of research" (Paterson et al., 2001, p. 5). This study investigated the methodological choices of the researchers using DBR. It is not a quantitative meta-analysis and does not seek to aggregate the results of the corpus of studies included.

Inclusion Criteria

Papers demonstrating a clear recognition of using DBR to investigate mathematical education issues were sourced from ERIC and Scopus. To ensure quality studies were investigated, only peer-reviewed papers demonstrating well thought out and practically implemented projects were included. As such, conceptual papers, book chapters and reports did not meet these criteria and were excluded. Conference papers were also rejected as they tended to lack methodological detail for coding in this meta-study.

The search period included papers published from after the Anderson and Shattuck (2012) review until February 2022, when the search was conducted. The full search terms are reported in Fowler et al. (2022). The following PRIMSA flow chart (Moher et al., 2009) in Figure 1 details the search method.

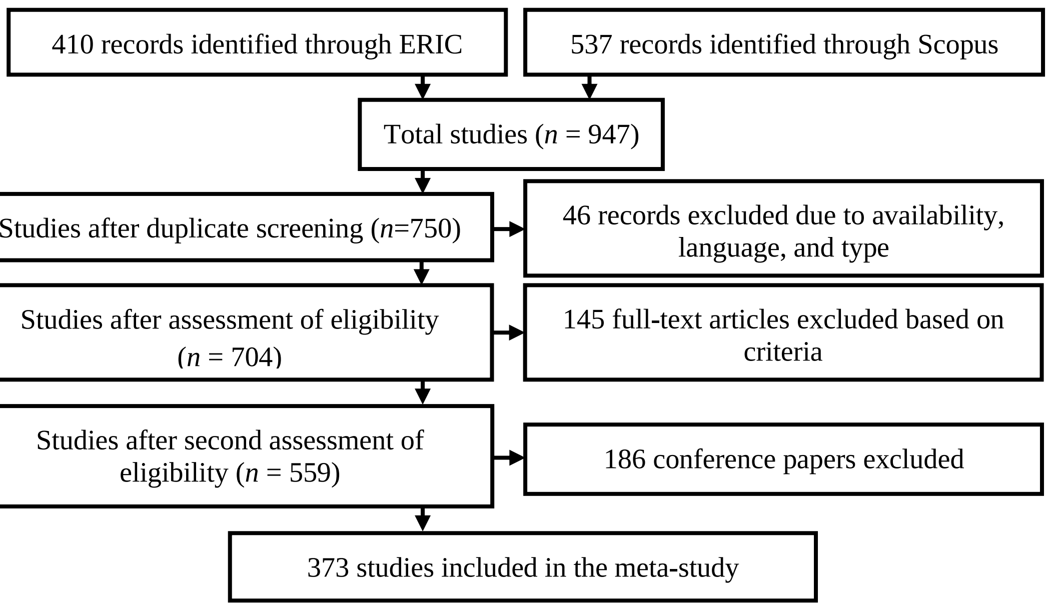

Figure 1. PRIMSA flow diagram of search method.

The qualitative coding system, also explained in full in Fowler et al. (2022), explored locus of refinement (Pedagogy, Educational tools, Understanding of student thinking, Theoretical foci, Systemic environment and Epistemology), methodological choice (Meta-analysis, Survey/Interview, Empirical observation, Quasi-experimental, Randomised control trials and Case Studies with triangulation) and the number of iterations reported. Intercoder reliability between two coders was determined with a 15% sample of the papers. Codes relating to iterations, focus of the intervention and method were compared. Cohen's κ was run to determine if there was agreement between the two coders. There was moderate agreement between the two coders on iterations ($\kappa = 0.477$ $p < 0.001$) and the focus of the study ($\kappa = 0.411$, $p < 0.001$). Reasons for coder error are discussed in the results. There was substantial agreement about method ($\kappa = 0.647$, $p < 0.001$) (McHugh, 2012).

Results

Locus of Refinement of Papers

To illustrate the types of educational phenomena DBR used to investigate, coding emphasis was placed on the focus or "locus of refinement" of the papers (see Figure 2).

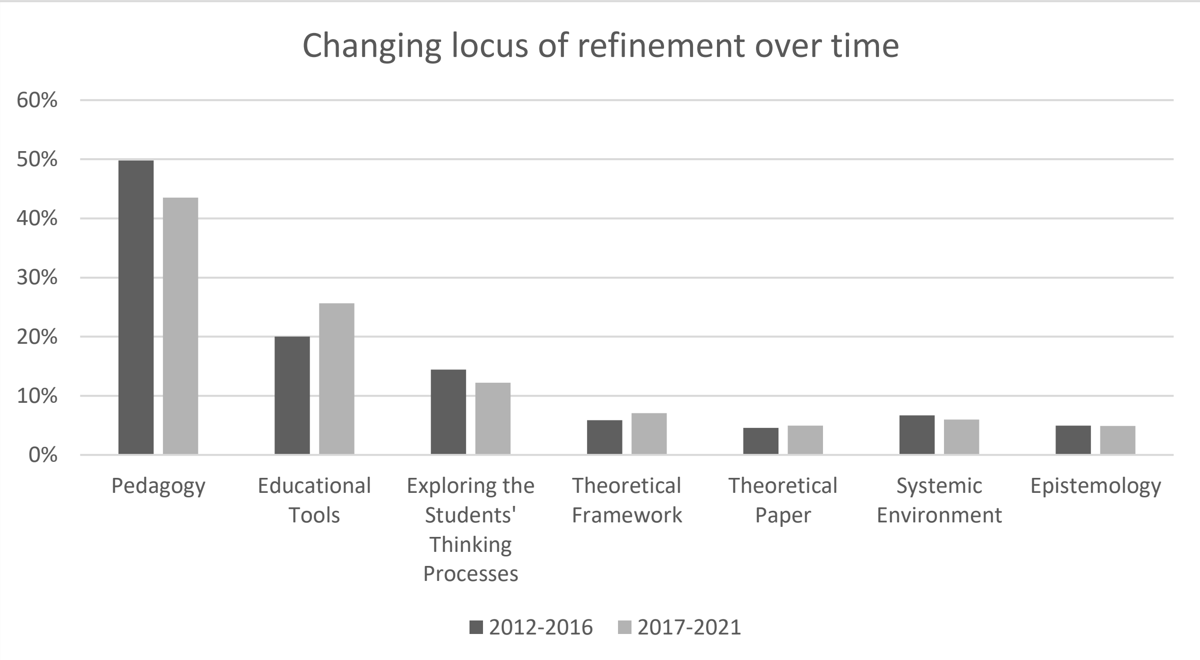

Figure 2. Changing locus of refinement over time.

Seven codes were formulated for this analysis. By far the two most coded items were *Pedagogy* and *Educational Tools*. *Pedagogy* was coded for studies that explored how teachers developed their students' learning but also, in the case of some papers, how this could be improved. *Educational Tools* on the other hand, indicated studies aimed at improving digital or analogue tools (e.g., textbooks, sets of problems) for use by schools. The third most important code related to the confluence of the two former codes in the form of *Exploring the Students' Thinking Processes*. These three codes understandably had significant overlap and focus in DBR studies of mathematics, which may have caused the lower inter-rater reliability scores as each paper was given only one focus code.

Theoretical Papers were coded for studies exploring issues relating to mathematics and DBR that did not use research methods to collect and analyse data. Studies were coded *Theoretical Framework* when studies used research data to assess the practical implementation of a framework to enable greater refinement of the theoretical models. The *Systemic Environment* code referred to studies that explored how policy was formed and enacted within the larger educational system.

Most categories tended to remain quite stable throughout the study period apart from a general decline in the still dominant pedagogical focus and an increasing interest in educational tools; however, this decline was not statistically significant. It should be noted, however, that pedagogies have been studied in more complex ways moving beyond quasi experiments using classroom testing as evidence and adopting a greater use of multiple data sources.

Method Choices

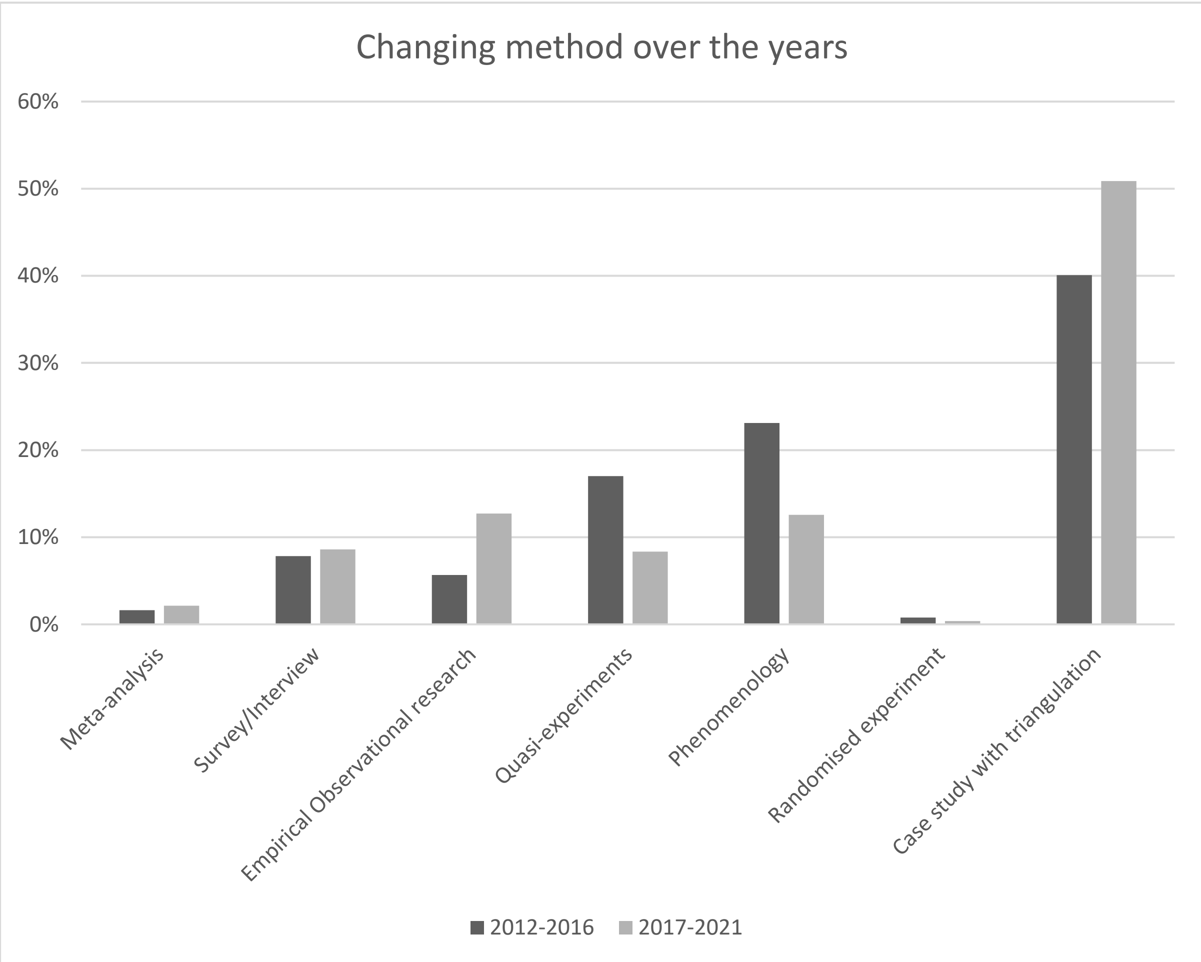

Figure 3. Changing method choice over time.

Much in the spirit of the original design experiments that predated DBR (e.g., Brown, 1992), a case study approach seeking increased credibility through the use of multiple sources of both quantitative and qualitative data were the predominant choice of methods reported in the papers analysed (see Figure 3). In recent years the greater use of technology has facilitated more accessible and effective ways to collect and analyse data, leading to deeper descriptions of educational phenomena. Common data sources used for triangulation in these studies were interview data, work samples and video of participants.

Quasi experiments and phenomenology were a more common methodology in earlier studies, and in non-OECD countries (e.g., Indonesia), but their use has declined over time as researchers have tended to source more data for triangulation. Phenomenology was most prevalent in studies of pedagogy (21% of papers with this foci) and epistemology (22% of papers with this foci) where deeper descriptions of experience were more important than more quantitative measures.

Surveys, interviews and forums have remained important, but they are now often supplemented with additional data. Technological advancements (e.g., improved coding software, online surveys) and accumulating knowledge about effective educational research have most likely been influencing factors in the greater collection and more thorough analysis of educational data in DBR studies. Empirical observational research, which seems to ignore the interventionist nature of DBR (McKenney, 2018), was generally conducted using coded video, work samples or academic tests. Empirical methods were more strongly favoured in studies of educational tools (12% of papers with this foci) and understanding of student thinking (17% of papers with this foci).

Iterations

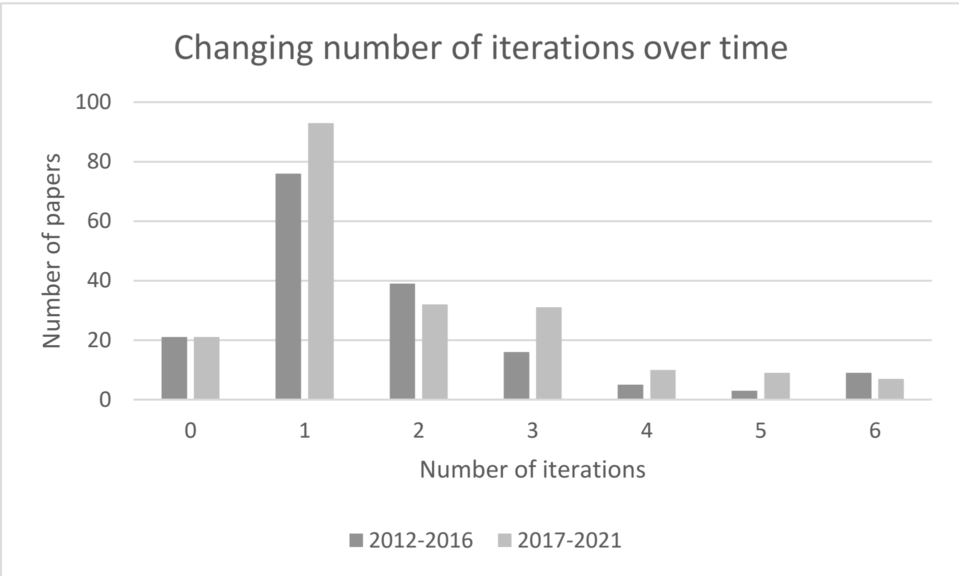

Figure 4. Changing number of iterations over time.

Figure 4 displays the number of iterations. Whilst there was little trend evident over time the distinction of iteration by the papers was quite varied making the coding of this aspect difficult. Theoretical papers involving no practical implementation were coded as 0 and those that applied an intervention but did not clearly explain iterative development were coded as 1. Some of these single (non)iterative studies treated different phases or stages within a study as iterations but they supplied little evidence that data from the former phases effected the development of the next phase. Instead they often referenced phases such as "analysis", "design" and "evaluation", derived from influential proponents such as McKenney and Reeves (2012), whilst ignoring or failing to report on larger macro-cycles (Gravemeijer & Cobb, 2006). In effect, many papers represented literature review or hypothesising as "iterating" when no data were being used to affect change. Frequently the goals did not change, and the parts of the studies were pre-determined, suggesting they might be thought of as "phases" rather than "iterations" (Easterday et al., 2018).

Another definition of iterative development often presented was the teaching and tinkering of multiple lessons. Whilst this showed improvement of method (usually pedagogy) through repetition, the qualitative and quantitative data collected in the study were rarely used to inform decisions or change. Instead, they were used to assess the overall span of lessons. As such, the types of teaching activity described in papers such as Avcu and Çetinkaya (2021) showed tinkering and the collection of a range of data, but the data did not influence the change and hence could only be identified as a single iteration.

Discussion

Summarising the intent of the methodology, Anderson and Shattuck (2012) identified DBR as interventionist, iterative, mixed methods research conducted collaboratively between educational researchers and practitioners in real educational contexts to identify design principles for future practice (pp. 16–17). Many of the studies investigated were true to parts of this definition. Most seemed to recognise the importance of context and referred to the important symbiotic relationship between the researchers and educators, even when little input from the practitioner was noted. Also, many of the projects reported little development through iteration. While some interventions showed adaptation throughout the process, this was often through teacher "tinkering", highlighting that "iteration" may sometimes be ambiguously defined.

Addressing this lack of genuine iteration, which ought to be the primary driver of theoretical development in the DBR methodology, will be critical if DBR is to support sustainable and scalable change. After almost two decades of use—more if we count the early design experiment movement of the 1990s—however, it is not likely that this problem will be addressed simply though upskilling researchers. Rather, we would argue that to fully realise the potential of DBR seen by Anderson and Shattuck (2012), as well as in our own studies, that our field must give consideration to some parts of our research practice and infrastucture.

A clear reason for a lack of iteration, for example, is that DBR is a resource intensive research methodology. This was a key finding in our initial study (Fowler et al., 2022), which showed that studies invovling multiple iterations almost exclusively eminated from the richer OECD countries, and even then were primarily the result of a PhD program with at least the candidate devoted to the project full time for 3–4 years. This challenge has been exacerbated by the trend identified in this paper towards greater use of mixed method case-study over and above simple quasi-experimental approaches based on a single measure. The time-frames required for this work, particularly when one considers the efforts required for realtionship building, funding and so on, are not consisent with our standard "publish or perish" publishing cycles, which instead encourage the rapid publication of early results and lead to a literature littered with reports on early work that did not proceed when sufficient resourcing could not be found.

As the need for near continuous publication is not likely to recede any time soon, thought must be given then to the modes of "serialising" DBR research that will be acceptable within our research community. In their oft-cited DBR methodology handbook, McKenney and Reeves (2014) suggest the option of collated studies such as that recently provided by Prediger et al. (2021) in summation of their 15-year DBR KOSIMA textbook project. Such an approach can allow for greater elaboration of the macro-cycles that house the micro-cycles of DBR research (Gravemeijer & Cobb, 2006), although they are hardly timely, which would detract from an approach for maximising the impact of DBR on scalable change.

A second concern emanating from the data is the lack of true collaboration between educators and researchers. A key definer of DBR has been the interventionist nature of the methodology and its potential for not only producing high quality research but increased epistemic alignment to reduce the theory/practice divide (Dunn et al., 2019; Fowler & Leonard, 2021). Whilst making reference to the researcher being in context, many DBR studies in mathematics education are still placing the researcher beyond the "fourth wall" (Kavanagh et al., 2022), where they can supposedly remain impartial in their observations. When used, this is seen to describe the study more empirically, but it lowers the sustainability of interventions and ignores the rich contextual understandings of the educators who can more fully identify subtle changes. There are signs of progress in this meta-study that show that this important aspect of DBR is improving, but mostly in well developed, and well-funded, research communities.

A way forward may be the development of "grey literature" DBR project sites that support groups with common goals to report and iteratively build on each other's work whilst providing opportunities for educational sites to indicate interest in projects. To some extent, this is an approach that the authors of this paper have essentially chosen to develop "in house" within our own research centre. We have been favoured with a large team within our research centre who make use of DBR to explore problems in mathematics education. We have also been fortunate enough to develop research practice partnerships with multiple educational stakeholders, allowing us to adopt an "accretion" model to our DBR work which draws together findings from multiple sites of research. These collaborations also encourage our research to address issues relevant to our educational partners resulting in clearer frameworks of understanding essential to high quality investigations and implementations. The pathway to regularly publishing the meta-research that emanates from this context, though, is not clear.

A glimpse of the first steps to overcoming this reporting issue, we suspect, can be found in pre-print peer review sites such as *Academic Karma* or the American Association for the Advancement of Science's *PRE-val*. What we are suggesting may simply be a development on this kind of platform. An "open" research repository such as ResearchGate may even serve the purpose. Whatever platform is chosen, though, it will be essential that contributing to this kind of activity is seen as valid use of researcher time within performance management systems of the universities, and so it will be essential that common and accepted approaches to scaling DBR are championed through organisations such as the Mathematics Education Research of Australasia (MERGA). Greater clarity of the macro-cycles and improved collaborative research practices through research practice partnerships will progress this popular methodological genre towards not only matching, but exceeding, the original goals of DBR.

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