Developing a material-dialogic approach to pedagogy to guide science teacher education.

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Abstract

Dialogic pedagogy is being promoted in science teacher education but the literature on dialogic pedagogy tends to focus on explicit voices, and so runs the risk of overlooking the important role that material objects often play in science education. In this paper we use the findings of a teacher survey and classroom case study to argue that there is a gap in the way that science teachers think about the role of materials and that this could be addressed by changes in the theory base of teacher training, augmenting the current constructivist and dialogic theory with the addition of new materialism in the form of Barad’s ‘Agential Realism’. Our findings suggests that science teachers do not *explicitly* consider the relationship between the material resources they deploy and the dialogic learning taking place. We argue that science teacher training and professional development should pay more attention to the material-dialogic relationships in the learning that emerges in science classrooms.

# Introduction

In this paper we argue that teacher education in dialogic pedagogy in the context of science needs to be expanded and developed to become teacher education for a material-dialogic pedagogy. We make this argument through an analysis of interview and observation data from teachers’ experiences of a dialogic inquiry-based science education topic as a stimulus to think through a novel theoretical approach. Our analysis shows a lack of explicit consideration by teachers of the interaction between the material nature of science classroom practice and classroom dialogue and suggests ways in which a different approach to science teacher education could address this.

Research suggests that teacher education is crucial to developing effective dialogic pedagogy (Pehmer, Groschner, and Seidel 2015). This is significant as education for more effective dialogue is central both to the scientific argumentation approaches and the inquiry-based learning approaches which have been emphasised in recent science teacher education ([Hetherington et al. 2016](#_ENREF_2)). In addition to dialogic pedagogy, much research that has been influential for teacher education has focused on the use of practical work with tools and materials in school science, often using constructivist and social constructivist ideas (Leach and Scott 2003; Duit and Treagust 2003). However, the relationship between dialogue and the materiality of the science classroom has remained largely unexplored.

Theories of education informed by constructivism and social constructivism have generated strong research programmes in science education around conceptual change (Taber 2006). Wegerif (2011), questions some of the assumptions of constructivism, arguing that Bakhtin’s approach to dialogue offers a distinct theoretical framework. The capacity to make dialogic switches between different perspectives in dialogue is crucial, Wegerif claims, to the growth of understanding in science and this capacity depends on the quality of relationships. Crucially, the voices that are relevant in the science classroom are not limited to those embodied within individual humans. Bakhtin wrote that ‘I hear voices in everything and dialogic relations among them’ (Bakhtin 1986, p. 169). White (2014) is clear that ‘dialogic pedagogy is not a case of hands-off approaches to teaching, but instead an opportunity to “risk genuine encounters with a multiplicity of others”’ (White, 2014, p. 229). In science education those ‘others’ must include material objects.

From a Bakhtinian perspective, knowledge is a phenomenon that emerges through dialogic interactions; a perspective that sits well within a typical model of teacher education through professional dialogue between teachers and trainee teachers and teacher educators. The importance to continuing professional development (CPD) of establishing a dialogic space between teachers has been brought out in recent research (Hennessy, Mercer, & Warwick, 2011: Warwick, Hennessy, & Mercer, 2011). However, in science education in particular, the dialogic space needed for effective cpd and teacher education needs to include not only the voices of the teachers but also the ‘voices’ of materials. The idea that materials might enter into dialogic learning is not obvious and requires a new theory if it is to make sense and also if it is to be of use to teacher education. A key role of teacher education is to challenge the implicit theories of teachers and to provide them with new theory as a guide to action.

There are several attempts to account for the relationship between dialogue and materiality in science education which have implications for the education of science teachers, (Chappell and Craft, 2011; Cowie et al 2015; Mercer et al, 2010; Kress et al, 2001). However all these attempts essentially maintain a binary distinction between human and non-human in which the material is *used* by humans to create meaning. We use Barad’s work to explore an alternative that, like Wegerif’s concept of ‘dialogic space’ (Wegerif, 2011), begins with the relationship rather than with the separate parts. In other words, we reject a substance ontology in favour of a relational ontology. Barad uses her expertise in quantum theory to argue that both matter and meaning are produced through what she calls a material-discursive process. We argue that this material-discursive understanding can be used to extend a dialogic account of the production of meaning in science teacher education and CPD in a way that includes the ‘voices’ of the material.

This paper explores in particular the difference that this theoretical perspective can make in relation to dialogic pedagogy in the context of science teacher education, building on case study data collected within a large design-based research study, ‘Science Education for Diversity’ that explored dialogic pedagogy as a means of engaging diverse learners with science (Griethuijsen et al. 2015; Wegerif et al. 2013; BouJaoude et al. 2013). Drawing out the insights that emerge from interacting this materialist theoretical perspective with the empirical data, we put forward a material-dialogic pedagogy for science teacher education.

## Agential Realism

Inspired by the physicist Niels Bohr, Barad develops a ‘material-discursive onto-epistemology’ in which matter is an active participant in the performance of phenomena. Barad’s theory does not assume a separation between matter and meaning but sees both as united in a single entangled reality. Matter is not given separate agency but becomes an active participant in the process of learning. This approach to agency takes into account that the teacher, pupils and materials all actively make a difference to learning. Rather than understanding teacher agency as ‘the capacity for autonomous action’ (Calhoun, cited in Biesta and Tedder 2007) or a relational effect between individual and environment (see Priestley et al. 2012) where the environment *mediates* the realization of agency, Barad’s work suggests that the agency of the teacher, student and material all *come to exist* in the performance of teaching and learning.

For Barad, the primary ontological units are not ‘things’ but ‘phenomena’, which emerge through ‘material-discursive intra-actions’. This is a move away from a representational approach in which language is used to denote or represent, to a performative one where knowledge and the world are materialised through material-discursive practices. Within agential realism, agency is understood in a relational sense, not as some kind of capacity or power aligned with human intentionality but as ‘the ongoing reconfiguring of the world’ (Barad 2007, p. 170); it is ‘a matter of intra-action; an enactment, not something someone or something has’ (Barad 2007, p. 177). This implies that matter has a role to play in agency. However, to say that non-human ‘things’ have agency - as Latour seems to (Latour 2005) – would be to misunderstand Barad and to maintain the human/non-human binary which she seeks to overcome. Whilst there are some similarities between Latour’s argument in the context of Actor-Network Theory and Agential Realism there are also differences. Latour is very clear that objects are actors within an assemblage but in a distinct way to human actors. For agential realism, by contrast, agency is not a capacity that things might have so things are not directly agentive. Agency is rather understood as something enacted performatively as material-discursive practices make ‘agential cuts’ that close some possibilities whilst holding open others.

Applying this theory to science classroom practice we can see that that the teacher, students and experiment all participate in learning by making ‘cuts’ – by making some things possible and not others *in the way they relate to and intra-act with each other.* It is this that makes the ‘discursive’ aspect of Barad’s approach important (and in the science classroom, highlights the role of dialogue whilst maintaining a focus on the material).

Barad builds on the insight from research into quantum level reality that the way in which experiments are designed does not simply enable observation of a pre-existing reality but actually brings apparent reality into being. In the famous two slits experiment that is often used in classrooms one way of observing produces light as particles while another way of observing produces light as waves. For Barad then, apparatuses (including but not restricted to scientific apparatuses) are not simply given to us as things in a world but are ontologically primary mechanisms for creating particular worlds within which they then appear, retrospectively, as phenomena. Apparatuses are open-ended boundary-producing practices which enact agential ‘cuts’: they are both productive of, and part of, phenomena (where phenomena are both matter and meaning). Wegerif presents ‘dialogic space’ as a similarly ontologically primary concept, ie not an actual space but an opening of a potentiality out of which new configurations of actual spaces, times and meanings emerge within dialogues (Wegerif, 2011). Although previously the focus of dialogic theory in education has been on the interaction of human voices, the concept of opening a dialogic space goes beyond this. Dialogic space includes the interaction of ‘voices’ that are not human. Entangling the ontologically similar concepts of ‘dialogic space’ and ‘apparatus’ suggests a way to understand how matter is always already part of the dialogue and how dialogue is also always, in a sense, a material configuration.

Lenz-Taguchi (2011) has applied Barad to education, developing what she calls an intra-active pedagogy, focusing on using pedagogical documentation within material-discursive practices of teacher education. This intra-active pedagogy pays particular attention to the role of pedagogical documentation in enacting agential cuts that both enable and constrain learning. This focus on the role of ‘documentation’ (texts and artefacts) can be used also to illuminate teacher education where material documents like writing frames for lesson plans and teacher appraisals also enable and constrain the enactment of agency.

## Dialogic Pedagogy in teacher education

Dialogic pedagogy teaches student teachers how to engage in dialogue for learning together as well as teaching content matter through dialogue (e.g. Warwick et al 2016). What makes any pedagogy dialogic is the aim of teaching and learning for dialogue as an end in itself in addition to the aim of teaching knowledge. Dialogic pedagogy in teacher education offers a vision of drawing student teachers into participation in continuous professional education as a form of shared inquiry (Warwick, Hennessy, & Mercer, 2011). Up to now presentations of dialogic pedagogy for teaching and for teacher education have not engaged effectively with the material aspect of dialogues, for example the use of key documents to make agential cuts as described above. To investigate the role of the material within a dialogic approach to teaching and learning in science, we have re-analysed data collected as part of the Science Education for Diversity (SED) project (Van Eijck 2011; BouJaoude et al. 2013) alongside new case study data.

# Research Design

The empirical data discussed in this paper are drawn from an EU-funded international study that used design-based research (DBR) (Anderson and Shattuck 2012; Barab and Squire 2004) to explore theory-driven science education pedagogies for diverse students, following a large-scale exploratory review of international science curricula (Morgan et al. 2012) combined with a survey and field interviews with teachers and students (Van Eijck 2011). A DBR approach was used as it recognizes the need to test theory in practical settings using a range of methods to triangulate multiple sources of data within each context to document the enactment of theory-driven pedagogy (The Design-Based Research Collective 2003). Broader findings from the SED project, including questionnaire and interview analysis, are reported elsewhere (see Griethuijsen et al. 2015, for details.; Van Eijck 2011; BouJaoude et al. 2013). Table 1 outlines the SED project research design: in this paper we use data drawn from Work Package 3 (WP3) as a broad context, but focus mainly on data from the DBR element in the UK (WP5).

Table 1: Science Education for Diversity Project Methods, Sample and Analysis

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| --- | --- | --- | --- | --- |
| SED Work Package (WP) | Methods | Sample | Analysis | Secondary analysis for MD study |
| 3Partner Countries: UK, India, Malaysia, the Netherlands, Turkey, the Lebanon.  | Survey:Interviews: | Total: 9171 students; 331 teachers. Focus group interviews with 192 students. Individual interviews with 75 teachers. | Deductive coding using a coding scheme generated from analysis of pilot interviews with a focus on diversity, to ensure international consistency | No further analysis, conclusions drawn from the primary analysis were used. |
| 5 | Observations, analysis of classroom materials, interviews and questionnaires.  | 2 schools per country.For the case study in this paper: Rural English comprehensive school. 2 classes included in the sample, 1 class of 28 students aged 12-13 and 1 class of 25 students aged 14-15. All pupils participated in focus group interviews (n=53), and 2 teachers were interviewed. | Inductive coding of qualitative data using constant comparison method of open coding followed by axial coding within each case in each country, then across cases within each country before thematic synthesis between countries.  | Revisited case study school, re-interviewed 3 teachers and interviewed 2 for the first time. Re-analysed original interviews alongside new interviews using open coding and axial coding.  |

For the purposes of this paper, we draw on the international survey and interview findings to contextualise the importance of practical experience for teacher science education, and then use data from one of the UK case studies which we have recoded inductively to explore in depth the implementation of the dialogic pedagogy with respect to our focus on the role of the material in dialogic pedagogy and teachers’ perspectives on their practice with implications for teacher development. Since DBR is a cyclical process involving long term relationships between researchers and context (The Design-Based Research Collective 2003), we also returned to the setting after 4 years and conducted a further 5 individual, semi-structured interviews with teachers (3 of whom had been interviewed for SED, 2 were current trainee mentors, and 1 trainee) to explore longer term perspectives on the dialogic pedagogy introduced in the project. SED WP5 interviews used a semi-structured format, with a relatively structured interview protocol to ensure consistency between partner countries, then follow-up in a more open-ended style towards the end of the interview; the later interviews used a semi-structured interview schedule. Interviews were analysed by a process of open line-by-line coding of each individual interview, followed by axial coding and the identification of key themes, which were then checked iteratively by re-coding each individual interview.

# Findings

After we briefly outline the results from the large-scale international survey, which highlights the relevance of the role of material resources in science education we focus on the analysis of interviews with teacher bringing out material relevant to teacher education. This was augmented by observations but we do not have space to present that data here. Our analysis reveals that teachers see materiality in two ways depending on context, in the context of information and communications teachnology they see materiality as a support for learning through dialogue but in the context of the ‘practical work’ that is a key feature of science education, they see materiality as a way of illustrating concepts. They thus fail to see the potential of dialogue stimulated by/with the materiality of objects for creative learning and growth in understanding. This gap can be traced back to teacher education and could be overcome, we argue, by a revised teacher education based on a material-dialogic pedagogy.

## Survey findings on use of materials in science education across countries

The international survey of pupils and teachers found that a range of material resources played an important role in science lessons, with differing emphases depending on the distinct national contexts: all countries included mention of practical work, with India, the Lebanon and the UK making most use of standard lab equipment, whereas text books were less commonly used in the UK and the Lebanon compared with other countries (Van Eijck 2011). This variability in the use of materials within science settings is of interest in considering the relationship between the material and dialogic pedagogy and the extent to which science teacher education addresses this relationship.

## Interview Findings

Here, we report the relevant findings from an inductive thematic analysis of teacher interviews from one of our case study schools, a rural secondary comprehensive school in the SW of England. One of the key findings was that teachers think quite differently about two forms of materiality, the materiality of practical work with objects and tools is thought of in terms of illustrating concepts wheras the materiality of whiteboards and other technology of communication is thought of in terms of opening and supporting dialogue. This gap needs to be addressed by teacher education and is the stimulus for our proposal of a teacher education approach using agentic intra-action from Barad to support teachers thinking about science pedagogy in a new way that includes the voices of materials in the dialogue.

### Teachers talking about dialogue and materiality

Teachers described their approach to dialogue in terms of the exchange of ideas between pupils, enabling them to try out ideas and experiment with their thinking.

Teacher F: “…you’ve got to show kids that sometimes first of all there isn’t necessarily a right or a wrong answer and that there is a place to be creative and there is a place to be brave.”

They also identified an exchange of ideas between pupil and teacher within a dialogic pedagogy as fostering an approach where differences of opinion could be highlighted and valued, but also as an opportunity to highlight to pupils the role of evidence in developing an argument in science, thus using a dialogic approach to develop pupils’ understanding of the nature of science.

The use of stimulating topics such as natural selection and radiation, were identified by teachers as important in engaging pupils successfully in debate and discussion. Stimulating discussion through raising big questions, or by using an exciting demonstration or practical hands-on activity showed that teachers clearly considered both their questioning and verbal interaction with the students and the use of particular materials within the lesson as important teaching tools. This shows some implicit thinking in relating the material classroom experiences to the exchange of ideas through stimulation of class debate, but, as shown later in the findings and discussion, this relationship is rarely made explicit.

Teacher B: I like teaching evolution…I like the debate to start with, I like to set it up as a debate and then we'll look at the Darwin's theory and your little jokes about evolution and stuff and you can really get the class engaged with thinking about, you know, 'if we evolved from monkeys, why are there still monkeys?' and you can just start that as a lesson and have them think about it, and the arguments you get in the class, the quite heated debates are quite nice.

Teacher F: I like teaching radiation because I think it's an exciting subject, it's something that students come across probably for the first time at secondary school. It's reasonably visual, it's got a danger element to it, it stimulates discussion.

This hints at the stimulating nature of the practical work available within these topics, although this link was not specifically made by Teacher F.

The use of film clips and the interactive whiteboards as a basis for prompting discussion, thinking through ideas and questioning was mentioned by multiple teachers in the case study (a finding that was also noted in the broader international interview data set). This is one of the few points where the teachers made explicit reference to some form of material resource in relation to dialogue.

Teacher C: there might be something on the whiteboard that they would, a question or an image, something that would start them thinking about the topic for example, so they might discuss that in groups and then answer questions.

To summarise, teachers used dialogue in the classroom in tandem with material resources to promote debate and discussion, encourage questioning and a scientific approach, and to enable them to elicit and be responsive to pupils’ ideas. Although the materiality of the subject and the classroom is hinted at in relation to dialogue, in our data there was little evidence of clear pedagogical thinking about the role of these materials in the dialogue. It appears that teachers clearly made use of them to stimulate and extend discussion but little was said about how this took place. In order to develop teachers’ dialogic pedagogy as part of professional development, we would therefore suggest that professional dialogue in a teacher education or professional development programme begins with a focus on surfacing how teachers use dialogue in the classroom in and of itself and in relation to the classroom materials and environment. The concept of agency as developed by Barad suggests that the intra-action of teachers, students *and* materials are all crucial to the performance of learning, in this case in the science classroom. The need to be responsive, as identified by the teachers in this data, is crucial to this agentic intra-action but the focus in the data remains on teachers responding to students, with little consideration of the material. This gap could be addressed through teacher education through the use of teachers’ pedagogical and classroom documentation and dialogue in a fashion that models the intra-actions in the science classroom.

### Teacher’s talking about their use of material resources in science education.

Teachers made use of a range of material resources in their lessons and made regular reference to the use of science-specific resources on the one hand and technology on the other. The use of materials and modelling to construct ideas was mentioned. This is interesting in the context of this paper as it is one potential aspect of science teachers’ common practice that could be drawn upon to develop their understanding of material-dialogic relationships.

However, although science-specific material resources were seen to be important, it was, as noted above, rare for teachers to make explicit *how* they used these materials in relation to dialogic pedagogy or to stimulate pupils’ thinking. One exception to this was Teacher A, who participated in the Science Education for Diversity intervention and was concerned to ensure that practical lessons were used to explore ideas.

Teacher A:…even if I was doing a practical I would make sure that was interspersed with some sort of coming together, exchange of ideas, etc.

Teachers in this case study school all valued and made use of technology. They felt that technology could be used to stimulate thinking and prompt discussion, as illustrated by the quote from Teacher C above, and Teacher E’s statement that he ‘uses technology, and media input to get them thinking about things’. Teachers regularly noted that a lack of technology could be an obstacle to learning, and were keen to use cutting edge technologies in their lessons.

Interestingly, there was more regular consideration of how technologies such as iPads, interactive whiteboards and film clips could be used to stimulate thinking and in the context of class or group discussion than when teachers discussed the use of scientific practical equipment. Teacher education and professional development has been more explicit in linking these aspects, with practical work being more likely to be discussed with reference to conceptual illustration and development, and scientific inquiry and investigation as a general pedagogical framework than explicitly dialogic.

Teacher E: Very briefly and as simply as possible, [good teaching is] putting the learning in the pupils hands, giving them materials and resources for them to construct their own ideas.

Teacher B: I've got my year eights marching on the playground to do refraction of light, just teach them to march very, very quickly, 'when you cross this line you have to slow down, hit it at an angle the whole lot moves' and you actually pupil model the refraction of light really, really well.

Modelling has long been an important aspect of science and science education, with teaching incorporating the use of scientific models and the notion of modelling as an important aspect of the nature of science, alongside the use of both physical and mental models as teaching aids (Gilbert and Boulter 1998). This important element of science pedagogy is often a core concept included in science teacher education and it is therefore no surprise that teachers mentioned the use of models to aid pupils in understanding concepts and constructing ideas. As the two quotes above show, teachers are keen to use materials, including pupils’ own bodies, to help them model scientific ideas in order to understand them. Again, of interest in relation to this study, teachers regularly mentioned the use of various kinds of models for this purpose, but did not explicitly link their use to classroom dialogue – they did not tend to explore or explain how they could use dialogic pedagogy to work with pupils to construct models or use models to construct their own ideas about science. This, it seems to us, is one locus of potential in supporting teachers to further develop their practice in material-dialogic pedagogy as there is already an implicit relationship between material, model, classroom talk and scientific concept.

### Teachers talking about teacher education in relation to dialogue and to materiality

The teachers in our case study discussed teacher education in relation to the importance of good relationships with pupils, and being able to use practical work effectively firstly in a logistical sense and then in the sense of stimulating thinking.

The teachers in the sample regularly noted the importance of good relationships with the pupils in order for dialogic teaching and indeed, all science teaching, to be effective, and also highlighted this aspect as something that is crucial in teacher education. For example, Teacher E felt strongly that the ‘single most important thing in teacher training…is [for trainees to] be aware that good teaching is based on a relationship with first of all the group, then groups, then individuals’.

The trainee teachers’ mentors (these were experienced teachers within the school who support trainee teachers in the classroom and shape the teaching experiences they are offered) tended to note that new teachers needed supporting with the use of practical work, but initially in a logistical sense before they could consider how to use the practical most effectively to stimulate learning.

Teacher C: So he (the trainee) might say ‘so what we need to focus on isn’t necessarily the pedagogy of using practicals to help learning but it’s more about the logistics of practicals in the room’.

Teacher G: (The trainee) misses out on capitalising on practicals.

Interestingly, this point mirrors Abrahams and Millar’s framework for effective use of practical work through effectiveness at the level of ‘observables’ and the level of ‘ideas’ (Abrahams and Millar 2008). In this study, Abrahams and Millar noted that practical work was often effective in terms of making observations and completing the task, but less often effective in supporting students’ developing understanding. Further, the teachers’ discussion, both in our findings and in Abrahams and Millar’s work, lacks exploration of the role of dialogue in relation to the practical work (i.e. the use of materials) and how they work together.

There tended to be little focus in the conversations of mentors or trainee on the way dialogic pedagogy can be used in relation to practical work or other materials such as the use of interactive whiteboards. This is crucial because the mentors are the key point of contact for trainee teachers undertaking their training in school, observing them teach and discussing their teaching with them with a view to improving and extending their practice. One teacher in the case study school noted that they let the pupils discuss during practicals but they did not focus on scaffolding those discussions:

Teacher G: It’s sometimes very interesting to listen to their conversations when they’re doing practicals…I suppose it gives them something solid to talk about’

This teacher went on to explain that she lacks confidence in running discussions, noting that ‘I’m not particularly good at saying, “go away and talk about this”, perhaps I don’t set it out right; the conversation drifts”. This teacher was herself involved in teacher education as the montor to a trainee teacher in the school. It is evident from this and other comments by the teachers that there is a need for more teacher education and continuing professional development about how to make effective use of dialogue and dialogic pedagogy in relation to classroom practice in science, both generally and in a practical context.

# Discussion

The interview findings show that material and dialogue both play a clear role in science classroom practice. However, although both elements are valued and (using a material-discursive framing) are intra-acting to perform or enact learning, there is no explicit consideration by teachers of the interaction between the material nature of classroom practice and the dialogue that takes place. The dialogues are material through words, signs, cards, templates and practical demonstrations, which all both constrained and enabled learning, making a difference (and making new material configurations) that open up new material-dialogic spaces. Our findings also show how, mirroring this classroom practice, the trainee-teacher and teacher mentor relationship within school (a key part of teacher education in the UK) has both material and dialogic elements but that there was no explicit consideration by teacher mentors of material-dialogic interaction either with classroom materials or teacher education pedagogical materials in the performance of teacher learning. The importance of relational interactions between teachers and pedagogic materials in teacher learning has previously been highlighted by McNicholl, Childs and Burn (2013), who argued that teachers’ pedagogical content knowledge could no longer be viewed as individualistic but rather distributed via artefacts held in school science departments, with practical implications for teacher education in the importance of contribution to shared pedagogical materials and the need for a shared physical space for teachers to collaborate. However, they conceptualise the material and dialogic spaces separately.

The separation commonly found in the literature between dialogic space and the voices participating in learning, and the material world, was also highlighted in the teacher interviews – the material was valued as offering stimulating practicals, enabling modelling and illustration of concepts, and in the use of technologies to stimulate thinking and questioning, but there was no clear articulation by these teachers about the relationship between the material, the dialogue and the learning. For example, the role of evidence in scientific argumentation and dialogue is one aspect where, although the material nature of that evidence was not made explicit in the teacher interviews, materiality may have a key role to play. Similarly, Teacher B’s comment about the stimulating nature of the visual demonstration associated with teaching about radioactivity demonstrates that although teachers were clear that both material resources and dialogue helped to stimulate pupils’ thinking, links between material and dialogue appear to be implicit rather than explicit in the teachers’ thinking. From the comments made we can deduce that this separation of dialogue from material stems from teacher education and could be addressed through changes in teacher education.

Drawing together a Bakhtinian dialogic pedagogy (Wegerif 2008) with Barad’s material-discursive onto-epistemology (2007) may offer a theory that could underpin a teacher education approach that would take a more dialogic approach to relationships with materials. Looking at the data using this lens, we can see that teachers, students *and* materials enact ‘agential cuts’ through their intra-actions that enable particular learning phenomena to emerge. An ‘agential cut’ is a particular observation that divides reality making some aspects visible and others invisible. In the classroom we see how discourse and matter conspire to produce key decisions that shape learning. In collaboration between science teachers to develop their pedagogical content knowledge such as studied by McNicholl et al., the concept of the agential cut could also be useful in exploring *how* the space, pedagogical artefacts and teachers intra-act to enable particular learning.

Significantly, the distinction between a pedagogical approach influenced by Barad’s agential realism and other dialogic pedagogical approaches, is in the understanding that the material has agency in enacting agential cuts. The argument goes beyond the suggestion that science teachers should pay attention to the material in their lessons. This is evidently already the case. What we are arguing for is a pedagogy in which science teachers are explicitly aware that their intra-action with both the students *and* the material generates distinct phenomena that matter in the world; that the ‘becomings’ of material-student-teacher (i.e. learning) are enabled and constrained by the choices that are made through those ongoing intra-actions.

In teaching about electrical circuits, teachers could ask themselves what learning is enabled and constrained if the practical materials are offered to the students as a locktronics kit with ‘recipe’ style instructions to follow, or they are given the same kit and they are told to play with it and present their findings to the group, or if they are given some everyday objects, wires, crocodile clips and a few cells and asked to ‘make the objects work’. This could be supported in itself through the relationship between material and dialogue within a teacher development programme. For example, in the case study school here, trainee teachers are required to use particular forms of documentation: the ‘agenda’ and the ‘framework for dialogue about teaching’ ([Hetherington, Postlethwaite, and Skinner 2015](#_ENREF_1)). These pieces of documentation ask the trainee teacher to make explicit their intentions for a lesson in relation to an aspect of their own development (not the students’ learning which is the focus of the lesson plan). They then teach whilst their mentor makes non-evaluative notes against their intentions as outlined in the agenda. The agenda and annotations then become the focus of reflective dialogue between trainee teacher and mentor in a discussion that may be supported with reference to the ‘framework for dialogue about teaching’. In the example suggested above, how the trainee teacher frames the electrical circuit lesson could be written into an agenda about the use of practical resources and thus used to explore the material-dialogic intra-action in the classroom. In the case study, this process was not being used to focus on the material dialogic relations in part because mentors were not confident to do so and in part because it was not a focus suggested by the University (an example of an agential cut!). Teacher education and development could therefore be extended by the University making the material-dialogic interaction an explicit potential agenda focus and supporting mentors in this through their mentor development programme, and by making stronger use of the agenda tool within trainee teacher placements. Using the pedgagogical documentation of teacher education in this way would also model for trainee teachers and their mentors how material resources can be seen as entering into the ‘material-dialogic space’ through reflective discussion of how the framing, use and discussion of an ‘agenda’ makes ‘agential cuts’ in the learning of the trainee teacher and mentor (and, indeed, the students in the class. Although the range of learning opportunities offered to the students could be standard, the difference here is in the way the teacher *approaches* the lesson and how they plan to scaffold the lesson through material-dialogic interaction with an interest in responsively acting on the learning that emerges as a result.

This awareness of how matter enters into and shapes learning extends the dialogic space. Recognising how a particular tool, a piece of graph paper for example, both constrains and enables learning enables that tool to be interrogated and to enter into the larger dialogue not as passive background but as an active or constitutive voice within the dialogue. Science teachers taking up a material-dialogic pedagogical approach will therefore need to consider how their choices of materials and communication tools intra-act in dialogue with themselves and their pupils in generating emergent learning, and, given that this is not currently an explicit element in science teacher education, we suggest that science teacher educators need to engage with such an approach.

It is apparent from our findings that although teachers value pupil discussion in science and link this to teaching the nature of science, there is not always a strong sense that those experienced teachers who are involved in teaching student teachers are confident in using dialogic pedagogy even in a school involved in practice-based research in this area.

Further, the focus on developing logistical competence *before* focusing on pedagogical rationale suggests that in initial teacher education, dialogic pedagogy could remain a theoretical concern until trainee teachers are competent in managing the materiality of classroom practice. However, teacher education and professional development that will enable teachers to feel confident in using material-dialogic pedagogy will be challenging to implement, if lessons learned from the ‘Getting Practical’ project, which aimed to support teachers in using ‘minds on’ as well as ‘hands on’ approaches to practical work, are considered (Abrahams, Reiss and Sharpe 2014). A multi-pronged approach to shifting pedagogy that brings material-dialogic theory to practice through University-based teacher education programmes and tools, school-based experiences and collaborative dialogue between teachers, and teacher-pupil-material intra-actions through shifting classroom pedagogy are all necessary elements in bringing these ideas to fruition in practice. This requires further exploration of effective teacher education pedagogy with respect to these ideas as well as time and support for teachers.

We would argue, however, that shifting focus towards a material-dialogic approach would support both teachers and teacher educators in facilitating new teachers to manage both elements of the class simultaneously and effectively. For example, one challenge for student science teachers is how to differentiate a practical activity. A common default for differentiation is setting book work for those who finish early. A dialogic material-discursive alternative is to allow the students to explore working with the equipment to see what happens when they configure it differently. What applies to students in classrooms applies even more strongly to student teachers within teacher education. Rather than teaching the use of material to illustrate conceptual knowledge student teachers should be taught how to play with materials in order to explore knowledge. This would enable them to experience the potential of working with matter in a way that allows its voice to speak and enter into a dialogue. For dialogic pedagogy the aim is, amongst other things, to expand understanding and the potential for creative action by expanding the dialogic space. In current classrooms too much that pertains to the material conditions and media of science education is taken for granted and so becomes the passive context and frame for dialogue. Incorporating a greater awareness of material conditions of every kind that limit as well as enable dialogues is a way of expanding dialogic space. Simply playing with equipment and exploring alternative configurations of tools is a way of bring the inert background into active play within learning dialogues. This pedagogical framework has the potential to transform science teacher education by combining the mastery and use of tools for teaching with the mastery and use of dialogic pedagogy because these are now seen to be just two aspects of one sole process – the dialogic discursive material process of learning.

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