

Thinking, Doing, Talking Science: the effect on attainment and attitudes of a professional development programme to provide cognitively challenging primary science lessons

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engineering organisations, community groups and cultural venues and works particularly in Oxfordshire and Buckinghamshire. In 2019 the programme expanded to include the Science Oxford Centre – a science education centre set in 15 acres of woodland which is founded on the TDTS ethos of maximising opportunities for higher order thinking through creative and challenging practical science and facilitated discussion. Science Oxford is on Facebook, Twitter and Instagram @scienceoxford

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Abstract

This study investigates the impact of a professional development programme for teachers that encourages more cognitively challenging, practical, and interactive science lessons. Using a Randomised Controlled Trial, its impact was measured by pupil learning outcomes - the aspect identified as the most important result of successful professional development by Guskey (1986, 2000). Pupils aged 9-10 at 42 primary (elementary) schools in Oxfordshire (England) were randomised to receive either the 'Thinking, Doing, Talking Science' (TDTS) programme, or to be in the business-as-usual control group. Two teachers per school attended five training days over the school year. These were designed to enhance their skills in providing conceptual challenge and improving pupils' higher order thinking by facilitating more discussion, more practical work and less (but more focused) writing in science lessons. The main outcome measure was an age-appropriate pencil-and-paper science test covering a range of topics and question types. Pupils also completed attitude surveys. Analysis of the scores for the 1264 pupils who took the pre- and post-tests shows this low-cost intervention had a statistically significant effect on attainment, with an effect size of +0.22. The impact was stronger among girls and slightly stronger among those with lower prior science attainment. Data from 1189 pupil surveys suggested that TDTS had also improved their attitudes to science.

Keywords: primary/elementary schools, higher-order thinking, (quasi)-experimental research, professional development

Introduction

Young people's understanding of, engagement with and attitudes towards science cause ongoing concern. Slavin, Lake, Hanley, and Thurston (2014) pointed out that economies are increasingly reliant on workers capable in science, mathematics, and engineering; thus, fostering success in these areas has become a global priority. And yet, reflecting on the 2015 results of the Programme for International Students Assessment (PISA) study of 15-year-old students from over 70 nations, the Organisation for Economic Co-operation and Development (OECD) noted their disappointment that in most countries the results in the science test remained almost unchanged since 2006 (OECD, 2016). Moreover, each citizen needs the skills to 'think like a scientist' (OECD, 2016, p.2) and appreciate scientific practices (National Research Council, 2012), even if they do not go on to pursue a career in the subject.

In the context of the massive amount of information available to everyone, there is a need for the development of cognitive skills to be able to consider evidence in order to reach valid conclusions (OECD, 2016). Science can be used to develop such thinking skills and the opportunity for classroom discussion facilitates their acquisition (Abrami et al., 2015). As Burdett and Weaving (2013) declared, we need to ensure that science education not only delivers students who 'know facts' but also young people who understand and can use that knowledge (p. 2).

It is essential that science is taught to younger pupils in ways that interest them and also increases their attainment in the subject. Data from the TIMSS international testing of mathematics and science show that Year 4 and Year 8 students with more positive attitudes tend to have higher achievement scores (Marginson, Tytler, Freeman & Roberts, 2013). The research literature on pupils' attitudes to science is extensive (Barmby, Kind, & Jones, 2008; Bennett, Braund, & Sharpe, 2013; Osborne & Dillon, 2008). A Royal Society report (2010)

noted that attitudes towards science form early and have already become less positive when pupils reach the end of primary (elementary) school. In the same report, Martin Rees declared that children's natural curiosity about their world has often been eroded by the time they start secondary (high) school and re-engaging them with science and mathematics can prove impossible (p.1). Osborne and Dillon (2008) identify the quality of teaching as the key determining factor of pupil interest. Similarly, the European Commission (2007) acknowledged that the reasons for lack of interest in science are complicated, but found evidence that attitudes towards science are connected to the way it is taught.

The foundations laid in early childhood and primary education are crucial to STEM proficiency and appreciation of the importance of this stage of education in determining pupils' intentions to pursue STEM-related subjects and careers has been growing (Marginson et al., 2013).

Clearly, high quality science education for this age group is crucial. Appropriate research is important to ensure beneficial teaching approaches are developed and implemented. In his work on evaluating professional development, Guskey (2000) identified five levels of change necessary to increase pupil attainment. He criticised evaluations for concentrating on participant response to the training programme itself (the lowest of his five levels) instead of the development of participants' learning and practice, and ultimately pupil learning outcomes (the top level). Slavin et al. (2014) stressed the need for rigour in such research and urged a move from short pilot tests to longer-term, authentic trials of interventions using valid and meaningful assessments of their impact.

Research Questions

This study was designed to implement and evaluate a professional development programme for primary school teachers: Thinking, Doing, Talking Science (TDTS). TDTS aimed to enable participating teachers to make their science lessons more creative, practical and cognitively challenging for pupils by a clear focus on the development of pupils' higher order thinking. We then investigated whether this focus on thinking would impact pupils' attitudes to science and their attainment in the type of test that they would typically experience in schools.

The evaluation (led by the first and fourth authors) was commissioned and conducted independently of the programme development and implementation (second and third authors). Its scale allowed us to establish whether there was sufficient promising evidence to progress to a larger trial.

A two-armed Randomised Controlled Trial (RCT) using a business-as-usual control was employed to explore whether TDTS had any impact on:

- (1) pupils' attainment in science, incorporating content knowledge, conceptual understanding and scientific process skills;
- (2) pupils' attitudes towards school science, particularly their engagement in and enjoyment of lessons, including practical work; and
- (3) participating teachers' classroom practice

The logic model (Figure 1) illustrates how the research questions aligned with the expected mechanics of the programme, and what outcomes were measured. Although outcomes included teachers' responses, this article focuses on pupils' attainment and attitudes (first two research questions).

Figure 1: see appendix

The project (Hanley, Slavin & Elliott, 2016) was funded by the Education Endowment Foundation (EEF), an independent grant-making charity that focuses on all children fulfilling their potential regardless of background.

The Thinking, Doing, Talking Science intervention

TDTS is a professional development programme for primary teachers, focused on boosting their abilities to increase the level of conceptual challenge in science lessons by encouraging pupils' higher order thinking.

In England, primary school teachers usually teach one class across all subjects rather than teaching one subject to a number of classes, making them generalists not specialists. In most cases, there is a science subject leader who gives guidance and promotes science, but it is very rare for this person to teach science to all classes across the school. Studying science is compulsory for all 5 – 11 year old pupils in state-funded schools (Department for Education, 2013) although the mandatory national science test during the last year of primary education (age 10/11) was abolished in 2009.

For TDTS training, the teachers came together in a central venue for five full days spread across one academic year. Figure 2 gives an overview of the content and timing of the programme. Two teachers from each school attended to facilitate collaboration and mutual support, which research shows supports effective professional development (Cordingley, Bell, Thomason & Firth, 2005; Scher & O'Reilly, 2009).

Figure 2: see appendix

Figure 3 outlines the key components of the TDTS programme which were visited and revisited systematically on each professional development day and exemplified through different areas of the science curriculum (identified through an audit of teacher confidence).

Figure 3: see appendix

A key aim was to enhance teachers' skills to encourage pupils' higher order thinking, so this is at the centre of the diagram in Figure 3, surrounded by ways of facilitating that thinking. However, as highlighted by Wegerif (2010, p.3), there is a lack of consensus as to the actual meaning of higher order thinking. Lewis and Smith (1993) considered many and varied definitions, concluding that 'it occurs when a person takes new information and information stored in memory and interrelates and/or rearranges and extends this information to achieve a purpose or find possible answers in perplexing situations' (p.136). This was used as a working definition and shared with the teachers, as was Bloom's (1956) Taxonomy which described six levels of thinking arranged hierarchically in order of complexity. The teachers were urged to consider how science lends itself to the development of higher order thinking and how to facilitate this within their lessons. As Wegerif (2010) pointed out, 'Excellent creative thinking is much easier to recognise when you see it than it is to define or explain' (p.4). and the teachers were encouraged to recognise it in their pupils' responses.

Teaching for thinking through talking about science

Talking features in Figure 3 because it is key in the development of pupils' thinking. According to Adey and Shayer (1994) and McGregor (2008), research evidence shows the success of developing children's intellectual capacity by giving them challenges and encouraging them to talk through the problems towards a solution. The Bright Ideas Time is a

short discussion slot (possibly only 5-10 minutes) to be used within every primary science lesson, with a specific set of prompts to stimulate pupil talk. Illustrative examples are provided in Table 1.

Table 1: see appendix

The Odd One Out is the simplest prompt and was the first to be introduced to the teachers. Pupils select the odd one out from three or four items and justify their choice. An example is given in Table 1, with pupils' actual responses. They were asked to find the odd one out from a hippopotamus, a bird, a child, and a cat. Because there is no correct answer, pupils are supported to think deeply and creatively, and the level of their thinking can be assessed from the reasons they give for their answers. Individual pupils can join in the discussion at their own level, making it a highly inclusive strategy - as shown by the pupil who chose the hippo simply because it lives in water. The responses include the common misconception that a human is not an animal, which demonstrates the usefulness of this strategy in eliciting pupils' existing ideas.

Table 1 shows examples of two further prompts, one being a de Bono thinking tool, the 'PMI' (De Bono, 1986): a scenario is set and children identify and discuss P (positive), M (minus) and I (interesting) features. 'The Big Question' is the most challenging prompt and the two sample responses given in Table 1 to the question, 'How do you know that the Earth is a sphere?' demonstrate the range of thinking possible in 10 year old pupils: one being pragmatic about water running off the edge of a flat Earth, and the other working from first principles to reason that if gravity pulls towards the centre of the Earth with an equal-sized force, then it must result in a sphere. An advantage of such wide-ranging discussions is that by listening to each other's ideas and using them as inspiration to further their own reasoning, pupils act as cognitive models for each other (Smart & Marshall, 2013).

The Practical Prompts for Thinking are short practical teacher demonstrations, prompting discussion and catching pupils' imaginations. The example in Table 1 causes the pupils to be amazed that a can released on a slope rolls uphill, and so ignites their natural curiosity and sense of wonder, driving them to give possible explanations for what they have seen (Harlen, 2015). A wide range of all the different prompts was shared with the teachers throughout the development days, exemplified within different areas of the curriculum.

Having been introduced to the repertoire of strategies for the development of pupils' thinking through talking, and the underlying ethos and theory, teachers were encouraged to use their professional judgement to evaluate and employ them wisely, not mechanistically. Pre-prepared lesson plans were not produced – the teachers continued with their own planning, incorporating the TDTS strategies as best-suited their context. They were however provided with a range of examples for all talking strategies, in each area of the science curriculum, including some background subject knowledge notes. They could draw on these and develop their own as they grew in confidence and experience.

The training aimed to enthuse participants about science and equip them to plan and teach exciting, creative lessons for thinking. Teachers were given time in the development days to participate in the full range of TDTS strategies to encourage discussion, and to undertake a wide range of practicals for themselves.

Teaching for thinking through doing science

The TDTS approach to practical work has many similarities to Inquiry-Based Science Education (IBSE), which emphasizes curiosity and observations, followed by problem solving and experimentation (European Commission, 2007). The National Curriculum in England is clear that primary pupils should undertake 'different types of science enquiries that help them to answer scientific questions about the world around them' (Department for Education, 2013, p.3). However, in their study of primary and secondary schools in England,

Abrahams, Reiss and Sharpe (2011) found that practical work can be more ‘hands-on’ than ‘minds-on’. In other words, pupils engage with the materials, but not necessarily with the underlying ideas and concepts. To tackle this, after TDTS teachers had undertaken a practical investigation, they reflected on the opportunities it presented for the development of a ‘minds-on’ approach with their pupils to encourage their higher order thinking. An example shown in Table 1 is an investigation to find out which shoes have the best grip. Planning a fair test is a challenge in itself for primary-aged children, but one way to increase the challenge even further is not to put out any equipment - the pupils have to request it, thereby avoiding any leading by the teacher.

As shown in Figure 2, each day of the training was focused on a different curriculum area and the teachers participated in a range of practicals suited to that area. Electricity is an ideal topic for problem-solving: it is a challenge for primary pupils (and many adults) to make a light bulb light when it is not in a holder, and this challenge can be increased by supplying aluminium foil, rather than wires.

To reduce the amount of writing in a lesson, the concept of focused recording was introduced. Rather than writing down everything they have done in a practical investigation, pupils focus their recording on the learning objective(s) in the teacher’s planning - for example planning a fair test or drawing a conclusion from their findings. The teachers found that this then releases the time for the thinking, doing and talking components in the lesson, whilst providing good evidence of the pupils' learning.

Questioning underpins and feeds into all aspects of TDTS in Figure 3; the teachers were encouraged to consider how to use questions to extend pupils’ thinking about scientific ideas and to encourage pupils’ own questioning. Smart and Marshall (2013) demonstrated a direct relationship between teachers’ questioning levels and the cognitive level of their

pupils' responses throughout lessons, as they had opportunities to explain, justify and rationalise.

Participating in all the TDTS activities themselves often caused teachers to reconsider their own scientific understanding. The programme included subject knowledge inputs and notes on each day in response to this to bolster their understanding and confidence.

The professional development model

The design of the professional development had many parallels with Clarke and Hollingsworth's (2002) 'interconnected model of professional growth' shown in Figure 4.

Figure 4: see appendix

This drew on Guskey's model of the process of teacher change (Guskey, 1986) which identified evidence of positive change in the learning outcomes of students as a prerequisite to significant change in the attitudes and beliefs of most teachers - in other words, it is the impact on pupils that encourages teachers to continue with any new developments in their practice. Clarke and Hollingsworth (2002) built on this but, rather than a linear model of professional development and change, theirs suggests that change occurs through the mediating processes of 'reflection' and 'enactment' in four distinct domains. These are the personal domain (teacher knowledge, beliefs and attitudes), the domain of practice (professional experimentation in the classroom), the domain of consequence (salient outcomes seen in their classroom), and the external domain (in this case, the TDTS development days).

A complementary lens through which to view the adopted model of CPD for the TDTS project is the Refined Consensus Model (RCM) of Pedagogical Content Knowledge

(PCK) (Carlson and Daehler 2019). The development of science teachers personal-PCK (pPCK) within TDTS was enhanced via the plan-enact-reflect cycle, and as made explicit in the RCM, the knowledge exchange between enacted-PCK (ePCK) and pPCK operates in both directions, so that the insight a teacher takes away from each interaction with students further informs the teacher's pPCK.

TDTS teachers were set intersessional gap tasks (Figure 2) to try out and evaluate a selection of the strategies with their own classes. On each training day they discussed their reflections on the task within peer groups, particularly their pupils' responses and learning. They also completed on-line feedback forms. The aim was to incentivise putting TDTS strategies in place immediately, thus facilitating the enaction and reflection cycle. It was anticipated that reflecting on their pupils' responses would lead to an impact on teachers' knowledge, beliefs and attitudes.

Precursor to TDTS

The Thinking, Doing, Talking Science approach to teaching built on a previous research project, 'Conceptual Challenge in Primary Science' project (Mant, Wilson & Coates, 2007), funded by the AstraZeneca Science Teaching Trust. A programme was developed to introduce more cognitively challenging, practical, and interactive science lessons to Year 6 (10/11-year-old) pupils. Teachers from 16 schools attended eight days of professional development and four twilight sessions, spread out over the course of one academic year. They developed science lessons that were characterised by more open, investigative practical work, more discussion, more thinking and less (but more focused) writing. The proportion of pupils achieving the highest level (level 5) in the national science tests for 11-year-olds then operating was compared to the proportion in matched-school pairs before and after the intervention. There was a 10% (95% Confidence Interval 2–17%) increase in the proportion

of pupils achieving the top level in the intervention schools. In addition, pupils and teachers alike reported greater engagement with science as a subject and increased motivation to learn.

Methodology

Randomisation

A two-armed clustered RCT was carried out with a total sample of 42 schools¹ in Oxfordshire, a county in south-east England that is relatively rural and has fewer English as an Additional Language (EAL) and free school meals (FSM) children compared to the national average. Randomisation took place at the school level to avoid contamination between the intervention and control arms. The schools were matched into pairs based on pre-test results, EAL, FSM and size of school. Using random allocation, one of each pair was placed in the group receiving TDTS and the other continued with their usual practice (these schools were offered TDTS the following year, creating a delayed treatment control group).

Research measures

It was hypothesised that, by improving thinking skills, TDTS would also improve academic attainment. Consequently, performance in science was used as the main criterion of its success and the measured outcomes were pupil science attainment (in a school-style test) and attitudes to science.. In recognition of the thinking skills element, existing tests probing the science inquiry process as well as content knowledge and conceptual understanding were chosen. They were designed for a previous primary science RCT (Bennett, Hanley, Abrahams, Elliott & Turkenburg-van Diepen, 2019) using standardised assessment questions

¹ Using Optimal Design software, it was calculated that a total sample size of 40 schools would be needed to give 80% probability of detecting an effect size of 0.25 (assuming 45 pupils per school year; $R^2=+0.49$; $ICC=0.10$; $p<.05$)

(Russell & McGuigan, 2001). Questions (including multiple choice, short-form and more descriptive answers) spanned the current curriculum. Year 4 (pre-test) and Year 5 (post-test) versions of the 40-minute test were administered. Subsequent analysis showed a strong relationship between the pre- and post-test marks (correlation coefficient $r = 0.71$, $p < .001$). The trainers and participating teachers had no prior knowledge of the content so could not 'teach to the test'.

To assess impact on attitude, a 23-item questionnaire was adapted from Kind, Jones and Barmby (2007) and focused on Likert-type ratings of various aspects of science, including learning (e.g. 'science lessons make me think'), practical work (e.g. 'I look forward to doing science practicals'), and attitudes to science more generally (e.g. 'science is fun').

Data analysis

Information about the study was circulated to parents/guardians and they could choose to withdraw their children from the testing. The pre-test was administered to all Year 4 pupils in December 2012/January 2013 before randomisation. In June/July 2014, the same cohort of pupils (now towards the end of Year 5) completed a post-test and an attitude survey (Figure 5).

Figure 5: see appendix

Pupils completed the tests on paper, overseen by their teachers. Analysis was restricted to pupils who returned both pre- and post-tests. Tests were scored by independent markers who did not know which arm of the trial pupils were in.

The analysis used an intent-to-treat design, such that responses would be included based on their initial randomisation regardless of non-compliance with the assigned treatment.

Hierarchical Linear Modelling (HLM) was used to assess the impact. Schools had been put into matched pairs for randomisation, so this was also accounted for. Accordingly, pupils were nested within School which were nested within Pair. The HLM used degrees of freedom reflecting the number of schools. After controlling for their pre-test performance, pupils allocated to TDTS were compared with those experiencing 'business as usual'. An analysis was conducted on all pupils, then on subgroups: boys and girls; those getting high (greater or equal to the median) and low marks (below the median) at pre-test; and pupils ever eligible for free school meals (reflecting the funder's interest in raising attainment amongst disadvantaged pupils). Hedges (2007) was used to calculate the effect size and the 95% confidence interval (CI) equated to the estimate ± 1.96 SE (standard error).

Mean scores were calculated for the pupil attitude statements. Calculating mean scores for Likert-type questions is controversial (Knapp, 1990). Whilst recognising that technically the response categories have a rank order and should be treated as ordinal-level measurement, a pragmatic decision was taken that the categories were close enough to a scale to allow analysis as if they were interval-level. Previous simulations (Dowling & Midgley, 1991; Kerlinger & Lee, 2000) have failed to show large errors when using interval level formulae for ordinal data, and the results from using summated scales and assuming equal intervals were acceptable.

Findings

Study profile

One control school (comprising 38 pupils) pulled out of the study and another 211

pupils (108 intervention and 103 control) did not complete the post-test because they had left or were absent on testing day. 41 schools and 1264 pupils remained from the original numbers of 42 and 1513 respectively, representing 2% school attrition and 16% for pupils. Attendance at training was high, with 17 of the 21 schools sending teachers to all five sessions. Fourteen schools always sent the same two teachers (with an occasional absence). Only three schools combined poor attendance and inconsistency in personnel, due to high staff turnover.

As indicated by the baseline profiles shown in Table 2 (first three columns), the composition of the intervention and control groups was well-balanced by average pre-test score, gender and FSM eligibility at randomisation. A t-test run on the pre-test means showed no statistically significant difference between the two groups (2-tailed significance of 0.973). This comparability remained in the sample at post-test analysis (final three columns).

Table 2 HERE

1289 attitude surveys were returned and analysed (654 TDTS, 635 control).

Impact on science test performance

Table 3 shows the raw means for the two treatment groups (TDTS and control) and the 95% confidence intervals for the means. The first column shows the number of pupils for whom a valid post-test was available in each group, with the number lost from the original randomised sample shown in brackets. For the total sample and for each sub-group analysed (gender, FSM and pre-test attainment) the raw mean was higher for the TDTS group.

Table 3 HERE

A three-step modelling process was used to ascertain whether there was any difference in outcome variable between TDTS and control. Firstly, analysis established that Pair and School were both essential components of the multilevel model. The schools had

been selected to be representative of all schools available to the study, so Pair and School were both included as random factors in the model.

Secondly, the effect of the pre-test score for each pupil was included in the model. This showed the importance of the pre-test in predicting outcome scores, given the school the pupil was in. There was a strong correlation ($r = .71$, $p < .001$) between pre- and post-test marks.

Finally, a check was run to see if the effect of the pre-test score on the post-test score varied by school or not. The fit of the model was not improved by incorporating this effect, indicating that the impact of the pre-test on the post-test score was consistent across all schools.

The final multilevel model, accounting for schools and pairs as random factors, was fitted and tested, and adjusted for pre-test marks. This model tests the effect of TDTS against the control after accounting for the pre-test measure and the multilevel structure of the data. Diagnostics for this model were assessed and found to be adequate, demonstrating that the model is robust.

After taking pre-test mark and school variability into account, the post-test score for the TDTS sample were 1.5 units marks higher than the control [95% CI (0.74, 2.25)]. This result is statistically significant [$F(1, 36.50) = 6.61$, $p = .014$]. The analyses were repeated for the gender and attainment level subgroups.

Table 4 shows the primary outcomes. There was a moderate effect size of +0.22 which translates into about 3 months' extra progress over the year compared with the control group (Higgins et al., 2015).

Sub-group analyses

There were moderate effect sizes for three of the sub-groups (lower and higher

science pre-test attainment and girls) (Table 4). The effect size was much lower for boys (+0.12), and it is possible that this effect was produced by chance. Indeed, the difference between the effect sizes for the two genders was large enough to provide evidence that TDTS was more effective with girls than boys ($p=.023$). For pupils on free school meals, the effect size was +0.38, but this is not a statistically robust finding. Although the numbers of FSM pupils were similar in TDTS and control groups (147 and 138 respectively), the pattern of distribution amongst schools was highly irregular. Nearly two-thirds of the 285 FSM pupils were found in just 11 schools, and four schools had no pupils who had ever qualified for FSM.

Table 4: see appendix

Impact on pupil attitudes and opinions

Results of the attitude survey have been presented in two ways (Table 5). The column headed ‘most favourable’ shows the percentage of pupils choosing the most positive response on a 5-point scale² for each statement (‘agree a lot’ for positive statements, or ‘disagree a lot’ for negative statements). Whilst this allows comparison of pupils in the TDTS and control groups, it does not account for pupils being clustered within schools or schools being paired. To compensate, a second analysis was conducted. Mean scores were calculated for each statement in each school using the 5-point scale (reverse-scored for negative statements) and compared within each pair of the 19 pairs matched at randomisation (the pairs containing the school that withdrew and one that did not return the attitude survey were excluded). The last three columns of Table 5 show how many TDTS schools had higher (‘TDTS more favourable’), lower (‘Control more favourable’) or the same (middle column) mean score

² agree a lot, agree a bit, not sure, disagree a bit, disagree a lot

compared with its paired control school. For example, more pupils in TDTS schools (49% vs 37%) agreed ‘a lot’ that science lessons are interesting and in 15 of the pairs, the TDTS school had a higher mean score than the control and in three cases the reverse was true. The small sample size precludes robust statistical analysis and these findings should be treated as indicative only.

Table 5: see appendix

. For most attitude statements relating to learning science at school, pupils in the TDTS schools were more positive than those in the control schools. This was especially true for science lessons being interesting, and science being both something they looked forward to and would like to do more of. The responses indicated that, in accordance with the TDTS model, TDTS schools were holding more discussions and doing less writing in science. Pupils in TDTS schools were also much more inclined to agree that science lessons made them think, and that they enjoyed the discussions. Self-reported levels of understanding, and of enjoyment of solving science problems, were closely matched between TDTS and controls.

With reference to practical work in science lessons, pupils from TDTS schools were more favourable within the majority of pairs. Those doing TDTS were more likely to look forward to practicals and think they were fun. Nonetheless, the high overall percentage who ‘agree a lot’ for both statements underline that practical work was an enjoyable and eagerly awaited element of science in control schools as well. As would be expected with the TDTS approach, practical work was reported as happening more often in the intervention schools than in most of the controls.

More than half of all pupils agreed a lot that it was important to learn science, but within 16 of the 19 pairs of schools this was endorsed more heavily in the TDTS school. Similarly, although 'science is fun' got a favourable response across the board, this was even more evident amongst pupils in TDTS schools. On 14 occasions, TDTS schools gave a more positive response to 'I like thinking about scientific ideas' than the controls. There was no real difference between TDTS and control schools for science being difficult to understand. The two sets of pupils also responded similarly to the statement 'I am just not good at science', with approximately a fifth in each group strongly disagreeing. Approaching two-thirds of all pupils disagreed 'a lot' that 'science is for boys', suggesting that it is becoming an outmoded stereotype.

Discussion

The results of this project were encouraging. TDTS appeared to have a positive impact on the science attainment and attitudes of pupils, with participating teachers often reporting surprise at the level of understanding expressed verbally by pupils with low prior attainment. The developers ascribed this to the emphasis on talking rather than writing. This makes TDTS pupils' higher post-test attainment particularly striking, since an intervention that promotes discussion has apparently impacted favourably on a conventional written test. The higher impact on girls was not anticipated and merits further research. Although the data suggested that the approach had an especially positive effect on those pupils eligible for free school meals, this would need to be replicated with a larger sample. The attitudinal improvement was most evident for dimensions associated with the aims of the intervention, including science lessons being interesting, making pupils think and science being fun.

(1) Comparison with other studies

As previously noted, the TDTS approach has many similarities to Inquiry-Based Science Education (IBSE). The findings reported here echo previous studies linking IBSE with students' cognitive and attitudinal outcomes in science and, alongside this, positive correlations between student achievement and aspects of inquiry, such as doing scientific investigations and reaching conclusions from data (Cheng, Wang, Lin, Lawrenz & Hong, 2014; Marshall & Alston, 2014).

In contrast, it is interesting to compare the current study with a previous RCT of a science-based professional development intervention in English primary schools (Bennett et al., 2019). That intervention focused on developing teachers who held the science subject leader role in their school into 'primary science specialists', equipping them with the necessary subject-specific knowledge, PCK and skills to lead science teaching within their school. It was a three-armed trial (one group receiving 14 days' professional development over a school year, one receiving four days, and a business-as-usual control group). Outcome measures included the same pupil test and a very similar attitude survey to those administered for the TDTS evaluation. However, there were no statistically significant differences between test scores for the three groups and despite some positive attitudinal shifts, there was insufficient consistency to draw any conclusions about how these had been impacted by the intervention (Abrahams et al., 2014). The reasons why the two studies showed a difference in impact will inevitably be complex. However, a key difference was that the intervention evaluated in Bennett et al. was designed to train teachers to become the primary science specialists in their school, whereas the TDTS study aimed to enhance the skills of the existing classroom teacher. A key tenet of the TDTS project was the recognition that primary teachers should be celebrated as being specialists in pedagogy. Consequently, the professional development was designed to work from pedagogy to science subject knowledge, rather than

vice-versa. It employed pedagogical strategies that developed the teachers' own higher order thinking so they could use these same strategies with their pupils. Through this in-depth thinking, teachers became aware of their own requirements as regards subject knowledge and this was addressed through discussions and input in the training sessions. Hence it was a 'bottom-up' approach, as the participants identified their own needs and were then given input and resources to work on them.

(2) Study limitations

There were three main limitations. Firstly, the trial was localised to Oxfordshire and several participating schools had low rates of FSM/EAL, limiting its generalisability. Secondly, the primary outcome measure was not a nationally standardised test although the questions had been extracted from standardised assessments, and it was administered (but not marked) by staff who were aware of whether their school was in the TDTS or control group. Finally, post-testing happened immediately on conclusion of the programme, giving no opportunity to measure the longevity of impact on the pupils or the teachers – did the benefits for pupil attainment and engagement persist? Did teachers continue to use and embed the strategies in their teaching?

(3) Overcoming challenges

Retention is often a problematic aspect of an RCT (Song & Herman, 2010) but this project had a high rate of retention both to the project and the evaluation. Logic suggests that schools are more likely to drop out of the intervention arm if they do not enjoy implementation, find it too demanding or see no benefit for themselves or their pupils, although there is little specific research on this. In this study, initial enthusiasm was created by having a launch day in each school, where the approach was modelled to staff by delivering it to pupils not due to participate in the actual study. Efforts were made to provide engaging, interactive training events across the year and to develop close relationships with

the TDTS schools. Schools were not left out-of-pocket: they received cover payments for teachers' training sessions and for an additional two days of planning time in school, and there was also an equipment grant of £500 per school. The project needed no specialist equipment so this was merely to thank schools for participating. It was anticipated that the involvement of two teachers per school would provide mutual support, and the intervention was also designed to build a team ethos and community of practice, focused around active experimentation. There is evidence that such collaboration lends itself to changing practice and helping establish teacher commitment and ownership (Cordingley et al., 2005).

The control group was offered the intervention a year later than the TDTS schools, and this, along with the relatively low burden of the evaluation and personal phone calls to more reluctant schools from the lead evaluator in consultation with the developers, helped to keep all but one of them engaged.

Recruitment is another potential difficulty in RCTs and it proved more time-consuming than the developers expected, with many hours spent on persuasive phone calls to schools. Having personal contacts in the study's tightly-defined geographic area was an advantage. Crucially, interested schools were invited to a meeting with developers, evaluators and other potential participants. The intervention and the structure and philosophy of RCTs were explained in more detail, with an opportunity to ask questions or express concerns. Importantly, the critical role of the control group, which is often underestimated or misunderstood, was stressed. The project requirements were clearly laid out and not onerous for the schools. This was true of the intervention itself (since TDTS strategies could be incorporated within existing lesson plans) and of the evaluation (restricted to two 40-minute pupil tests separated by over a year, and a short teacher and pupil survey).

(3) Future steps

Following the promising results of this evaluation, the EEF funded a larger trial to establish whether the impact could be maintained with a more sustainable, ‘train the trainer’ delivery model (Kitmitto, González, Mezzanote, & Chen, 2018). 205 schools and almost 9,000 pupils were involved across England. Two trainers in each of seven geographical areas were trained to deliver TDTS by the designers and deliverers of the original project. The programme for participating teachers was reduced from five days to four, to recognise the pressure under which schools are currently operating. The same outcome measures were used.

This second trial failed to find any evidence of an impact on pupils’ science attainment except for FSM pupils (albeit too small to be statistically significant). However, analysis of the attitude statements revealed an increase in pupil interest and self-efficacy in science. It was hypothesised that possible reasons for the discrepancy between the trials included trainers new to TDTS, rather than the programme developers, training the teachers; the reduction from five to four days of professional development; and the withdrawal of cover costs that had previously allowed two extra days of teacher preparation. Because of the positive findings of the smaller trial, the promising outcomes for FSM pupils in the second trial, and the positive attitudinal changes found in both, the funder (the EEF) is funding another trial with an enhanced train-the-trainers model, an updated attainment measure and longer-term follow-up..

Conclusion

Thinking, Doing, Talking Science is a low-cost intervention targeting a crucial, early stage of science education. . The results of this trial provide evidence that the TDTS programme was effective in improving science attainment and fostering more favourable

attitudes to school science compared with business-as-usual. The effect sizes show that it had a particular impact on girls and on those with low prior attainment. However, a subsequent larger-scale RCT of the intervention did not replicate the overall findings although some attitudes to science were improved (Kitmitto et al., 2018). It is not unusual for EEF trials that show promise at the initial, ‘efficacy’ stages of evaluation (where the intervention is delivered under conditions that are as ideal as possible) to fail to reproduce this success at the later, larger-scale ‘effectiveness’ stage (e.g. Hodgen, Adkins, Ainsworth, & Evans, 2019; Roy et al., 2019). It would be valuable to investigate this phenomenon more closely in an attempt to establish whether there is an underlying reason for this, perhaps related to trial methodology or the upscaling of interventions.

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The Bright Ideas Time			
<i>Prompt</i>	<i>Curriculum Area</i>	<i>Example</i>	<i>Example of pupils' responses</i>
Odd One Out	Living things	A hippo, a bird, a child, a cat	Hippo because it lives in water The bird is the only one that is not a mammal Human is the only one not an animal
PMI	Electricity	A world without electricity	P: You won't waste so much energy P: The world would be equal M: It would be very scary walking home at night I: People might be fitter – less T.V.=more exercise
Big Question	Earth in Space	How do you know that the Earth is a sphere?	Why doesn't water fall off the edge if the Earth is flat?' Because gravity comes from the centre of the earth, because a sphere is the smallest shape you can make from the centre, it is most likely be pulled up into a sphere.
Practical Prompts for Thinking			
<i>Prompt</i>	<i>Curriculum Area</i>	<i>Example</i>	
The uphill can	Forces	A sealed can is placed on a slope and released. It rolls uphill. Why? A 1Kg mass is taped inside the can & this is placed on the uphill side of the can. Pupil answers included: a hamster inside the can, magnets, invisible string.	
A range of types of science practicals			
<i>Practical</i>	<i>Curriculum Area</i>	<i>Type of practical</i>	<i>Notes</i>
Make the bulb light	Electricity	Problem solving	Equipment: a battery, Al foil and a bulb (not in a holder)
Which shoes have the best grip?	Forces	Fair test	No equipment put out to provide hints. Challenge: devise a fair investigation

Table 1: Examples of TDTS Strategies

Table 2: Pupil characteristics

	All pupils at randomisation			All pupils in final analysis		
	TDTS	Control	Overall	TDTS	Control	Overall
Number of pupils	763	750	1513	655	609	1264
Pre-test score, mean (SD)	24.0 (6.2)	24.0 (6.8)	24.0 (6.5)	24.2 (6.2)	24.3 (6.8)	24.2 (6.5)
Gender, n (%)						
<i>Male</i>	367 (48.1)	374 (49.9)	741 (49.0)	328 (50.1)	328 (53.9)	656 (51.9)
<i>Female</i>	359 (47.1)	311 (41.5)	670 (44.3)	325 (49.6)	276 (45.3)	601 (47.6)
<i>Missing</i>	37 (4.8)	65 (8.7)	102 (6.7)	2 (0.3)	5 (0.8)	7 (0.6)
FSM (ever), n (%)						
Yes	178 (23.3)	161 (21.5)	339 (22.4)	147 (22.4)	138 (22.7)	285 (22.6)
No	548 (71.8)	524 (69.9)	1072 (70.9)	506 (77.3)	466 (76.5)	972 (76.9)
<i>Missing</i>	37 (4.9)	65 (8.7)	102 (6.7)	2 (0.3)	5 (0.8)	7 (0.6)

Table 3: Raw means at post-test

	Raw Means					
	TDTS group			Control group		
	n (missing)*	Mean (95%CI)	SD	n (missing)*	Mean (95%CI)	SD
All pupils						
All pupils	655 (108)	22.25 (21.72, 22.77)	6.71	609 (141)	21.05 (20.49, 21.62)	6.92
Gender						
Boys	328 (39)	21.77 (21.00, 22.53)	6.90	328 (46)	21.25 (20.48, 22.02)	6.94
Girls	325 (34)	22.75 (22.03, 23.47)	6.48	276 (35)	20.84 (20.01, 21.67)	6.90
Free school meals						
FSM pupils	147 (31)	19.52 (18.48, 20.56)	6.38	138 (23)	17.62 (16.60, 18.65)	6.11
Prior attainment						
Lower than median	298 (55)	18.10 (17.41, 18.79)	5.96	274 (75)	16.47 (15.84, 17.10)	5.21
Above or equal to median	357 (53)	25.71 (25.16, 26.26)	5.17	335 (66)	24.80 (24.17, 25.44)	5.8

*all pupils with pre-test and post-test scores (missing: those with pre-test but no post-test results)

Table 4: Primary outcomes

	Effect size	
Outcome	n in model (TDTS, Control)	Effect size (95%CI)
All pupils	1264 (655, 609)	0.22 (0.11, 0.33) P<0.001
Gender interaction		
Boys	656 (328, 328)	0.12 (-0.03, 0.27) P=0.12
Girls	601 (325, 276)	0.32 (0.16, 0.48) P<0.001
FSM interaction		
FSM pupils	285 (147, 138)	0.38 (0.15, 0.62) P=0.002
Attainment interaction		
Lower than median at pre-test	572 (298, 274)	0.30 (0.13, 0.46) P<0.001
Above or equal to median at pre-test	692 (357, 335)	0.22 (0.07, 0.37) P=0.004

Table 5: Pupils' attitudes to science

		Most favourable (% of pupils) ⁱ	Comparison of mean scores (school-level) ⁱⁱ		
			TDTS higher mean score	TDTS = Control	Control higher mean score
Learning science at school					
Science lessons are interesting	TDTS Control	49 37	15	1	3
Science lessons are boring*	TDTS Control	51 40	12		7
Solving science problems is enjoyable	TDTS Control	43 36	10		9
I enjoy discussions in science lessons	TDTS Control	32 25	13		6
We often have discussions in science lessons	TDTS Control	51 41	13		6
We spend a lot of time in science lessons copying from the board*	TDTS Control	33 24	9		10
We do a lot of writing in science lessons*	TDTS Control	8 4	12		7
Science lessons make me think	TDTS Control	40 29	14		5
I understand everything in my science lessons	TDTS Control	13 13	8	1	10
I look forward to my science lessons	TDTS Control	38 28	15		4
I would like to do more science at school	TDTS Control	36 30	13		6
Practical work in school science					
I look forward to doing science practicals	TDTS Control	53 46	15		4
Doing practical work in science lessons is fun	TDTS Control	61 49	14		5
Practical work in science is boring*	TDTS Control	58 50	13		6
We do practical work in most science lessons	TDTS Control	26 17	15		4
We already know what will happen when we do science practical work*	TDTS Control	21 17	13		6
I can decide what to do for myself in science practical work	TDTS Control	20 16	12		7
General attitudes towards science					

I like thinking about scientific ideas	TDTS Control	41 34	14	1	4
Science is fun	TDTS Control	49 36	16		3
It is important that we learn science	TDTS Control	70 57	16		3
I find science difficult to understand*	TDTS Control	17 21	11		8
I am just not good at science*	TDTS Control	25 23	12		7
I think science is more for boys*	TDTS Control	63 62	12		7

**reverse-scored: most favourable response is "disagree a lot"*

ⁱ TDTS n=654, Control n=635

ⁱⁱ n=19 pairs of schools

Figure 1: A Logic Model for the TDTS project

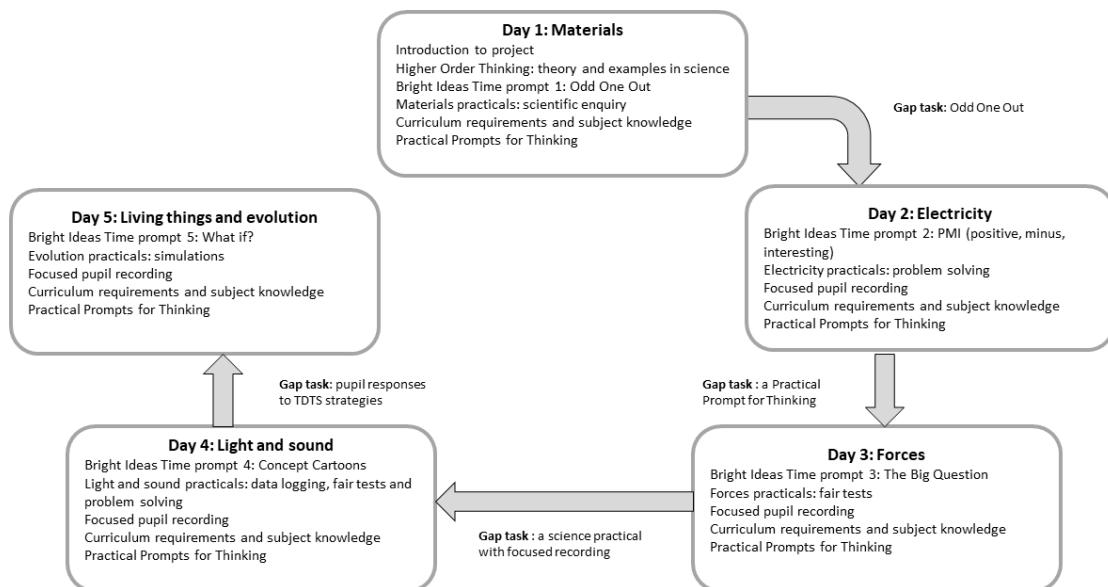
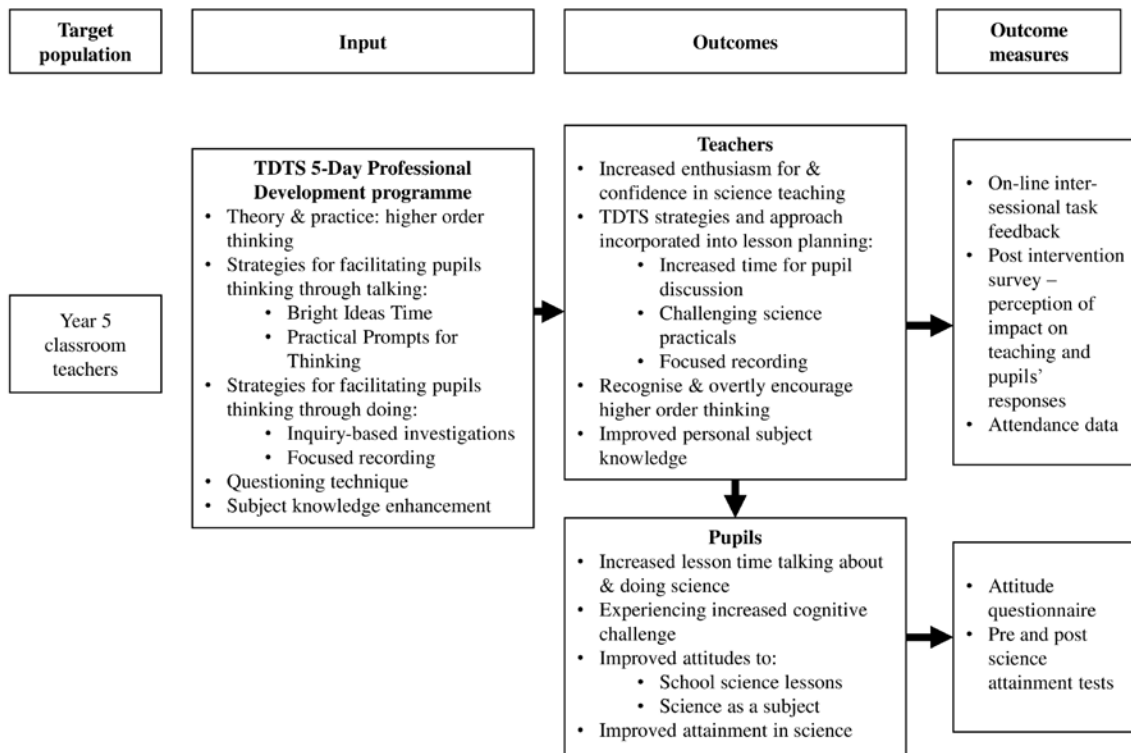


Figure 2: TDTS Programme outline

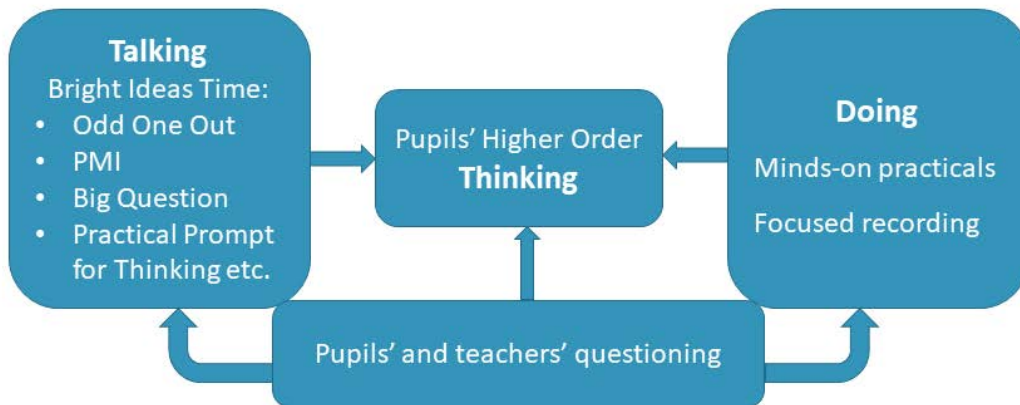


Figure 3: project overview

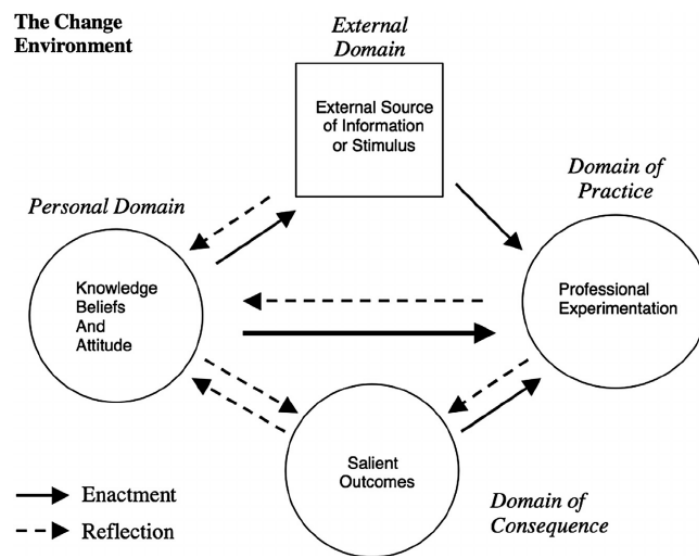


Figure 4: The interconnected model of professional growth

Activity	2012			2013												2014							
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	
Recruit schools	■	■	■																				
Pupil pre-tests			■	■																			
Randomise schools				■																			
Professional development day 1												■											
Professional development day 2														■									
Professional development day 3																■							
Professional development day 4																		■					
Professional development day 5																						■	■
Pupil post-tests																						■	■
Pupil attitude survey																						■	■

Figure 5: Timeline

Figure 5: Timeline