Practical Theorising in the Professional Development of Primary Teachers: Outcomes of the 'Thinking, Doing, Talking Science' Project

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Abstract

In this chapter we apply the concept of practical theorising to the context of primary teacher education, focusing specifically on the ways that teachers develop subject knowledge alongside critical engagement with creative approaches to pedagogy. We begin by framing critically the concept of practical theorising in the context of primary teacher education. Then we move on to explore a successful example of practical theorising through the *Thinking, Doing Talking Science* (TDTS) project. TDTS draws on research that identifies key features of a creative pedagogy that supports cognitive development in science (McGregor 2007; McGregor and Gunter 2006; Davies and McGregor 2017) and focuses on teachers applying theoretical propositions related to a constructivist approach to learning science in a practical and inclusive way. A key component of the programme is the nurturing of 'adaptive expertise' (Berliner 2001) or the capacity to adopt a flexible, research-informed approach to the teaching of Primary Science. Through participation in the programme, teachers are encouraged to develop creative and challenging science lessons that encourage pupils to develop higher order thinking skills. Teachers enable their pupils to think and talk about scientific concepts through open discussion and through creative investigation and problem solving. In so doing, teachers model practical theorising as well as organising teaching and learning in a way that is underpinned by this concept. Results from the Education Endowment Foundation's (EEF) funded efficacy trial (Hanley *et al* 2016) indicated that school pupils (aged 9-10) using the approach made approximately three additional months' progress in science. The EEF research also presented evidence that there was a positive effect on girls and those pupils with lower prior attainment. There were also indications that the approach had most impact on pupils eligible for free school meals. With this in mind, we argue that the 'practical theorising' approach adopted by teachers engaged with the TDTS pedagogy provides more equitable opportunities for all pupils and has clear benefits for them, both in terms of learning outcomes and positive attitudes towards science. In terms of professional learning for teachers, TDTS provides clear guidance for them to practically theorise ways of affecting change in pupils' learning in their science classes.

Introduction

The earlier chapters of this book are primarily concerned with the ways that beginning teachers adopt and adapt varied forms of practices informed by theoretical frameworks. In this chapter the ways that TDTS project has been theorised, interpreted and enacted by primary teachers concerned with teaching science is presented and considered as a form of practical theorising.

The TDTS project has helped teachers in applying theoretical propositions about both science and pedagogy in a practical, engaging way. A key component of the programme, although not named as such in its implementation, is the nurturing of 'adaptive expertise' (Berliner 2001) or the capacity to adopt a flexible, research-informed approach to the teaching of Primary Science. Through participation in the programme, teachers are encouraged to adopt and adapt various kinds of activities that challenge pupils to extend and deepen their thinking. This was inspired by Mant, Wilson and Coates's (2006) tailored concept of higher order thinking (Lewis and Smith 1993). In the context of TDTS, teachers were encouraged to engage their pupils in higher order thinking by adopting practices that demonstrated their adaptive expertise focused on facilitating thinking and talking about scientific concepts. This was achieved through dedicated discussion time, hands-on practical activity, creative investigation, and problem solving. Results from the efficacy trial (Hanley *et al* 2016) showed that in schools adopting this approach, pupils (aged 9-10) made approximately three additional months' progress in science. With this in mind, we argue and illustrate how a 'practical theorising' approach (as described below) provided more equitable opportunities for learning in science for all pupils.

Practical Theorising

Drawing on the work of Alexander (1987), MacIntyre's (1995) framing of practical theorising provides a valuable lens through which to interrogate the benefits of the TDTS approach. Crucially, McIntyre frames theorical knowledge as, "tentative, inadequate, and constantly to be questioned" (1995 : 366), highlighting how a lack of consensus can be normal and, indeed, a preferable expectation for teachers to provide space for the framing of their practice. If one is able to frame teaching as a profession within which no consensus on theory or practice is to be expected, argues MacIntyre, it may be possible to instil a critical disposition as the starting point for teachers to engage in their professional lives. As MacIntyre puts it, practical theorising should offer space for going beyond reflection on practice, incorporating instead an "experimental use of ideas from many sources, including both the elucidated practice of experienced teachers and also a diverse theoretical and research-based literature, i.e. with theorising about practice" (1995 : 366). A major challenge to engaging with practical theorising in the real world of schooling, however, is the continuing drive towards a consensus around what ‘counts’ as disciplinary knowledge, theoretical or otherwise, and what ‘counts’ as a valid means of teaching and assessing this knowledge. Arguably, this is as much the case for prescriptive government mandated approaches to teacher education (Hagger and MacIntyre 2006) as it is for examples of curriculum oriented towards high stakes assessment (Harlen 2007). For teachers involved in the TDTS programme there is space to consider what they know instinctively, what they know to do technically, and what they believe to be the ‘evidence’ about what works that can inform the enactments of their practical theorising. A complication of marrying theory and practice is the propensity to make linear the temporal relationship between theory and practice. This can lead to assumptions that one must or should precede the other. Such a fixed framing of the relationship between theoretical knowledge and practical experience (that the former precedes and shapes the latter, or that the latter generates the former) creates an *a priori* tension between these aspects of learning. Instead, practical theorising goes some way to suggest that theory and practice are married together simultaneously in the present, and that therefore neither can exist without the other. Moreover, the co-existence of theory and practice in any kind of educative process offers the possibility of a productive, critical space where consensus is always under development. The inductive approach of TDTS described below is an example of such an approach.

The context and crisis for teachers teaching science in primary school.

Science education is a particularly good context for reflecting on practical theorising. A crucial component of the scientific method involves critical engagement with evidence that marries consensus around existing evidence with an acknowledgement that consensus is never (or should not ever be presented as) hegemonic or total. At the same time, the reality of delivering science education in primary settings often reveals a lack of confidence or agency on the part of teachers to engage with core scientific principles, and thus also with the process of practical theorising. Teachers provided with resources, materials and ideas that constituted the TDTS approach adapted the ways they used them in their particular schools, thereby modelling practical theorising underpinned by creative pedagogies. The pedagogic approach involves presenting conundrums, in a variety of forms, and engaging pupils in discussion to creatively and collectively resolve the scientific challenges.

Before exploring TDTS in more detail, however, it is worth briefly considering the nature of science education in English primary schools prior to development of the project. Science has long been a core subject, along with English and mathematics, in primary (elementary) schools in England. Up to

May 2009 science was included in the Statutory Attainment Tests (SATs), compulsory national measures of assessment, taken by all pupils at the end of their final year in primary education. However, science was removed from these, partly because it was hoped *teaching to the test* (Murphy and Beggs 2003) would decrease and a cessation in constantly measuring pupil's performance levels, using summative testing methods would provide space and opportunity for teachers to be innovative in primary science classrooms. However, Ofsted (2019) indicate that science provision has remained weak in comparison to numeracy and literacy and that science has been de-prioritised in primary schools since the scrapping of the SATs. Prior to this the Wellcome Trust (2013, p. 5) had reported there was a lack of science expertise in most primary schools and the confidence to teach it was low and few practical lessons were reported to take place. As Fitzgerald and Smith (2016, p. 64) described, as 'generalists, primary school teachers must determine how, when and where they attend to a range of explicit science curriculum demands, while also attempting to balance teaching and learning requirements across all curriculum areas'. Peacock and Dunne (2015) suggest, teaching science is challenging because of the traditional ways in which it is often presented. Science concepts related to forces, electricity and evolution, for example, have long been understood to be 'hard' (p. 27) and even 'boring' (p.28). Perceptions of both teachers and students have long held the view that science is complex and often 'counter intuitive' (ibid, p. 28) and that this may result in avoidance of it. For teachers and pupils alike, this representation of the highly theoretical nature of scientific knowledge is exclusionary and drives a wedge between theory and practice. TDTS offers an approach to help resolve this seemingly national issue.

It is important to promote teaching of science to younger pupils in ways that engage them and capture their imagination whilst also improving their knowledge and understanding of the subject. Ironically, however, at times the practice of science education can get in the way of theorising about science (or about science education). Against a backdrop of teaching challenging subject matter that requires competence and confidence to design and conduct effective lessons those new to teaching science understandably can require clear guidance and support about how to go marrying theory and practice productively in the primary school environment. Regimes of compliance (including programmes of teacher education) can make it very difficult for teachers (and especially new teachers) to feel that they have the power to make regular challenges to the status quo of educational research and school practice. Such agency can be developed through the practice of research or through experiential development of the theoretical, institutional or practical knowledge required to challenge the *normal* (MacIntyre, 1995). Introducing different 'ways of being' (Bourdieu

1991) can provide teachers with opportunity to critique the consensus and in so doing become more agentive teachers of science.

Developing expertise in primary science teaching

Berliner (2001) in his summary about key influences on the development of pedagogy considers how beyond just talent and practice it is the context, i.e. the situation in which teachers find themselves, that can affect what characterises teaching expertise. The TDTS approach provides participating primary teachers with a teaching framework that encourages them to engage critically with the tensions outlined above between theory and practice in the primary classroom. In the process, teachers develop the capacity to be adaptive and fluid in their practice. The following discussion presents the approach in detail to demonstrate this.

The TDTS approach

The TDTS project enabled teachers to champion the lack of consensus in science teaching practice as a positive outcome of their critical engagement with creative pedagogy and core aspects of the scientific method. Initially, inspired by the theoretical framing of higher order thinking and recognising the value of discussion to promote such, as indicated by Adey and Shayer (1994) the TDTS project embraced constructivist approaches practically demonstrating to teachers different ways they could engage learners in thinking and talking about science (McGregor *et al,* 2020). The development of the TDTS materials builds on the 'Conceptual Challenge in Primary Science' project funded by the AstraZeneca Science Teaching Trust (now the Primary Science Teaching Trust) which took place in sixteen English primary schools in 2002 – 2003 (Mant *et al*, 2007). Learning activities are characterized by cognitive challenges, practical activities and discussions (as outlined in Figure 1), rather than rote revision or a transmissive communication of a scientific 'body of knowledge' (Murphy and Beggs 2003). The TDTS has been developed jointly by Oxford Brookes University and Science Oxford. Two TDTS trials have been undertaken thus far, funded by the EEF, a grant-making charity that focuses on pupils fulfilling their potential regardless of their socio-economic background.

The EEF is committed to improving teaching and learning and funds projects and evaluations of innovations to 'extend and secure the evidence on what works and can be made to work at scale' (Hanley *et al* 2015 p.2). Their preferred methodology of Randomised Controlled Trials (RCTs), involves independent data collection and analysis undertaken by a professional body separate from those who have developed and delivered the intervention. The TDTS approach has been recognised by the EEF to be a promising project and significant funding has been invested to set-up an effectiveness trial with 42 schools (reported on by Hanley *et al* 2015), an efficacy trial with 205 schools and a further Randomised Control Trial (RCT) is planned with another 140 schools (during the 2021-2024 academic period).

The TDTS approach in detail

TDTS is a five-day professional development programme for primary teachers, focused on augmenting their recognition of, and confidence in, encouraging pupils to talk, think and problem solve in science and thereby become more independent learners. The approach was based on the assumption that focusing on cognitive challenge within primary science curricular contexts would engage pupils' interest and subsequently improve their attainment. Two teachers from each school participated in the training to facilitate collaboration and mutual support, which research shows supports effective professional development (Cordingley, Bell, Thomason & Firth, 2005; Scher & O'Reilly, 2009). Training is designed to create a team ethos, with cohorts of teachers working together to explore and develop their practically theorised practice.

The TDTS activities each illustrate different ways that learners can be challenged to promote constructivism within primary science classrooms. Early development of TDTS tasks adopted Lewis and Smith's (1993, p.136) notion about higher order thinking and the ways consideration of new information connects or relates to existing knowing. Acknowledging how pupils' thoughts, ideas or concepts may need re-organising to take account of both their former perspectives and fresh information is promoted in training. Various mediational techniques are practiced with the teachers so they clearly appreciate what Berliner (2001) would describe as adaptive expertise. The key features of TDTS (as represented in figure 1) focus on enabling teachers to appreciate what conceptual challenge looks like and how to present appropriate thinking and learning opportunities that stretch the pupils. Providing experiences for teachers so they appreciate how to cognitively challenge their learners and actively engage them in thinking about science is integral to the TDTS philosophy. Each training session involves teachers reflecting and sharing perspectives about the impact of the different TDTS strategies on their pupils' engagement with science. Engaging in professional dialogue of this kind, throughout the year on five whole-day occasions, offers multiple opportunities to reflect on personal experiences and relate them back to their classroom contexts and initiate thinking about 'what works' and 'how it works' to begin to 'practically theorise' (McIntyre 2009) about the implementation of TDTS in their own particular schools.

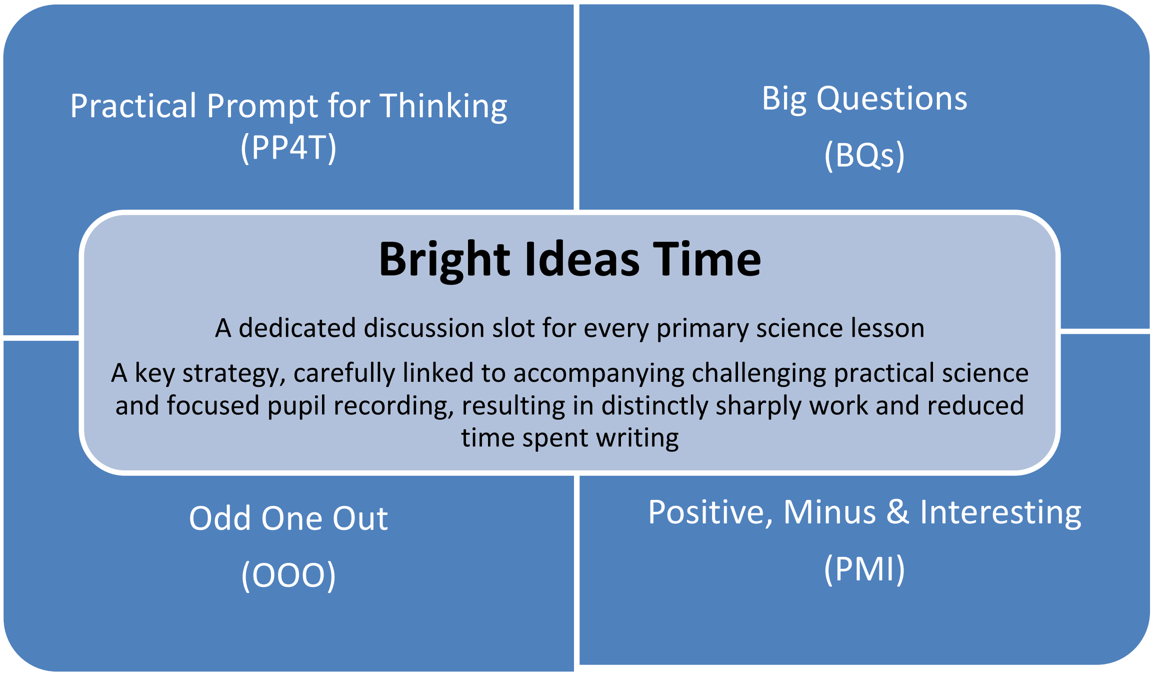

Figure 1 : Some of the key features of TDTS

TDTS strategies and constructivism

Views of constructivism vary in the extent to which they draw on Piagetian notions of how children learn. Piaget (1950; 1959) describes how when children encounter 'something' hitherto unknown to them, they wrestle with this 'new' information, observation or experience and cognitively re-structure what they retain (or assimilate) as their personalised interpretations of the world around them. Over time they gradually re-structure their ideas to explain each new phenomenon as they encounter, interact with it and make sense of it. The Piagetian notion of *dissonance* is often interpreted as cognitive challenge. This can be presented in a variety of ways for pupils to engage in thinking and reasoning about their views and/or ideas about something that resonates with the TDTS intentions. Practically theorising about activities that provide stimuli for learners to think about things that are counter intuitive and don't immediately make sense (like the flame under a balloon that doesn't 'pop' it, because it is full of water that isn't immediately visible) is concretised for the teachers. The strategies outlined in table 1 below, that constitute the *Bright Ideas Time* and support the generation of novel and creative thinking, enable the practising of various cognitive processes, with the result that the learners engage in a range of experiences to promote thinking about science in various ways. These affective and cognitive experiences can then be drawn on in subsequent tasks, tests and assessments.

TDTS Activity	Element of constructivism clearly demonstrated

a. Practical prompt for thinking	The learner responds to the conundrum, perturbation or disequilibrium and re-equilibrates their ideas. The learner cognitively engages in explaining observable/experienced phenomena.
b. Odd One Out	Opportunities are provided for learners to [mentally] manipulate materials to make sense of them by themselves.
c. Positive Minus Interesting	Engaging in the activity leads to cognitive development of learner.
d. Big Questions	The learner generates meaning from the (inter-) activity with the environment.
e. Practical Activity	The presentation of materials that the learner can interact with provides learning by experience. The learner should show initiative.

Table 1 : A summary of the ways each TDTS teaching strategy supports development of different features of constructivism (From McGregor *et al* 2020).

The thinking processes promoted and practiced by the pedagogic strategies listed in table 1 are designed to provide learning encounters for pupils that engage them in considering and talking about why they believe something is as it is in the world around them, how it has come to be, how contrasting objects are different and similar and what can be done to solve practical problems. Within the dedicated, ring-fenced space entitled the 'Bright Ideas' time the pupils are encouraged to consider scientific things in many different ways. Discussion is valued because it underpins encouraging social interaction to promote shared thinking in TDTS activities. This extends Piagetian (1950) perspectives of self-construction by helping teachers realise how a Vygotskyian (1978) approach to develop thinking, through engaging collectively in joint activities and promoting social exchange to solve problems, highlights how language plays a formative role in the development of advanced mental processes. For example, ensuring that :

> 'Children solve practical tasks with the help of their speech, as well as with their eyes and hands. This unity of perception, speech and action, which ultimately produces internalisation of the visual field, constitutes the central subject matter for any analysis of the origin of uniquely human forms of behaviour' (Vygotsky, 1978 p. 26).

This underpins why hands-on as well as minds-on activity is key in the TDTS approach. McGregor (2007) illustrates how social interactions with others (between peers, experts and novices) can promote discussion that heightens understanding about the matter in hand. Nine and ten-year olds, therefore, working together toward joint solutions or resolutions can attain what might be beyond them if they were working alone as an individual, which is described by Vygotsky as the zone of proximal development (zpd). Therefore, through the practice of solving problems collectively pupils develop experience and confidence in manipulating objects and thinking about multiple ways to achieve solutions to through the TDTS approach.

Encountering and engaging in new ways of thinking about science through the various activities, such as Positive, Minus and Interesting (PMI) which invites the pupils to think about the useful (positive) aspects of something, like for example, *plants being able to walk* or *a glass umbrella,* also involves them considering the negative side to these ideas as well as something that is interesting. Another strategy is where the pupils consider how several objects could be similar or different through the Odd One Out (OOO). This provides the opportunities for the nine and ten year olds to think about the world around them and make sense of it through reflecting on how contrasting objects, like sand, salt and iron filings, might have characteristics in common, but also might constitute being in a different group to the other two substances. Big Questions (BQs) pose really challenging concepts for pupils to grapple with. Questions such as *How do we know the earth is a sphere?* or *Why don't we sense the spinning of the Earth?* are used to really engage them in thinking carefully and deeply about science, what they observe, how they interpret the evidence presented and how it all makes sense to them. The Practical Prompts for Thinking (PP4T) also resonate with Piaget's view of *dissonance* (1950) or challenge that provides a visual stimuli for learners to think about things that might not immediately make sense to them and extend some kind of cognitive conundrum from their perspective (like a round cake tin that rolls uphill or water that appears on the outside of a glass in the summer when it isn't raining). Chin (2007) stressed how important it is for a teacher to mediate pupils' discussion and exchanges in ideas as they are critically linked to development of the ZPD (Vygotsky 1978). Mediating to enable learners' cognitive re-structuring as a result of interacting with the world around them (and others) is of significance in the TDTS approach.

The pedagogic approaches integral to TDTS therefore promote, support and encourage thought processes coming into existence through doing, thinking and discussion. In this way, teachers are actively engaged in practical theorising not only in relation to their own practice, but also in their dialogue with pupils through the substantive focus of the tasks. McGregor (2007, p. 255) suggests that thinking develops as pupils work together on challenging tasks, and being encouraged to discuss as they collaborate they more openly elucidate their thinking. Therefore, teachers setting up tasks that enable learners to work out and rehearse working jointly to solve problems offers practise in *knowing-how* to tackle unfamiliar challenges with no specific correct outcome. As McGregor (2007 p.41) describes '[r]etention, understanding, and the active use of knowledge can be brought about only by the learning experiences in which learners *think about* and *think with* what they' have learned'. Having been introduced to the repertoire of TDTS strategies and the underlying ethos and theory, teachers were invited to use their professional judgement to evaluate and employ them wisely, not mechanistically. Interestingly, participation in the TDTS programme arguably helped to shape professional judgement with an emphasis on nurturing creativity and criticality. For this reason, pre-prepared lesson plans were not produced, the teachers were encouraged to practically theorise how best the TDTS strategies worked with their pupils in their particular school contexts.

TDTS, therefore, adopts a range of pedagogic approaches that can engage learners beyond a narrow conceptualisation of learning science. It enables the development of pupils' thinking from a focus on scientific content, or factual *knowing-what,* to contemplate why things are as they are, consider possibilities, acknowledge multiple ways to solve practical problems and designing solutions. That is, they practice the development of *knowing-how*. McGregor (2007: 166) summarises how practitioners can scaffold and mediate to influence and support cognitive development through varied pedagogic tactics by presenting intriguing ideas, asking thought provoking questions, providing challenging tasks and reflecting on any outcomes. Mercer and Hodgkinson (2008) corroborate that it is the teacher's pedagogical beliefs *and* practices (that is, the choices they make about how they communicate with their pupils and the strategies they use) that steers the nature of the thinking. The relational recursive dynamic between theory and practice informs the ways that pedagogical enactments (i.e.: practical theorising) emerges in the classroom. A teaching approach that considers how and when to use particular materials, how to sequence and pose questions, encourage discussion, or mediate without giving away any answers (McGregor 2007: 161 – 164) will shape the ways that pupils engage in thinking. Ways of facilitating practical experiences (by reducing writing), for example, becomes more prominent with the concern that 'doing' and 'talking' (through small groups of pupils solving problems together) better promote Vygotskian notions of social construction (McGregor 2007: 55). As Mercer and Hodgkinson (2008) highlight, through such an approach, teachers consider, critically, not only their questioning technique but also their mediation and scaffolding strategies designed to cultivate pupils' thinking, rather than transmit scientific factual information. It is with this practical theorisation in mind that tables 1, 2 and 3 and figure 1 summarise and relate features of the TDTS approach that incorporate pedagogic frameworks supporting constructivist ways of learning in this way.

Teachers practically theorising how to implement the TDTS strategies

To examine how the teachers practically theorised the TDTS strategies, a range of research tools (detailed in McGregor, Frodsham and Wilson 2020) were applied to evidence how their science lessons became 'more practical, creative and challenging' (Hanley *et al* 2015).

To illustrate how expert teachers (Berliner 2001) had practically theorised encouraging pupils' plausible and reasoned thinking that considers scientific ideas and evidence, Mant *et al* (2006) illustrated ways the different pedagogical tactics could be implemented to frame TDTS activities (summarised in Table 2).

TDTS Activity	**Ways that expert teachers practically theorised how the TDTS approach can offer constructivist learning opportunities**
Practical prompt for thinking	Asking what will happen if a flame is held under an air-filled balloon and a water-filled balloon.
Odd One Out	Presenting water, chocolate and paper and asking which is the odd one out, with reasons.
Positive Minus Interesting	What would be positive, negative and interesting in a world without electricity?
Big Questions	How do we know the earth is a sphere? What would happen if we didn't get bigger as we got older?
Practical Activity	Design a metre run that ensures the marble reaches the bottom as slowly as possible.

Table 2 : A summary of key TDTS teaching strategies (From McGregor *et al* 2020) and the ways expert teachers practically theorised them.

An example of the way that a novice TDTS teacher illustrated adaptive expertise in supporting PP4T included a challenge witnessed by researchers. The teacher presented a conundrum to the pupils involving a coke can, not placed flat on the table, but balanced on a round bottom edge. The teacher asked, 'How is that possible?', paused and gave them time to think (as quoted on table 3)., This resulted in a range of replies that might suggest a particular liquid, magnet, sand or some other substance is inside it to enable the can to balance in an unusual position. The very visual PP4T encouraged prediction, scientific reasoning and hypothesizing through engaging pupils to constructively consider and explain something they have not seen or experienced before.

Features of the constructivist theory of learning	**Practical theorising as offered by interviewed teachers**
Learners respond to a conundrum, perturbation or disequilibrium and re-equilibrate	'…thinking questions are ones where you need some time to think about it. But also, [..] where you don't know the answer straight away, you've got to think about it. You might need to develop your thinking. And it could be, um, that you're using some prior knowledge, and you're [..] rearranging that knowledge, or [..] trying to […] put it into a different situation'
Learners show initiative and are agentive	'…towards the end of the lesson, you might have seen that children were saying, 'Well, I've discovered this, but I'm still curious about something else', So […] I would say is an ongoing curiosity'
Learners generate meaning through interaction with the environment	'…the teacher facilitating the learning rather than imparting knowledge all the time' 'I allow children to decide on their own areas for investigation. I think I allow children to plan their own investigation because very often we give them quite a formula in science'
Learners engage in explaining observable or experienced phenomena	'...the children have to say where they think the water has come from, but we don't give that away ..'
Learners have the opportunity to manipulate materials and make sense by themselves	'I've seen quite magical moments where children have gone off in completely different direction to the one I'd perhaps anticipated …but the discovery has been remarkable'

Table 3 : Prominent behaviours implied by the constructivist view (from McGregor *et al* 2020) of thinking and learning that have been practically theorised by teachers.

A second strategy, OOO, was adapted in a range of ways and encouraged children to think about sorting and classifying objects and deciding whether or not they have something in common, or were somehow distinctly different. An adapted example included, 'Which is the odd one out between a man, chimpanzee and teddy bear?' and the ideas and reasoning proffered included, 'I think that the teddy bear is the odd one out because it doesn't consume any food or drink and it doesn't have any bones' (Frodsham, 2017). This flexible strategy is easy for teachers to adaptively re-contextualise for use in any topic of science (as indicated in Table 3). For example, asking pupils to decide which is the odd one out, between a lion, a London bus and a tree with all its green leaves can stimulate a range of responses including, *'The lion because he's the only one that is brown'*; *'The bus was the odd one out because it's the only one that has wheels'*; *'The lion because it's the only one who lives in the desert.'* Pupils bouncing ideas off each other, and building on one another's thinking (also practically theorised as quoted in table 3) illustrated quite clearly how socially constructivist processes were valued and actively sought by the teachers.

The ways that teachers adopted and mediated the use of deBono's (2000) PMI supported a host of original ideas and suggestions emerging from the pupils. A teacher asked if there was an extended power outage, for some reason, and everyone lived in 'a world without electricity, *what would be positive*, *what would be negative? what would be interesting*?' Examples of positive reflections included: 'children wouldn't have computers so they'd be outside more and fitter'; '[there would be] no electricity bills' and we 'wouldn't be able to make guns and weapons without electric powered factories'. Examples of negative comments included: 'no streetlights so they'd be security issues and crime might go up' and 'food would go off because [there would be] no fridges so [there] might be more food poisoning'. Interesting points included: 'steam power would make a comeback or solar power would be more common' and 'it would be like going back in time' (Wilson and Mant 2005: 22 cited in McGregor *et al* 2020).

Another teacher's adaptive use of a BQ included 'How do you know you are alive?' This conundrum posed to nine and ten-year old pupils elicited responses, including, 'having/feeling a pulse', 'growing', 'being noticed', 'making objects move' and 'senses (feeling, touching and tasting)' (Frodsham 2017). This illustrated again, like OOO and PMI how teachers adapt use these strategies in a constructivist way, prompting unfettered ideas and suggestions from their pupils. Encouraging scientifically plausible responses to open queries is clearly demonstrated by the teachers' pedagogy designed to extend pupils' thinking and open up opportunities for contributions from the whole class, no matter what their gender, ability or social background.

Besides these illustrative examples, table 3 and 4 also evidence how teachers have adaptively changed their practice to enact various elements of the TDTS approach. The most prominent pedagogic changes that the teachers reportedly implemented in their science classrooms involved making science more interesting by doing more practical work, encouraging the pupils to talk and question more. They also reportedly provided more opportunities for pupils to make choices and/or determine what they did, independently of the teacher. Teachers also reported how the TDTS approach enabled them '…to gain new ideas or think about different approaches to teaching Science that… helped engage, motivate and enthuse all children' they saw that the pupils responded positively to the new ways of learning science. One practitioner even stated, 'Pupils have been fully engaged in what they have been doing and have been forced to really think about [the] impact the experiments have had on their learning [ideas and thinking] and asked a lot more questions as to why that is'. This quotation illustrates how teachers have successfully adopted practically theorised approaches that supported active engagement and child-led experimentation and on-going class discussions (like many practical theorisations in table 4). It also indicates critical evaluation of the constructivist nature of the TDTS strategies and the ways that adopting these strategies consequently altered their practice.

Features of the socially constructivist theory of learning	Practical theorising as offered by interviewed teachers
Learners mediate each others' zpd	'I'm a firm believer in not having all the answers, I think creativity is about the children learning from each other as was seen in the lesson when we talked about the learning and one of the pupils said, *I learned from other people*, I think having the opportunity to learn from each other is hugely important.'
Learners collectively consider queries (questions or tasks)	'…magic tricks. We'd get the children to work out the science behind them. … so, for example, a box and you balance it on something [..] after 40 seconds it falls off. The children have to work out what they think is inside the box to make it fall off, but, by the end of the session, I still haven't told them because I want them to [still keep thinking] and maybe draw a picture of it, or try to make one, or go home and talk about it.'
Learners discuss ideas and share their contrasting understandings to make sense of something	'…we're using little white boards for them to draw on. Not electronic ones, just you know, [little] white boards [..] getting them to draw how they think a shadow works [..] and then you get everybody involved.'
Learners collaborate to jointly find solutions	'There are many open-ended workshops where children make lots of the decisions as they go along. We don't rely on prescriptive worksheets. They [the activities] are very open-ended'
Learners exchange their elaborations and justifications for their ideas	'…you could see in the discussion that it moved their thinking forward, and then if you have some more input and you see that light-bulb moment .. but the light-bulb moment worked much better because they'd had the discussion first. That made me try and think every time [..] *How can I encourage the discussion here*?'
Learners develop meaning for themselves through the social interaction	'…it's … the talking which lets you know what they're thinking'

Table 4 : Prominent behaviours implied by the socially constructivist view (from McGregor *et al* 2020) of thinking and learning that have been practically theorised by teachers.

Conclusion

In the evidence outlined here and detailed further in McGregor, Frodsham and Wilson (2020) teachers have adapted their pedagogic expertise to embrace the constructivist approach of TDTS. Returning to MacIntyre (1995), the TDTS approach has at its heart a commitment to championing an experimental approach to theory and scientific exploration. The practice of talking and doing encourages teachers and pupils to address big, open questions where the consensus around answers is much less important than the active process of inquiry. Encouraging critical questioning and promoting discussion that encourages a lack of consensus is perhaps particularly challenging in the context of science education, where pupils (and some teachers) may anticipate more fixed answers. In order to account for this and to follow the TDTS approach effectively, teachers developed adaptive expertise in their delivery, flexing the nature of tasks to fit the specifics of a particular teaching context or discussion. The quantitative and qualitative evidence (McGregor *et al* 2020) suggests that a child-led, active, thought provoking and discursive approach has been more successful in improving academic attainment and increasing motivation to learn science than a transmissive and factually oriented pedagogical approach. The TDTS strategies make explicit for teachers how they can extend reasoned thinking *in science* and *about science,* and provides them with the confidence to re-orient their practice and not just teach to facts. Ways that adaptive expertise was clearly demonstrated by the teachers involved with TDTS intervention included the following principles :

- Supporting *Thinking,* both individually and jointly, about scientific conundrums;
- Engaging in *Doing* through practically working together to solve problems;
- Continuing to *Talk* and *discuss* whilst participating in all the TDTS activities.

Evidence from observations and interviews (McGregor *et al* 2020) clarified how teachers practically theorised their enactments of TDTS as more dialogic, affective and cognitive. As Hanley *et al* (2015) states the TDTS training programme and its adoption in primary classrooms '…make science lessons more creative, practical and challenging'. With the evidence elicited and presented here it is possible to substantiate '*how*' the teachers adaptively altered their pedagogy and '*why*' the TDTS approach could affect a 3-month improvement in nine-ten year olds' academic attainment. Pre and post-test data, collected through an RCT provided statistically significant evidence of the impact of the TDTS intervention (EEF 2016), but clarification of the ways that teachers practically theorised enactments of the strategies was required to provide insights for other practitioners, outside the intervention, to illustrate what they should pay attention to if they wish to ensure a similar result with their own classes. What has also become apparent through this project is a need for teachers to be reflexive in the ways they entwine theory and practice to adaptively present activities that engage pupils in challenging learning situations.

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