Entanglement, evaluation and practice in a professional learning innovation

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Abstract

Evaluations of professional development programmes often seek to represent definitive outcomes, with phenomena posited as discrete, bounded and independent entities, and researchers positioned as external actors. An alternative is to understand the complexity of these relationships as entanglements by applying Baradian concepts. The value of this is illustrated through the example of the evaluation of the Mathematics Teacher Exchange (MTE). The MTE is a transnational professional learning programme, part of a policy described as learning from East-Asian mathematics teaching to introduce 'teaching for mastery' in England. Four instances of entanglement are analysed. The first two of these relate to the entanglement of evaluation processes and the mastery innovation in knowledge production. The other two examples are entanglements and diffractions that are found in changes in pedagogical practice related to mathematics representations and ways learners are grouped in classrooms. Although the transnational nature of the MTE is unusual and specific to the current English context, similar entanglements may be found in more locally generated teacher change initiatives and in their evaluation. Thinking in terms of entanglements adds another conceptual tool for sociomaterial and related analysis and also draws attention to our ethical responsibility for these relationalities.

Introduction

Implementation of professional development programmes is often not uniform and this is recognised in evaluation research through concepts like adaptation, dilution, fidelity and compliance (see, Humphrey *et al.* 2016). Professional development programmes and related policy changes are viewed as linear processes, with individual teachers or organisations considered as tightly bounded subjects of programmes and foci for learning as discrete, independent objects. Innovations, from this perspective, are like seeds inserted into a containing context (Nespor 2002) and evaluators and researchers are positioned as independent assessors of implementation. Even when interconnection and multiple pathways are accounted for in professional learning models, programmes and innovations are taken as an external domain separate from other elements (for example, Clarke and Hollingsworth 2002). Further, from such perspectives, it is rare to include accounts of the ways that research and evaluation activities influence implementation and so outcomes.

Such approaches have been theoretically challenged by those identifying with, or adopting, the term 'sociomaterial', often associated with the actor network tradition, with entities and materialities posited as enacted relational effects (see Fenwick and Edwards 2010, 2011a, Fenwick *et al.* 2012, for overviews). Sociomaterial perspectives reconceptualise professional learning as being not (only) an individual quality of change over time but a systemic quality manifesting across complex systems and networks. Further, knowledge is conceived as immanently distributed within relationships and processes rather than in firmly bounded actors.

One potential criticism of actor network theory is that as a sociomaterial sensibility or tool kit (Law 2004), it is a means to study relationships but does not offer, in itself, a full substantive theory of the nature of these relationships (Mulcahy 2013). Related new materialist perspectives may have the potential to address these concerns and potentially to add to materialist analyses in other ways. However, as yet, there has been limited application of new materialist theory and methodology to research on professional development or to evaluation research practice. My aim is to address this gap by applying Barad's (2007) agential realism and the concept of entanglement.

The substantive example is the evaluation of a transnational professional learning programme the *Mathematics Teacher Exchange: China-England* (Boylan *et al.* 2019), referred to here as the MTE, as part of a wider 'mastery' policy in mathematics education in England. This policy is described as a process of 'learning from' East Asian mathematics teaching to introduce 'teaching for mastery' in England (DfE, 2016, NCETM 2016). The MTE involves English teachers visiting Shanghai to observe practice and teachers from Shanghai visiting England to demonstrate teaching. The longitudinal evaluation (2015–2019) of the MTE was conducted – as per the government requirements – using a relatively standard mixed-methods evaluation design (Boylan *et al.* 2019). However, the data, analysis, and my experience as part of the evaluation team surfaced a complexity that linear perspectives did not capture.

In the next section, I describe the mastery innovation, the MTE and the evaluation of the programme. Following this, theoretical and methodological sections provide an overview of Barad's agential realism, entanglement, and how entanglements may be traced. This is the basis for considering two aspects of the entanglement of the evaluation process, the mastery programme and the MTE. Following this, entanglements and diffractions in changes in two classroom practices are considered. These latter two examples are, first, a heuristic of concrete-pictorial-abstract representations in classroom practice which is a particular focus for professional learning and, second, practices of differentiation and grouping of learners in the classroom. A thread running through these two pairs of entanglement narratives is a reconsideration of a figure produced in the final report of the MTE (Boylan *et al.* 2019).

Mastery, the mathematics teacher exchange and evaluation

The mastery innovation is a major government policy initiative in English primary mathematics education (DfE 2016). Looking externally for solutions to perceived educational 'problems' has been spurred by globalisation, including the influence on policy of international comparisons. Such comparisons involve a shifting landscape of reference societies (Carvalho and Costa 2015) – countries and educational systems which perform highly in PISA and similar tests. From 2014, the government formalised the promotion of East-Asian mathematics education practices under the label of 'mastery' and later 'teaching for mastery' (Boylan *et al.* 2019).

A variety of different projects and programmes comprise the mastery innovation. There is no agreed definition of the term 'mastery' which is used to refer, variously, to a level of learning, a particular type of learning or skills, a way of learning, a way of teaching, beliefs that everyone can be successful, a type of curriculum, and learner mindsets (Boylan 2020). Some initiatives and programmes look to Singapore, with professional and curriculum development informed by Singaporean textbooks. However, Shanghai mathematics education is more central to government policy. Interest in Shanghai's success in international tests led to a number of government-funded study visits involving teachers, school leaders, officials and politicians, as a precursor for the MTE starting in 2014/15.

Teachers and school leaders from 48 primary schools participated in the first exchange. Subsequently, teachers from about 70 schools a year have participated. These teachers and other trained 'mastery specialists' work with groups of schools in their localities to enact system change.

The policy aims for half of English primary schools to have engaged with the mastery programme in some way by 2023. The MTE, and associated professional development, is led by the National Centre for Excellence in Mathematics Teaching (NCETM). The NCETM is funded by the government but has some operational independence.

Although teachers from England go to Shanghai and Shanghai teachers visit England, it is not an exchange in which parties are positioned as learning equally from one another. Typically teachers from England visit Shanghai for one week for activities centred on observing Shanghai mathematics teaching. Shanghai teachers visit England for two weeks and teachers in England observe them teaching using Shanghai methods in English schools. Observing teachers include those from the host schools, as well as teachers from other schools.

Using a longitudinal mixed methods design (Creswell *et al.* 2003), the evaluation aim, formulated by the Department for Education (DfE) – the government ministry – was to determine the potential of learning from Shanghai to impact on teaching in England. Full details about the evaluation have been reported elsewhere (Boylan *et al.* 2019) and in summary comprised longitudinal multiple case studies (Stake 2013) of MTE schools to support an impact analysis focused on pupil attainment. The effects on pupils' mathematics attainment over a three-year period were investigated through a quasi-experimental study using propensity score matching, based on comparison with a contrast sample of schools. The research was conducted with institutional ethical approval and in accordance with the British Educational Research Association guidelines, with further regular ethical scrutiny by the DfE.

Thus, in keeping with frameworks set out by the funder, the evaluation used a mixed methods design for implementation evaluation focused on outcomes and process. However, the data and analysis surfaced a complexity that linear perspectives embedded in the evaluation design did not capture, in particular, the way different elements of the programme, actors and evaluation interrelated in ways that were mutually constitutive. This led me to reconsider phenomena as entangled, entailing further analysis.

Barad's agential realism and entanglement

Sociomaterial perspectives and tools have been applied to: understanding professional learning (for example, Boylan 2010, Fenwick and Edwards 2010, Fenwick *et al.* 2012, Mulcahy 2013); educational reform (Fenwick 2011); policy change in general (Fenwick and Edwards 2011b); and transnational policy including the influence of PISA (Gorur 2011). Such accounts consider complex social phenomena as actor networks and assemblages. These two terms have different origins, and some argue that they effectively have the same meaning (for example, Law 2009) with others arguing they carry important theoretical distinctions (see, Müller 2015 for discussion). The meanings of both terms have developed and changed over time and are used differently by different writers across varying contexts. These debates notwithstanding, actor network theory and assemblage theory share an emphasis on relational ontology – contrasting with ontologies of discrete bounded entities – and an embrace of heterogeneity in theorisation and analysis – that is not privileging some classes or types of entities over others.

Barad's agential realism, her concept of entanglement and diffractive methodology, resonates with such analyses, as does her concept of manifolds, having a similar meaning to 'actor network' and 'assemblages'. Notwithstanding differences in precise meanings of these three terms, in this article the term 'assemblage' is used for the purposes of examining entanglement. Regardless of terminology, Barad's theoretical perspectives have not been previously applied, to any great extent, in relation to post-qualification professional learning in the context of educational reform and policy (although see Charteris *et al.* 2017 for an application of Baradian concepts to consider materiality and agency in coaching). Given this, an introduction to agential realism, entanglement and diffractive methodology is provided in this section and the one that follows.

Barad (2007) re-examines ontological and epistemological debates about the interpretation of quantum physics between Bohr and Heisenberg. A crucial and much noted experimental finding of quantum physics – one that has flowed into wider culture – is that, at a quantum level, in certain circumstances, the process of observation and what is observed cannot be separated. The most commonly cited example of this being that the position of a particle and other properties, such as its speed, cannot be calculated with precision simultaneously.

Both Bohr and Heisenberg agree that the process of measurement of quantum phenomena does not lead to definitive values. However, the meanings of important experimental results are open to different interpretations. One interpretation – encapsulated in the notion of Heisenberg's uncertainty principle – is that the process of observation and use of apparatus introduces uncertainty. In the aforementioned example, this interpretation means that the particle does have a specific position and speed but this cannot be known with certainty. Siding with Bohr, Barad argues instead for a principle of interdeterminacy – that things do not have determinate boundaries. From this viewpoint, measurements and language do not perform mediating functions of representation, even if sometimes this is with uncertainty. Rather, phenomena – including abstract properties such as position – are inherently and inseparably the entanglements of interacting agencies. Barad argues:

> What we usually call a 'measurement' is a correlation or entanglement between component parts of a phenomenon, between the 'measured object' and the 'measuring device' (Barad 2007, p. 337).

Barad refers to the inseparability and dynamic relationality as 'intra-action' in contrast with a view of interaction of distinct and bounded entities:

> In contrast to the usual 'interaction', which assumes that there are separate individual agencies that precede their interaction, the notion of intra-action recognizes that distinct agencies do not precede, but rather emerge through, their intra-action. (Barad 2007, p. 33)

Barad argues that given that indeterminacy is found in some phenomena – those in quantum experiments – the world is indeterminate, regardless of our perception. However, she goes further and, linking philosophy of physics to social theory, proposes that the social world is more like the quantum physical world than it is like the world of classical physics.

Quantum entanglement refers to how particles that have originated together or interacted share a state of non-independence that continues even if they are then separated, or otherwise in new states or positions. Within the paradigm of classical physics and everyday perception of the world, such separation means that mutually influencing interactions might be expected to cease. Quantum entanglement gives rise to astonishing and disturbing phenomena in which changes of state in one particle can lead to instant changes of state in another particle. However, entanglement and the 'at a distant' link between particles may end when either or both interact with their environment, notably through measurement. Barad gives entanglement a more comprehensive meaning in which measurement and perception are entangled parts of phenomena. There is no independent, separable reality being measured that is independent. For Barad components of phenomena – the knower, the known, and the means of knowing – are entangled. Pulling back from quantum concerns, such entanglements are found in the social world in material-discursive relationships which knowers and actors are not outside of –

  'there is no such exterior position' p. 396.

Within Barad's postulations, different forms of entanglement are identified: entanglement of knower and known and so methodological entanglement; of meaning and matter as phenomena; and entanglements of phenomena that are seemingly separate through intra-action. As she argues:

> To be entangled is not simply to be intertwined with another, as in the joining of separate entities, but to lack an independent, self-contained existence. Existence is not an individual affair. Individuals do not pre-exist their interactions; rather, individuals emerge through and as part of their entangled intra-relating. (Barad 2007, p. ix)

Flowing from this concept of entanglement is a philosophical position that ontology and epistemology are inseparable from ethics. If we are entangled in and with the world then we have an ethical responsibility for it. Barad reminds us of this through compound terms such as 'ethico- ontological-epistemological'.

Tracing entanglements and stacking stories

Barad proposes a diffractive methodology to shift from representational knowing to performative knowing in which distinctions between subject and object emerge through intra-action (see Barad 2007, page 89–90). She contrasts a diffractive methodology that attends to differences and entangled performative relationalities with reflective methodologies that seek to represent things separate from the subject. With regard to professional learning innovations, in evaluation research it is common for researchers to seek to represent or mirror differences between the intended programme and implementation in practice in terms of measures of fidelity.

From a diffractive perspective, attention is given to the differences as phenomena in themselves and how these differences come to be. Diffractive methodology has been taken up and developed as a form of post-qualitative research (see Bozalek and Zembylas 2017, for references). In taking up a diffractive methodology, I adopted an ethnographic sensibility (Baker and McGuirk 2017) to reconsider the evaluation practices used in the MTE evaluation by considering the different texts produced:

as ethnographic artefacts that provide windows into the mobilisation, creation and application of policy knowledge. These artefacts function on the one hand as texts that reveal particular ways of thinking and acting, and on the other, as lively texts whose itineraries and effects can be apprehended by following their 'traces' in different contexts (p. 434).

Identifying and mapping entanglements involved tracing of associations represented in different texts produced within the evaluation – including policy texts, texts produced in the research process and published research outcomes. Attention was paid to patterns of similarity and differences. For example, in the MTE evaluation the term 'mastery' itself is produced differently in relation to different artefacts and actors. Bringing together Baker and McGuirks' focus on itinerary with Baradian and sociomaterial concerns for agency, my aim was to surface ways of acting and the agency of itinerant meanings.

From sociomaterialist and new materialist perspectives, boundaries between phenomena are indeterminate. Indeed the notions of 'between' and 'boundaries' are problematic. Choices about where boundaries are temporarily drawn are, to an extent, pragmatic. Representing phenomena as distinct can mislead, and so a challenge arises of how to portray tracings of entanglements and these itinerant meanings; this endeavour might require an infinite map (Deleuze and Guattari 1987). However, as an alternative, Law (2011) has suggested engaging with baroque, a richness of representation resonant with multiplicity, uncertainty and heterogeneity. In literacy studies, Burnett and Merchant (2016) have taken this up by offering a technique of 'stacking stories' to overcome the boundedness of a single story and to focus on the gaps between stories and rhizomic threads of each appearing in the others, sometimes surfacing, sometimes disappearing and rubbing up against each other (p.267)

In adopting a similar approach, four stories are presented in total. The first two of these are narratives of the entanglement of mastery, policy and evaluation as the research-assemblage manifested. These narratives derive from analysis of the evaluation process from my perspective as a participant and actor in the process. The second pair of narratives is derived from tracing associations across texts produced before conducting usual evaluation processes of analytical reduction and representation in published reports and seeing how meanings shifted between these and published texts and what was agentic in producing these differences. Of these latter two narratives, one surfaces how Singapore, Shanghai and English classroom practices are entangled around a heuristic of concrete-pictorial-abstract representations – referred to by participants as 'CPA' – the meaning and origins of this heuristic are explained below. The second entanglement is surfaced in the diffractive responses to the MTE in relation to grouping children between or in classes by perceptions and discourses of 'ability'.

Entanglement of mastery, policy, and evaluation

In this section, I focus on entanglements of mastery, policy and evaluation tools and practice through two narratives. The first narrative describes the way in which the MTE and its evaluation are entangled with a wider political and ideological context. I describe why the evaluation was not independent, neutral and apolitical. In the second narrative, I go further showing how both the politics of mastery, evaluation tools and processes and schools and teacher practices are entangled in the construction of mastery.

Entanglement and the politics of knowledge production: interrogating causal arrows

Barad (2007) proposes apparatuses that produce knowledge are material arrangements through which particular concepts are given definition, to the exclusion of others, and through which particular phenomena with particular determinate properties are produced. As researchers, we make a 'cut' in a world of phenomena that are not manifest in themselves but that become temporarily manifest

through practices of knowledge production (Barad 2007, p.335–336). The apparatus in the MTE evaluation were entangled with the politics of evidence, research and ideologies of schooling.

The mastery policy and the evaluation design can be linked to a wider 'what works' movement in policy in England and elsewhere and the promotion of evidence-based education (Biesta 2010). Part of the justification for looking to East Asian mathematics education is based on that region's success in PISA and other comparative assessments. In England, an increased promotion of 'evidence' derived from meta-analysis and synthesis (for example, Hattie 2008) influenced the establishment of the Education Endowment Foundation (EEF). The EEF offers grants for randomised control trials and other quasi-experimental research designs. Much of EEF's funding comes from the government, aligned with a move towards promotion of experimental and quantitative methodologies in the development of policy in education in England. This linear model of educational change has been critiqued as 'interventionisation' of education, narrowing the focus of innovation and specified, time-bounded, mechanistic practices having the effect of narrowing educational practice, curriculum and values (Burnett and Coldwell 2020 2020).

In addition to contributing to the prevalence of 'what works' discourses in schools and influencing policy in this direction, the EEF had a more direct role in the development of the mastery policy. The EEF funded a curriculum development project by a large multi-academic trust; a multi- academy trust is an organisation that is responsible for a group of schools in similar way to charter school organisations in the US. By adopting the term 'mastery' to describe its programme (Jerrim and Vignoles 2016), the educational trust was able to enroll previous research on Bloom's mastery learning (Guskey 2007) to gain funds to develop and evaluate its programme. This is notwithstanding significant differences between the Mathematics Mastery approach and Bloom's mastery.

These various developments – the what works discourse, the influence of PISA, and the promotion of mastery as a way of describing an approach to teaching mathematics - influenced the Department for Education to establish an evaluation of the MTE and to commission an impact evaluation to quantify outcomes for learners, by assessing the extent to which participating in the MTE might lead to changes in pupil attainment. Figure 1 shows how the model of Shanghai informed mastery pedagogy is entangled into these wider discourses in the language used for different elements and in the overall structure exemplifying the logic of intervention and outcome. The transfer and container models of implementation suppose independence of new practices and old. This is figured in implementation models through causal arrows. However, such models simplify the relationship between Shanghai and English mathematics education. I contend that the ways both are conceptualised in the MTE and mastery policy indicates a process of co-production. In Shanghai, enrolment in the mastery assemblage fits with rhetoric of national pride. Like diffracted waves, this pattern of intra-action continues with similarity and difference across the assemblage. In both education systems, processes of selection took place of some schools and some teachers to participate in the exchange. Teachers in England and in Shanghai experience preparation before travelling. This is not to suggest that there is a deliberate or intended aim to create something artificial or different. However, such preparation helped shape perspectival lenses and filters and influenced the practice of participating teachers and so schools.
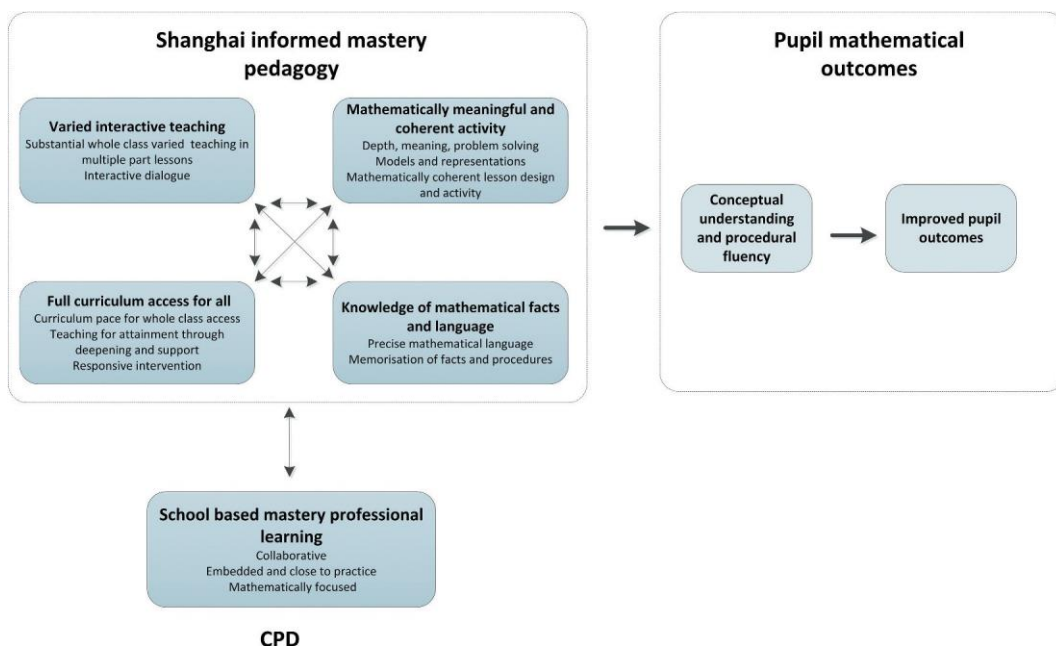
Figure 1. Shanghai-informed MTE mastery pedagogy. From Boylan et al. 2019, p. 69

Entanglement in the production of knowledge: reifying Shanghai-informed mastery pedagogy
The apparatus of knowing in the evaluation of the Mathematics Teacher Exchange consisted of a variety of materialities. These included academic texts, comprising products of previous research on mathematics education practices, and methodological texts. Important too were: (i) texts produced in the evaluation, such as research schedules, developed and agreed with both the funder and the implementer of the programme, and Department for Education reporting templates and style guides; (ii) generic and specialist software, including Word, Excel, SPSS, Nvivo; and (iii) tools such as telephones and recording devices.

In keeping with usual expectations in the research report genre, descriptive accounts of some of the texts and artefacts described above were provided in the evaluation report. However, such descriptions may hide ways in which processes entangle. Moreover, the associations are erased in texts that aim to represent innovation phenomena. The processes that led to the formulation of Figure 1, presented above, exemplify this entanglement. The discourse of mastery developed before and through the Mathematics Teacher Exchange. Prior to the exchange, the NCETM had adopted the term used in an existing programme that had been associated with Singapore mathematics education – this was the aforementioned Mathematics Mastery programme. The NCETM initially referred to 'mastery approaches' in its guidance to teachers (NCETM 2014). During the first year of the exchange the formulation changed to 'teaching for mastery' (NCETM 2016).

Teaching for mastery was partly formulated informed by what schools participating in the MTE were doing. It was soon apparent, in the evaluation, that schools were making a variety of changes to their practices. For the DfE, and for school leaders and teachers, an important question about changes in outcomes resulted from changing practice in ways believed to align with those in Shanghai or East Asia. This was potentially more important than simply assessing whether or not participating in the actual exchange led to increased attainment of pupils compared to other schools. To do this, some way of

describing school practices in relation to Shanghai practices was needed and for this categorisation to support quantification of differences, so allowing for statistical analysis.

Further, interviewers needed language to frame questions to research participants about what they experienced as different in Shanghai practices compared to their schools' practices, and about what changes they were making. Prior accounts of Shanghai and English mathematics education influenced research tools for data collection. This included grey literature reporting study visits and more formal published scholarship (see Boylan *et al.* 2019, pp. 35–40). Summaries of analysis of these previous accounts and draft research instruments were negotiated with representatives of the NCETM and the DfE. These were then used as the basis for conducting interviews and discussion with participants and informed early reporting to the DfE and NCETM.

These data collection tools were then used in the evaluation of exchange activity. However, how practice was conceived and what constituted desirable change was far from a simple naturalistic adoption or adaptation of practice. A pattern in some schools was for the MTE, Shanghai, and mastery to be used as a warrant to promote and justify practices that were already being introduced. Lessons taught were intended to showcase Shanghai-informed teaching. However, what was presented was constructed in ways that involved micropolitical choices. One mathematics coordinator in an English school hosting a Shanghai teacher helped the Shanghai teacher plan and adapt lessons before they were observed by English teachers so they were, in the coordinators' words, 'appropriate' for the English context. Although not always so visible, a process of negotiation took place in which there was a working out of what the other parties in the exchange wanted. Such negotiations as agencies work out how to be in relation to others appear more performative than linear processes of adaptation implied in process and implementation evaluation models. This echoes processes of enrolment (Callon 1986).

In the evaluation, an adaptive theory methodology was used (Layder 1998), combining inductive and deductive analysis, drawing on prior research and scholarship about East Asian mathematics teaching, as well as first-year findings. Emergent themes and categories were identified (Ryan and Bernard 2003) across the different interviews. This served, to erase the inscription processes.

After the first year of the evaluation, some participants took up the term 'teaching for mastery'. Particularly those teachers from schools who had engaged with the NCETM 'mastery specialist' course or were active in NCETM coordinated maths hubs. However, teaching for mastery had not been formulated prior to the start of the evaluation. Hence, in the report, the phrase 'Shanghai informed mastery pedagogy' was used with different elements and sub-elements than teaching for mastery, as shown in (Figure 1).

Some of the languages of these elements reflected the discourse of participants and so reflected constructions entangled with a variety of agencies, including, but by no means limited to: the NCETM, the DfE research aims and language, prior study visits to Shanghai, academic texts and descriptions, the influence of previous comparative studies, and innovations, including those from Singapore. However, the formulations used in the evaluation were not a product in simple, linear ways of these different influences, but in turn were elements in the production of the phenomena being researched and evaluated. Moreover, entangled into the produced figure and model, are tools and materialities such as the data analysis software and means by which interviews were conducted. These shaped what it was possible to discuss with participants and how this data was processed. Understanding these relationships as entangled recognises that research concepts, tools and practices not only mediate and shape knowledge that is produced but are enmeshed into it

Entanglement of teachers' knowledge practice and change

The next two narratives focus on examples of entanglement in teachers' knowledge, practice and change. These narratives should be read not as representations of 'what happened' in some simplistic sense, because the evaluation process was entangled with enacted practices. The first of the two narratives is about the heuristic of concrete-pictorial-abstract representations in classroom practice. The second is about differentiation and grouping learners by perceptions of ability. Across both narratives, elements of the mastery assemblage – texts, materialities, discourse and so on – were implicated in the teachers' apparatus of knowledge production.

Entanglement of here and there: Singapore, Shanghai and the concrete-pictorial-abstract heuristic

In Figure 1, the phrase 'models and representations' appears. In primary mathematics education models and representations are commonly taken to be forms through which mathematical concepts and relationships can be expressed. These include physical objects and manipulatives such as counters and blocks, diagrams and figures such as number lines, digital forms, and mathematical symbols such as digits and signs.

As noted, the mastery policy focuses on 'learning from' East Asian mathematics education. Prior to the adoption of the mastery policy by government, the *Maths No Problem textbook* based scheme had been adopted by some UK schools. This is a translation of Singaporean textbooks with attendant professional development. In addition, the term 'mastery' was adopted as the name for a curriculum and professional development programme which made reference to Singapore – *Mathematics Mastery* at least in its initial trialing (Jerrim and Vignoles 2016). Schools recruited to the first MTE cohort included four schools already engaged with these programmes. Consequently, using concrete, pictorial and abstract representations in mathematics teaching was important in these schools and abbreviated as 'CPA'.

The visit to Shanghai created opportunities for interchange between participants from England and a number of events were held afterwards. During the evaluation period the NCETM formulated what they described as mastery 'big ideas'; one of these was 'representation and structure'. However, the CPA heuristic was not explicitly promoted. Nevertheless, the CPA heuristic spread from teacher to teacher laterally rather than from the NCETM's central guidance. Already in the first round of interviews concrete-pictorial-abstract was part of the discourse of many schools. After the first year, a further 23 of the first cohort engaged with other mastery programmes including many engaging with the two aforementioned programmes. The CPA heuristic was then adopted more widely.

The importance of using multiple forms of representations in learning mathematics has been encouraged by English mathematics educators for some time (for example, Haylock and Cockburn 2013). Therefore, such ideas were potentially familiar to many teachers from their initial teacher education and existing practices in some schools. CPA in Singapore is rooted in Bruner's (1966) formulation of enactive, iconic and symbolic representations (Hoong *et al.* 2015). However, Haylock and Cockburn's model of representations, as contexts, mathematically structured images, symbols and language, shares a root in Bruner's formulation. Thus, the MTE helped foster further entangling of Singapore practice, already meshed with Anglophone mathematics education, with Shanghai practices. Thus, CPA became part of the knowledge apparatus of teachers through which Shanghai experiences and later NCETM teaching for mastery texts were understood.

Understanding the transnational flows of practices in the MTE is all the more complex given that both Singaporean mathematics education and forms of professional learning and, to a lesser extent, those

found in Shanghai, are themselves globalised hybrids influenced by western mathematics education research as well as other countries' practices. Thus, the current initiatives can be seen as another moment in a process of transitional entanglements of complex assemblages in which policy enactment may be seen as 'fragile enrolments of multiple ontologies' and policy and professional development innovations 'a patching together of different realities' (Fenwick and Edwards 2011b, p. 723).

Grouping children by perceptions of ability

In English primary mathematics education, sets of practices and discourses related to fixed-ability thinking such as labelling practices have been pervasive and arguably act against social justice (Marks 2014, Boylan and Povey 2020). Such thinking is enmeshed with beliefs and practices such as:

- differentiation of material and content,
- grouping learners by perceptions or constructions of posited mathematical ability,
- measuring apparatus leading to ascription of levels,
- pedagogies shaped by grouping practices.

In some larger English primary schools, pupils are put into perceived ability classes or 'sets' or, more frequently, in-class grouping is used where pupils who are perceived to have similar ability sit together (Hallam and Parsons 2013). This leads to differentiated access to the curriculum with different work available and required of different learners, typically with three to five different – though related – activities per class for each lesson planned in most participating schools prior to the exchange. One visible manifestation of this has been the use of learning objectives for lesson formulated in terms of 'all will', 'most will', 'some will'.

In Figure 1, one of the four components of Shanghai-informed mastery pedagogy is given as 'full curriculum access for all'. The interest in mastery is concurrent with, and influencing, curriculum changes with the discontinuation of using a system of ten National Curriculum Assessment levels in the 2014 National Curriculum (DfE 2014). These levels had helped create and reinforce the idea of differentiating teaching according to pre-determined expectations of what different groups of pupils could achieve. The new curriculum states that expected pupils are expected to progress together – this was sometimes referred to as the 'mastery statement' by mastery policy advocates. Thus, the MTE took place whilst wider changes in curriculum and assessment practices occurred. The change in the National Curriculum was a motivation for schools to review and change practice including engaging with the mastery innovation. A further influence has been a growing awareness of theories of mindsets (Dweck 1999) in English education and concern that routine labelling of children may lead to fixed-ability mindsets. There is a confluence and interrelationship between the curriculum change and mindset research cited as both complementary to and supportive of a mastery approach (for example, Drury 2014).

In Shanghai primary mathematics education material is not usually differentiated or children grouped in the ways they are in England. Rather, the expectation is that all children will learn the same content and individual children are supported in follow up sessions immediately if that does not appear to happen. For many participating in the exchange, the experience of seeing all children, regardless of prior attainment, taught together and experiencing the same curriculum and learning activities was a significant challenge to existing beliefs. Conversely, for those who already had beliefs and practices more aligned with those in Shanghai, the exchange helped to strengthen these.

Engagement with Shanghai practice acted in a similar way to a slit in a diffraction experiment leading to diffraction patterns, with new practices bifurcating into two types. One type represented the

strengthening of forces that tended to disrupt fixed-ability thinking. In some schools the new practices focused on 'everyone' and 'together'. This led to a reduction in the number of curriculum tasks in the classroom in any given lesson, but often an increase in the availability of supporting materials including manipulatives. Related to this was an emphasis on responding to what children did rather than pre-determining what they were expected to do.

In contrast, other practices represented a reassertion or reformulation of ability thinking. One of these reformulations was an adjusted continuation of existing practice. The number of different tasks set might be reduced, for example instead of five tasks three might be used, or, instead of three, only two. Sometimes the communication of learning objectives in the 'for all, most, some' format no longer took place, but three differentiated activities would still be used. In such cases, new language of 'deepening' found in mastery texts would be adopted, and language appropriated such as 'rapid graspers' used instead of 'high ability' to refer to some children. However, I contend that these do not represent changes to the underlying 'ability' logic; leaners are still described in ways that essentialise differences in their activity as differences in their capabilities and personhood.

Diffraction of Shanghai practices in relation to grouping (or not) of learners reveals both 'standing patterns' but also the embeddedness of ideas of mathematical ability as Shanghai practices are inverted, even though claims are made by teachers about adoption of new practices. Participants' interpretations of Shanghai practice, circulating discourses of mindsets, and the new curriculum documents form the ethico-ontological-epistemological apparatus that can lead to new practices but that can also lead to a continuation of ones that are very similar to those previously taking place.

Entanglements in researching professional development and in changes in knowledge and practice

Although a transnational initiative, the MTE brings into focus a wider set of issues, about researching and evaluating professional learning innovations, regardless of the extent to which they appear to originate locally. Attending to ways in which methods enact realities (Law 2004) in evaluation can help researchers to embrace greater uncertainty and indeterminacy about what happens in an innovation. My analysis of the mastery evaluation in mathematics adds to previous challenges to the call for, and discourses of, 'hard evidence' in evaluation processes, for example in literacy practices and policy (Burnett 2017). The analysis of the MTE gives insight into how the evaluation process, embedded in entangled complex socio-political-material systems, helps to produce its objects of study through intra-action.

The MTE evaluation also highlights a feature relevant to professional development programmes and professional learning more generally. Echoing actor network principles of heterogeneity, within the research-assemblage, localised seeming 'small' events and elements meet and entangle with state-level policy and transnational organisations such as the OECD. This is exemplified in how questions are worded in an interview or survey and material artefacts such as research report diagrams. The entanglements include actors seemingly somewhat distant to education such as trade policy, with the Mathematics Teacher Exchange both being a vehicle for closer economic ties and symbolic of intentions for trade. The initial policy decision to contract with Shanghai was part of a bilateral trade initiative, and when confirming continued funding for the MTE programme, the then UK Prime Minister linked the importation of mathematics teaching methods to England to exporting teaching English language to China (Elgot and Phillips 2018).

In the case of forms of representation, the enacted practices - summarised as 'use of models and forms of representation' – hide complex relationships including those that may be temporally distant. A

consequence of this, as for social inquiry more generally, is that in professional learning the closeness of relationship between different elements or their importance in a programme or in the outcomes cannot be read from their scale or type. Rather openness is needed to tracking the relationships as they are found. Important too are surfacing entanglements and relationships in which what happens in classrooms is connected to economic policy, through educational policy, with questions of value and social justice that pervaded choices made by policy makers, innovators, schools and teachers.

Conclusion

This paper has addressed methodological and theoretical challenges of understanding and researching professional learning in which different phenomena are closely interrelated. Previous socio- material analyses have sought to trace how phenomena are produced through interactions (Fenwick and Edwards 2010, Fenwick 2011). I have added to these accounts by introducing Barad's concept of entanglement to analyse a professional learning innovation. Two types of entanglement have been considered. The first is the relationship between research and evaluation processes and the objects of research. Like Barad, those advocating sociomaterial perspectives have rejected a view that the relationship of research process to research focus is representational (Fenwick and Edwards 2011b, Latour 1999, Law 2004). However, in professional learning contexts, how this happens in practice has not often been attended to. I have addressed this by focusing on the example of the mastery policy in England and specifically the Mathematics Teacher Exchange and its evaluation. The analysis points to ways that research processes and the research focus more than interact but rather are mutually constituted within the broader educational assemblage.

The second type of entanglement considered was the relationship between the stimuli for innovation, in this example East Asian Mathematics education, and various entities in the mastery assemblage, and changes in knowledge and practice. Two instances of entanglement were portrayed. The first instance was the concrete-pictorial-abstract formulation as a point of intra-action between Western mathematics educational theory, Singaporean practice and its mobility in England, Shanghai mathematics education and the MTE. The second instance was the diffractive patterns in ways that grouping of children was understood and changed in MTE cohort 1 schools. In both these examples, different types of entities – concepts embedded in materialities, policy documents, resources, and educational artefacts – together served as the teachers' apparatus for knowledge production. Thus, for teachers and others involved, like the researcher, there is entanglement in the knowledge creation process with the 'stuff'' of the MTE and mastery innovation.

Barad's philosophy is informed by materialist and feminist science studies and is developed from, and is illustrated by, considering the implications of quantum physics and so the ontological and epistemological indefiniteness of knowledge production. However, her scope is paradigmatic and proposes that entanglement is a feature of phenomena generally. If this is so, then entanglement between knower and known cannot only be an attribute of a specialised cadre of researchers and useful for examining evaluation practice. It also will be a feature of how others come to know – and this includes teachers and, taking a systemic view of knowledge, systems or assemblages. This extension is pertinent to the application of Barad to professional learning which has an aim of teachers coming to know or coming into new relationships to knowledge. Demonstrating the ways teachers are knowledge producers and implications of this has been supported by bringing these four stories together – stacking them (Burnett and Merchant 2016) – to allow reading across narratives of entanglement of evaluation processes and of the MTE programme and within the programme. Central to this process of reading across has been to delve into how a figure that appeared in the final evaluation report came to be. This figure depicted a construct of Shanghai-informed mastery pedagogy and how the MTE might lead to change, and is more

multifaceted than it might initially appear. Examining artefacts in other research texts through the processes of unravelling associations may also give insight into similar entanglements.

Considering the particular innovation and its evaluation as illustrative, Barad's concept of entanglement helps illuminate how myriad social and material relations, including processes of knowledge production, are implicated in the implementation and evaluation of professional development programmes. The analysis presented in the paper is indicative of the value of Barad's concepts, future research might explore in-depth ways in which particular materialities matter in process of entanglement in professional development.

Understanding entanglement of research practice and research focus implies that research phenomena, like subjects and objects in general, 'do not pre-exist as such, but emerge through intra-actions' and the 'the world is materialized differently through different practices' (Barad 2007, p. 89). For Barad entanglement implies attending to the 'lively relationalities of becoming of which we are a part' (Barad 2007, p. 393). Therefore, 'entanglement' not only adds another conceptual tool for sociomaterial and related analysis but also draws attention to our responsibility for these relationalities that we have and participate in. This is a reminder that how we produce knowledge – whether as researcher-participants or teacher-participants in professional learning innovations – has an ethical dimension.

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