Trial Evaluation Protocol
Primary Science Quality Mark

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Education Endowment Foundation

PROJECT TITLE	Primary Science Quality Mark
DEVELOPER (INSTITUTION)	PSQM, University of Hertfordshire
EVALUATOR (INSTITUTION)	RAND Europe
PRINCIPAL INVESTIGATOR(S)	Dr Alex Sutherland[1] (20 July 2018 – 14th June 2019) Dr Emma Disley (15 June 2019 – November 2019) Elena Rosa Brown (August 2019 – present)
PROTOCOL AUTHOR(S)	Dr Alex Sutherland Amelia Harshfield Dr Yulia Shenderovich Elena Rosa Brown Miriam Broeks
TRIAL DESIGN	Two-arm cluster randomised controlled trial with random allocation at school level
PUPIL AGE RANGE AND KEY STAGE	Whole-school intervention; focus of the evaluation on Year 5 (9-10 years old)
NUMBER OF SCHOOLS	140
NUMBER OF PUPILS	~3,500
PRIMARY OUTCOME	Pupil science attainment in study year 2[2]
SECONDARY OUTCOME	Pupil science attainment in study year 1, pupil attitudes to science and science teaching

Protocol version history

VERSION	DATE	REASON FOR REVISION
1.2 [*latest*]	April 2021	To capture changes to the impact evaluation and IPE plans which have been changed to minimise burden on schools in light of school closures as a result of COVID-19
1.1	June 2020	To capture changes to IPE and update project timelines in response to COVID-19
1.0 [original]	11 June 2019	

[1] Formerly RAND Europe, currently Behavioural Insights Team.
[2] Throughout the document, we refer to study year 1 (2019/20) and year 2 (2020/21).

Summary of update of version 1.2

As a result of the COVID-19 related lockdowns and social distancing measures introduced in England from March to June 2020 and from January to March 2021 activities for the evaluation of PSQM were revised.

The first lockdown from March to June 2020 closed schools to almost all students (only children of key workers were given opportunity to attend) and attendance was optional from June to July 2020. This made pupil testing unfeasible at the end of the 2019/20 school year. A second national lockdown from January 2021 to March 2021 closed schools again to almost all students (apart from children of key workers). The combination of the first and second lockdown meant that while schools participated in the PSQM programme their ability to participate in the PSQM programme and implement and evaluate action plans as intended was affected. A number of elements of the PSQM programme were adapted to support schools, including amendments to the programme to facilitate school participation with all training sessions from March 20 onwards delivered online, extending the deadline for PSQM submissions from June 20 to March 21, providing HQ led webinars during the summer and autumn terms in 2020 and COVID-19 Guidance documentation, reviewing assessment expectations and making additional hub leader support available post-submission to replicate the level of support schools would have normally received. While beneficial for delivery, these adaptations made the programme significantly different to what would be delivered under 'normal circumstances'. There was also some uncertainty over the extent to which pupils' outcomes would have been effected by given the relatively limited length of time PSQM would have been embedded in schools (i.e., due to extensions of submission deadlines) and the limited length of time pupils would have been in classrooms (due to the repeated lockdowns). A joint decision between the EEF, PSQM and RAND Europe teams was made to cancel the testing at the end of the 2020/21 school year. Given COVID-19 disruptions to education, it was considered that it would be more difficult to capture changes of the PSQM programme at the pupil using standardised tests. In addition, minimising burden on schools was prioritised and therefore the evaluation activities were overall reduced.

The changes are outlined in detail throughout this protocol. In summary, the changes are:

Table 1. Summary of changes to the evaluation

Original plans	June 2020 revised plans	April 2021 current plans

- Pupil outcome testing at end of 2019/20 school year (science attainment and attitudes towards science; secondary outcomes)
- Pupil testing at end of 2020/21 school year (science attainment (primary outcome) and attitudes towards science (secondary outcome))
- IPE activities (staff surveys and case study interviews) in summer of 2020
- IPE activities in summer of 2021
	- Pupil outcome testing at end of 2020/21 school year only (science attainment (primary outcome) and attitudes towards science (secondary outcome))
	- IPE activities previously planned for June 2020 shifted to December 2020-February 2021
	- IPE activities in summer of 2021
	  ○ Surveys in all schools
	  ○ Case studies: interviews and document reviews of PSQM submissions in 5 intervention schools
		- All pupil outcome testing cancelled
		- IPE activities planned for the period of December 2020 and February 2021 cancelled
		- IPE activities in summer of 2021:
		  ○ Planned surveys remain the same
		  ○ Number of case studies expanded from 5 intervention schools to 10 interventions schools and 10 control schools
		  ○ Number of schools to review science documentation/PSQM submission review expanded to 30

List of abbreviations

CPD	Continuing Professional Development
EAL	English as additional language
EEF	Education Endowment Foundation
ES	Effect size
FIML	Full Information Maximum Likelihood
FSM	Free school meals
GDPR	General Data Protection Regulation
HSPC	Human Subjects Protection Committee
ICC	Intracluster correlation
ICO	Information Commissioner's Office
IDEA workshop	Intervention Delivery and Evaluation Analysis workshop
IPE	Implementation and process evaluation
ITT	Intention-to-treat
KS	Key Stage
NFER	National Foundation for Educational Research
MAR	Missing at random
MDES	Minimum detectable effect size
MI	Multiple Imputation
MoU	Memorandum of Understanding
NPD	National Pupil Database
PRU	Pupil Referral Unit
PSQM	Primary Science Quality Mark
RCT	Randomised Controlled Trial
SLT	School Leadership Team
TDTS	Thinking, Doing, Talking Science
TIMMS	Trends in International Mathematics and Science Study
STEM	Science, technology, engineering and mathematics
TIDieR	Template for Intervention Description and Replication
VLE	Virtual Learning Environment

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Intervention

Primary Science Quality Mark (PSQM) was initiated in 2008 at the University of Hertfordshire to raise the profile of science in primary schools in England and promote professional development in science teaching and leadership.[3,4] PSQM is a developmental accreditation programme aiming to improve science education in primary schools through providing teachers and school science leaders with a framework for self-assessment, reflection and development as well as relevant training.

PSQM is delivered within hubs of schools (with a mean of 10 schools in a hub), supported by an experienced hub leader. Hub leaders have backgrounds such as Local Authority advisers, consultants, university lecturers and teachers who have achieved Primary Science Quality Marks in the past. Schools can work towards one of three Primary Science Quality Marks – PSQM, PSQM Gilt and PSQM Outreach. PSQM is for "schools which demonstrate how effective science leadership is *beginning* to have an impact on science teaching and learning across the school", whereas PSQM Gilt requires the demonstration of a "*sustained* impact", and PSQM Outreach is for schools that meet Gilt criteria and also impact science leadership and teaching in other schools.

Over the course of one academic year, PSQM involves the following activities (see Figure 1 below for the full logic model):

- Staff training, provided by the hub leader, completed over two full days or four half-days (topics: introduction to PSQM, creating and executing an action plan, and writing a reflective submission and collating appropriate supporting evidence).
- The subject leader works with colleagues across the school to audit existing provision in science and agree appropriate quality mark to work towards.
- The subject leader creates an action plan to develop aspects of science teaching, as specified in the PSQM framework and works with colleagues to implement it.
- Subject leaders are supported by the hub leader, with ongoing online mentoring provided via the PSQM Virtual Learning Environment (VLE), and access to resources such as the PSQM handbook and information on relevant Continuing Professional Development (CPD) offers.
- The subject leader collates and submits the evidence for the relevant PSQM, which is reviewed by a hub leader from another hub.
- Hub leader reviewers use PSQM evaluative criteria to consider whether a school has achieved the requirements to gain the chosen Primary Science Quality Mark.

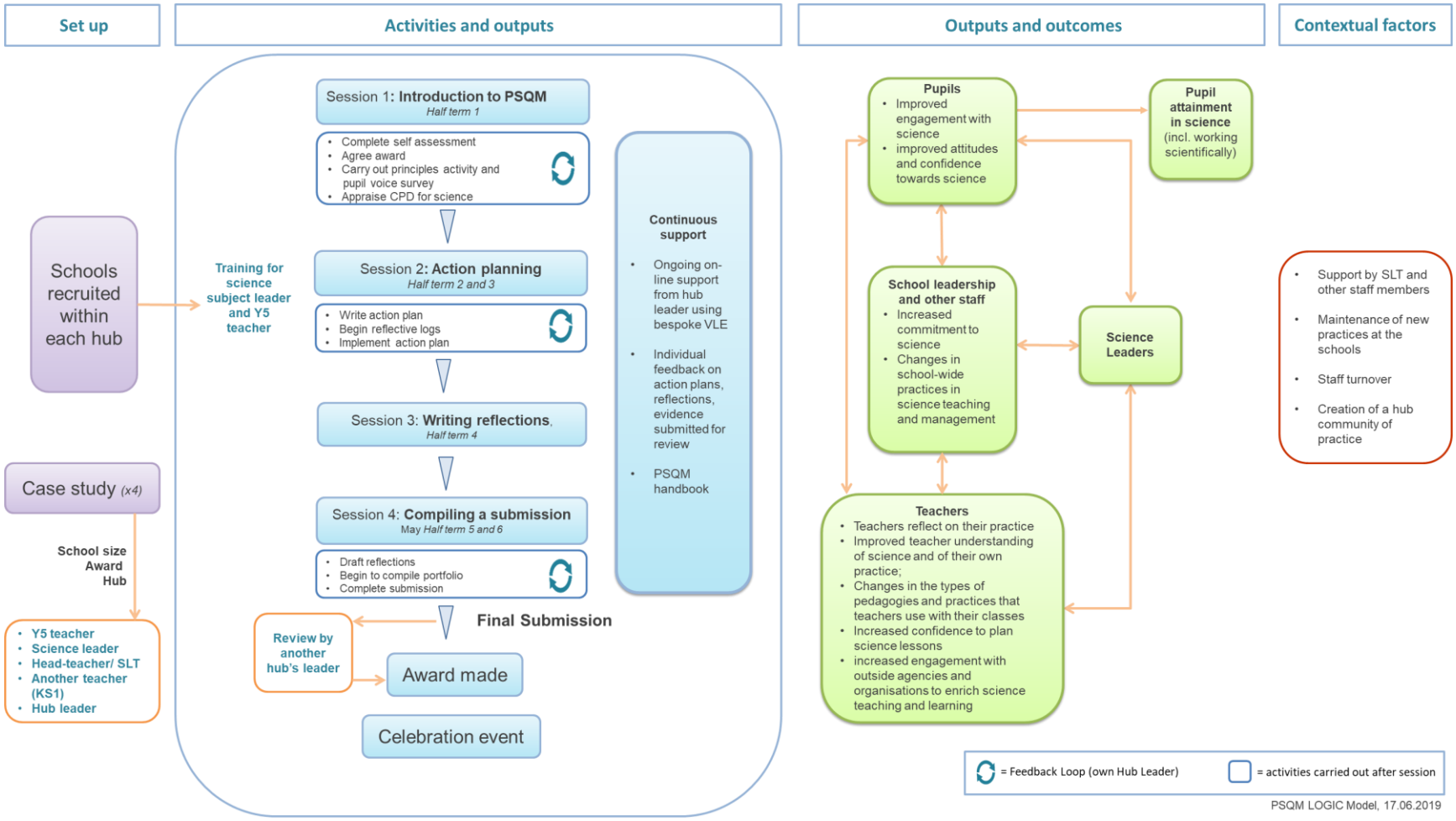
Awards are made to schools following an analysis of a series of documents that detail how the activities implemented during the intervention year have impacted on the science teaching and learning across the school and how the school meets the PSQM criteria. There are 13 PSQM criteria covering (1) primary school science leadership, (2) teaching (3) learning, and (4) wider opportunities Rather than the award itself being central, *the focus of the programme is on the process of self-assessment, reflection and development.*

All schools must complete the same self-evaluation and meet the same criteria, ensure that the subject leader (and another member of staff if possible) attend training, write and implement an action plan and submit common core documents. However, each school's action plan, implementation and final submission is relevant to its own context.

In the current trial, PSQM will be delivered in approximately 70 primary schools, with another approximate 70 schools assigned to the control arm. In the current evaluation, the programme will focus on the school's science subject leader and Year 5 teacher from each school (and a Key Stage (KS) 1 teacher, if the Y5 teacher is the subject leader).

[3] http://www.psqm.org.uk/what-is-psqm
http://www.psqm.org.uk/about-us
[4] http://www.psqm.org.uk/__data/assets/pdf_file/0010/123130/Primary-Science-May-2016-PSQM-update.pdf

Figure 1. PSQM logic model



Update: adaptations to PSQM delivery due to COVID-19 restrictions

To support delivery of PSQM, the delivery team made the following adaptations:

- Extended submission deadline from June 2020 to March 2021.
- Facilitated school participation with all training sessions from March 2020 onwards delivered online
- Provided PSQM Headquarter led webinars during the summer and autumn terms in 2020.
- Created a COVID-19 guidance document to help science subject leaders adapt planned actions and identify impact.
- Reviewed assessment expectations and moderation training for reviewers.
- Made additional hub leader support available post-submission to replicate the level of support schools would have normally received.

Study rationale and background

Recent surveys of UK Science Subject Leaders and teachers in primary schools (CFE, 2017; CFE, 2019), including 902 science leaders and 1,010 teachers, suggested that science is often seen as less important compared to English and mathematics. Challenges reported in relation to science education in primary schools include lack of teaching time, lack of quality monitoring, limited access to science expertise, among others (Wellcome Trust, 2014; Ofsted, 2019).

PSQM is aimed at improving school-wide science teaching and raising the profile of science in UK primary schools through: (i) effective science leadership and (ii) supported school self-evaluation. PSQM is already widely used – more than 2,840 schools have previously completed the programme (11.8% of all UK primary schools) and more than 550 are currently engaged.[5] PSQM has also been endorsed by OFSTED (OFSTED, 2013), and is the only national award for science in English primary schools.[6]

Existing qualitative research suggests that PSQM can benefit schools in multiple ways, such as contributing to raising the profile of science in primary schools and providing schools with a framework and professional support for developing science leadership, teaching, and learning (White, et al., 2016). Previous evaluations of PSQM drew on interview, focus group, and survey data from participating science leaders and hub leaders. Participants reported that their perception was that PSQM improved the profile of science and quality of science teaching within schools and facilitated dissemination of relevant good practices between schools (White et al., 2016; White et al., 2015).

However, there is no robust experimental evidence yet on whether PSQM accreditation leads to improvements in pupil outcomes in science or related subjects. The current study aims to produce rigorous evidence on PSQM's efficacy in relation to pupil outcomes in science.

Previous evidence is limited regarding the impact of accreditation programmes in primary and secondary education. However, existing literature suggests that accreditation programmes in higher educational institutions can improve the quality of teaching (Hanbury et al., 2008; Volkwein et al., 2006; Blouin et al., 2018). There is also evidence from survey data that accreditation translates into better outcomes for university students (Volkwein et al., 2006). If the criteria that schools must meet in order

[5] http://www.psqm.org.uk/about-us
[6] http://www.psqm.org.uk/__data/assets/pdf_file/0006/78405/PSQM-flyer-July-2017.pdf

to gain accreditation lead to improved pedagogical methods and, consequently, improved learning by students, this intervention should lead to improved attainment.

Furthermore, the active and collaborative style of professional development that PSQM draws on has been linked to positive effects on instructional practice and student outcomes (Opfer, 2016; Darling-Hammond et al., 2017; Gore et al., 2017). Nevertheless, CPD programmes that are active and collaborative do not always lead to improvements in pupil outcomes (e.g. Garet, 2011; 2016; Sims and Fletcher-Wood, 2018).

The PSQM programme is led by The University of Hertfordshire and will be independently evaluated by RAND Europe. The study is funded by the Education Endowment Foundation (EEF) and Wellcome Trust.

Impact Evaluation

Research questions

The impact evaluation was designed to investigate the following research hypotheses

Hypothesis 1: Year 5 pupils in randomly allocated primary schools participating in PSQM (intervention schools) will have higher levels of science attainment than the pupils in the comparison schools one year following the end of PSQM implementation, 2020/21 (Summer 2021; primary outcome).

Hypothesis 2: Year 5 pupils in primary schools participating in PSQM (intervention schools) will report higher levels of enjoying science than the pupils in the comparison schools in 2020/21 (Summer 2021; secondary outcome).

Hypothesis 3: Year 5 pupils in primary schools participating in PSQM (intervention schools) will have higher levels of science attainment than the pupils in the comparison schools at the end of the school year when the intervention takes place, 2019/20 (Summer 2020; secondary outcome).

Update: None of these hypotheses can be tested due to pupil outcome data collection being foregone or cancelled. However, details on the design of the trial are included as randomisation was completed. Further details of the rescoped research can be found in the Implementation and Process Evaluation (IPE) section below.

Design

Originally planned:

Trial type and number of arms		Two-arm stratified, cluster-randomised controlled trial, randomised at the school level
Unit of randomisation		School
Stratification variables (if applicable)		Region (hub) School size (single- versus multiple-form entry)
Primary outcome	variable	Pupil science attainment (Year 5 pupils in summer 2021)
	measure (instrument, scale)	Hanley 2015 (potentially modified to ensure fit with the National Curriculum), science assessment with scores ranging from 0 to 41 points
Secondary outcome(s)	variable(s)	Pupil attitudes to science and science teaching
	measure(s) (instrument, scale)	Trends in International Mathematics and Science Study (TIMMS)

The PSQM evaluation was designed as a two-group, parallel, stratified, cluster-randomised trial, with school as the unit of randomisation. To ensure comparability of schools in the intervention arm and the control arm ('exchangeability', see Oakes, 2013), we randomised schools within hubs, which served to balance the study arms on geographical location and, therefore, any regional differences.[7]

During the recruitment period (2018-19 academic year), schools were asked to nominate one Year 5 teacher (in case there were multiple Year 5 classes) to participate in PSQM. The class of this teacher was going to be considered the focal class for the evaluation, assessed in the summer 2020 following implementation. In Summer 2021, the Year 5 class taught by the same teacher would be assessed. If the teacher left or moved to another Year, we planned to assess the Year 5 class or randomly select another Year 5 class (if there were more than one Year 5 classes).

To minimise the burden on pupils and schools, the evaluation planned to use administrative data for baseline, with schools providing pupil identifiers, which was going to be linked to the National Pupil Database (NPD). After schools were recruited and the pupil and teacher information collected, the Evaluation Team randomised schools to one of two arms: intervention or control.

Intervention schools were not charged to take part in the PSQM programme and will receive a payment of £1,500 towards teaching cover and £120 towards travel costs. Control schools were not allowed to participate in PSQM while the study was running but they will receive a payment of £1,500 on completion of the trial.

Update: Due to the issues outlined above, testing was foregone, thus, the data for primary and secondary outcomes listed in the table above were not collected.

Control schools were still offered £1,500 on completion of IPE data collection activities.

Randomisation

Randomisation occurred as planned in July 2019.

Randomisation was conducted in Stata by the Evaluation Team's Primary Investigator. Hub was the main stratifying variable, with around 16 hubs recruited. In addition, we stratified on school size (single-entry versus multiple-entry school), as reported by the school. The trial allocation was recorded and communicated to the implementation team and the EEF in a password protected Excel file to prevent editing. Initial outcome analyses were going to be conducted blind to allocation.

Baseline equivalence will be examined based on the initial randomisation. A well-conducted randomisation will, in expectation, yield groups that are equivalent at baseline (Glennerster & Takavarasha, 2013). Because schools are randomly allocated to the control and intervention conditions, any imbalance at baseline will have occurred by chance. To assess imbalance at baseline, we will compare groups at school and pupil levels, by means of cross-tabulations and histograms that assess the distribution of each characteristic within the control and intervention groups.

Participants

SCHOOLS

Schools were recruited by the PSQM team and PSQM hub leaders, based on the following eligibility criteria:

Inclusion criteria:

[7] That is – if one were to swap the intervention and control groups the results from the trial should be the same.

- The school cannot have received a PSQM award in the last 3 years (i.e., a school has not participated in PSQM in 2017, 2018 or 2019).
- The school must be a state primary, junior or all-through school.
- Schools with mixed Year 5/6 or another combination are eligible if they have Year 5 pupils taught separately by one teacher for science.

Exclusion criteria:

- Infant or first schools, private schools, special schools, Pupil Referral Units (PRUs) or middle schools are not eligible.

The following areas were included in the recruitment:

- Aylesbury Vale
- Barnsley and Kirklees
- Bracknell and Slough
- Cambridgeshire (East)
- Cannock
- Chorley
- Crewe and Nantwich
- Merton
- Cumbria
- Devon (North)
- Essex
- Isle of Wight
- Loughborough
- Newent
- North Yorkshire
- Oxford & Banbury
- Portsmouth
- Ross-on-Wye
- Suffolk coastal
- Tewksbury
- Thanet and Medway
- Waltham Forest
- Warrington

Pupils

No inclusion/exclusion criteria based on pupil characteristics were used as PSQM is a universal intervention. To minimise burden on schools, pupils enrolled at the time of school recruitment in 2019 were included in the study, but pupils who joined the schools at a later time were not included in the evaluation as this would require additional information collected from schools.

Minimum Detectable Effect Size (MDES) calculations

Table 2. Statistical power calculations

		Main effect
Minimum Detectable Effect Size (MDES)		**0.197**
Pre-test/ post-test correlations	level 1 (pupil)	0.63
	level 2 (class)	NA
	level 3 (school)	0
Intracluster correlations (ICCs)	level 2 (class)	NA
	level 3 (school)	.15
Alpha		0.05
Power		0.8
One-sided or two-sided?		Two
Average cluster size[8]		25

[8] We have set the average class size to 25, but acknowledge that there may be variation across schools where some classes are smaller with less than 20 pupils, and others are larger with up to 30 pupils.

Number of schools	Intervention	70
	Control	70
	Total	140
Number of pupils	Intervention	1,750
	Control	1,750
	Total	3,500

Power and minimum detectable effect size (MDES) calculations were performed using the PowerUp tool for main effects (Dong & Maynard, 2013) and moderators (Spybrook, Kelcey, & Dong, 2016; Dong, et al., 2017). Based on EEF guidelines (EEF, 2018) and on a recent evaluation working with science outcomes in this age group (Kitmitto 2018)[9], the amount of variation explained by covariates for 140 schools with an average of 25 pupils each, is assumed to be 0.40 (equivalent to correlation of 0.63) for level 1 (pupils) and 0.00 for level 2 (schools). The efficacy evaluation of Thinking, Doing, Talking Science (TDTS), which used the same primary outcome (Hanley et al., 2015) reported an intracluster correlation (ICC) of 0.15 in the analyses. With one class per school included in the evaluation, we assume an average cluster size of 25 pupils. We also assume an alpha of 5% and an intended 80% power to detect effects. We use two-level clustered designs, assuming a continuous, normally distributed (Gaussian) outcome.

Using the parameters above and with equal allocation to intervention and control the MDES was intended to be 0.197 (Column A). We believed it was important to power to d=0.2 despite this being an efficacy trial because the universal nature of the intervention is likely to result in comparatively smaller effect size.

Based on EEF's guidance[10], we focused on a moderator effect defined as a statistical interaction of intervention and moderator variables. Based on the average number of free school meals (FSM) pupils in UK primary schools – 14% in 2018 - we assume 4 FSM pupils per class.[11] However, PSQM recruitment for the trial focused on high-FSM areas, so the actual number may be higher. Using the same assumptions as the main analysis, MDES difference regarding Cohen's d was intended to be 0.251 (95% CI 0.059; 0.331).

Baseline measures: The evaluation planned to use pupils' KS1 mathematics, reading and writing data that was collected in Year 2 as baseline data to assess baseline equivalence of the intervention and control groups after the randomisation process of the schools. These data was also going to be used as covariate(s) in outcome analyses.

Update: pupil baseline data will still be analysed for equivalence to understand if randomisation was successful (in line with similar trials that had impact evaluations foregone because of COVID-19 restrictions). Data will be included in the EEF archive for future, longitudinal analysis.

Outcome measures

Primary outcome

[9] The effectiveness evaluation of TDTS (Kitmitto, 2018) found variance explained at Level 1 to be 0.40 for the same primary outcome as in the current trial and KS1 reading/writing and mathematics as baseline, so we expect the current trial to have at least the same variance explain as a minimum.

[10] https://educationendowmentfoundation.org.uk/public/files/Evaluation/Writing_a_Protocol_or_SAP/EEF_statistical_analysis_guidance_2018.pdf

[11] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/719226/Schools_Pupils_and_their_Characteristics_2018_Main_Text.pdf

It was planned to use an independent science test at post-test, administered and marked by a third-party, the National Foundation for Educational Research (NFER) for outcome testing. This approach would have allowed for blinding to allocation, as a list of schools to the could be supplied assessors without revealing allocation. KS2 science is teacher assessed and would, therefore, bring the problem of biased measurement/non-blinding.

More specifically, it was planned to use the test on knowledge, thinking and reasoning in science used in the EEF evaluations of TDTS (Hanley et al., 2015). This test was compiled from questions developed by Terry Russell and Linda McGuigan for an unrelated Randomised Control Trial (RCT) funded by the Wellcome Trust and covers a range of topics in biology, chemistry and physics. It includes process/inquiry-based, concept-based; and open-ended conceptually-based questions. The test is currently under external review by a team at York University, commissioned by the EEF, to ensure compatibility with the current National Curriculum. The team is redesigning the instrument in four phases during 2020 involving piloting and validation. In January 2020 it was piloted in two schools with 24 children (phase 1) and in February in 22 schools with 958 pupils (phase 2). Phase 3 is planned for October 2020 to test the psychometric properties of the test in 14 schools. It will involve piloting a version of the test made up of 15 questions and lasting approximately 45 minutes. Phase 4 (November 2020) will assess the test-retest reliability of the instrument. Any changes to the outcome(s) will be conveyed through updated versions of this protocol.

As whole-school changes take time, we planned to evaluate the effect of the intervention on pupil science attainment and attitudes following the 2019/20 implementation year with the second Year 5 cohort, in 2020/21 (labelled Cohort B) in all schools. Initial plans were to administer the science attainment test and the 'attitudes to science and science skills' test among Year 5 pupils in the nominated class at the end of 2019/20 academic year, both as secondary outcomes. However, school closures resulting from COVID-19 and the significant disruptions faced by schools led to the cancellation of testing in the summer of 2020.

Update: Changes to the trial were made in March 2021 given the disruptions brought by the January 2021 national lockdown. It was decided to forego all outcome testing for the trial and to only collect IPE data.

Secondary outcomes

To assess changes in pupils' attitudes towards science, we planned carrying a post-test survey at the same time as the primary outcome assessment. The attitudinal measure at post-test were also going to be administered by NFER using paper forms. The attitudinal measures were going to be compiled in machine-readable forms, to allow scanning, data entry and scoring by RAND Europe.

Enjoyment of science, confidence in science and engaging teaching in science will be measured using the 'enjoyment of science' subscale adapted from the Trends in International Mathematics and Science Study (TIMMS) Grade 4 surveys from TIMMS 2015.[12]

If possible, it was planned to capture science enquiry skills from relevant items in the science attainment test by Hanley and colleagues.

Update: Owing to reasons outlined above, secondary outcome testing was foregone.

Analysis plan

Update: This section outlines the analyses that was initially planned for the trial. However, due to the reasons outlined previously it will no longer be possible to conduct these planned analyses.

The primary outcome for the second wave of Year 5 pupils (Cohort B) was going to be science attainment as measured by the science test. Intervention and control arms were going to be compared

[12] https://timssandpirls.bc.edu/publications/timss/2015-methods.html

in terms of the difference in means between groups at follow-up, conditional on baseline measures (KS1 mathematics, reading and writing) and stratification variables (area and school size).

The unit of analysis here would have been pupils. There is an ongoing discussion about how 'best' to analyse results from RCTs that involve clustered data. One approach, 'analyse how you randomise' (Senn, 2004), suggests that one should explicitly account for clustering via multilevel models (AKA 'random effects'). This approach assumes that the schools in the study are a random sample of all schools – which is often a source of contention – but one benefit of this approach is being able to explicitly partition variance and more flexibly handle complex variation within schools (Snijders and Bosker, 2012). Our approach will be to conduct sensitivity analyses to assess results against different model specifications. These will be detailed in the Statistical Analysis Plan. The general equation for the multilevel model is given below as Eq.(1):

$$y_{ij} = \propto + X_{ij}\beta + Z_j b_j + \delta PSQM_j + u_{ij} + u_j \qquad i = 1..N, j = 1..M, \quad (1)$$

where y_{ij} denotes the pupil level outcome; i and j denote pupil and school indexes, respectively; X_{ij} is the $1 \times k$ vector of individual characteristics that include the KS1 measures as a pre-test;[13] Z_j is a vector of the stratification variables mentioned above (hub region and school size); $PSQM_j$ is a dummy variable denoting intervention /control group at the school level; β and δ are the $k \times 1$ and 1×1 vectors of regression coefficients; u_{ij} is the pupil-level error term; and u_j is the school-level error term. The coefficient δ will constitute the main result of the trial.

The outcome analysis will be on an intention-to-treat (ITT) basis. Once randomised, schools and participants will be analysed according to the allocation of the school regardless of whether the school complied with the intervention or not. It is important to note that cluster-randomised designs mean that both school and pupil level attrition may be possible post-randomisation, with subsequent implications for analysis (see Schochet and Chiang, 2011).[14] The ITT approach is inherently conservative as it captures the averaged effect of *offering* the intervention.

Our approach would have been to adhere to the ITT analysis in the event of pupils migrating between intervention and control schools after randomisation. Pupils joining schools after the new school year had begun would be excluded from the evaluation.

Update: Given that outcome data collection was cancelled none of the above planned analyses can be conducted.

Baseline data

Update: We will collect baseline data from the NPD so that we can review baseline equivalence. Data on pupils, including their allocation to treatment or control, will be uploaded to the EEF archive for future, longitudinal analysis.

The baseline pupil measure from the NPD was going to be used as a continuous variable. NPD baseline data would have been matched to the science attainment scores for each pupil.

KS1 mathematics, reading and pupil data will be obtained from the NPD, based on the lists of pupils participating in the trial. Pupil information was provided by all trial schools during recruitment to randomly allocate schools to control or intervention conditions.

[13] Assuming that the KS1 measures are not too highly correlated to be included in the same model e.g. if the correlation between measures is *r* >= .7 we would include only one measure (e.g. KS1 reading).

[14] While not widely known or reported, random effects models may yield biased estimates of ITT in cluster randomised trials under certain conditions when there is individual level noncompliance. Thus, it is critical to minimise individual level noncompliance and to include adequate covariates to reduce between-cluster variance. See for example Jo et al. (2008).

Effect size (ES)

We planned to use the effect sizes for cluster-randomised trials given in the EEF evaluator guidance – an example, adapted from Hedges (2007) is given below:

$$ES = \frac{(\bar{Y}_T - \bar{Y}_C)_{adjusted}}{\sqrt{\sigma_S^2 + \sigma_{error}^2}}$$

Where $(\bar{Y}_T - \bar{Y}_C)_{adjusted}$ is the mean difference between intervention groups adjusted for baseline characteristics and $\sqrt{\sigma_S^2 + \sigma_{error}^2}$ is an estimate of the population standard deviation (variance). The ES therefore represents the proportion of the population standard deviation attributable to the intervention (Hutchison and Styles, 2010). The exact effect size used will depend on whether there are equal or unequal sample sizes in trial arms.

Same approach for primary and secondary outcomes

Moderator analyses

Two moderators were planned to be examined to explore intervention heterogeneity:

1) EverFSM
2) Gender - motivated by the gender gap in Science, technology, engineering and mathematics (STEM) careers in adult population.

Missing Data

Attrition across trial arms was going to be explored as a basic step to assess bias (Higgins et al., 2011). To gauge systematic differences between those who drop out and those who do not – and whether factors should be included in analysis – we would model missingness at follow-up as a function of baseline covariates, including intervention. For item non-response, the extent of missingness may in part determine the analytical approach.

For less than 5% missingness overall a complete-case analysis would suffice, regardless of the missingness mechanism (EEF, 2018). Our default would be to check results using approaches that account for missingness that rely on the weaker missing at random (MAR) assumption, building the MAR conditioning variables from our initial work predicting missingness. If there was systematic missingness of predictor variables, for example, we would explore options for using Full Information Maximum Likelihood (FIML) and/or multiple imputation (MI) (EEF, 2018; for a discussion of FIML vs MI see Allison, 2012).

Implementation and process evaluation

Update: In line with the decision to cancel testing for the trial and with the intention to minimise burden on schools in as much as possible while maintaining the quality of data collected for the evaluation, the planned IPE activities were revised. IPE data collection has been reduced to only one round in June 2021 (removing planned data collection for 2020). However, IPE data will be the only source of information for the project. To strengthen this aspect of the evaluation the planned case studies will now also include control schools (initially planned only for intervention schools). While the extension of case studies to include control schools may seem like an increase in school burden, overall, burden on schools from the trial has been reduced as there are no more requirements for testing (which would have impacted *all* participating schools and potentially required more coordination to arrange). In addition, with the current plans input will be requested from case study schools at only one point in time. Exact details on the updated activities are provided in Table 3, with more detail provided in the text that follows.

Table 3 Overview of IPE data collection (updated plan)

Data type		Participant	When	Who collects the data	Topics
Online Surveys	**Headteacher survey 1**	Headteacher/ SLT	Year 1, September 2019	RAND designed, and shared with schools	- Experience with other trials/research school status (baseline) - Usual practices around teaching science (baseline)
	Teacher survey	Y5 Teachers (teacher selected for PSQM)	Year 2, May-June 2021	RAND to design, PSQM to share with schools	- Experience with intervention activities (intervention schools only) - School's commitment to science (all schools) - Teacher's background (highest education in science, years teaching, years in the school) (all schools) - Whether Y5 teacher who took part in PSQM continued teaching the Y5 or not (interventions schools only) - Sustainability of changes related to PSQM (interventions schools only)
	Science subject leader survey	Science subject leaders	Year 2, May-June 2021	RAND to design, PSQM to share with schools	- Experience with intervention activities (intervention schools only) - School's commitment to science (all schools) - Leader's background (years as subject leader) (all schools) - Whether Y5 teacher who took part in PSQM continued teaching the Y5 or not (interventions schools only) - Sustainability of changes related to PSQM (interventions schools only)
	Hub leader survey	Hub leader	Year 2, May-June 2021	RAND to design, PSQM to share with schools	- Interactions with the schools, perceived level of school engagement, perceived barriers and enablers (intervention schools only)
	Headteacher survey 2	Headteacher/ SLT	Year 2, May-June 2021	RAND to design, PSQM to share with schools	- Usual practices around teaching science (all schools) - Sustainability of changes related to PSQM (intervention schools only)
Case studies	**Interviews**	Teacher, headteacher, science subject leader (3 people per school)	Year 2, May-July 2021	RAND to design/conduct,	- Experience with intervention activities (intervention schools only) - Usual practices around teaching science (all schools)

Data type	Participant	When	Who collects the data	Topics
				- School's commitment to science (all schools) - Sustainability of changes related to PSQM (intervention schools only)
	Hub leader	Year 2, May-July 2021	RAND to design/conduct, PSQM to help contact participants	- Experience delivering programme and perception of school engagement (barriers and enablers)
Documentary review	Schools	Year 2, May-July 2021	PSQM provides VLE documentation to RAND. RAND requests other relevant documentation from schools	- Assess evidence of science presence/relevance in school plans and communications
Monitoring data from PSQM	Schools	From trial start up until PSQM submission due February 2021	PSQM to share with RAND	- Non enrolment numbers/reasons (all schools) - Post-randomisation drop-out/reasons for drop-out (all schools) - Training attendance logs (intervention schools only) - School task completion logs (intervention schools only)

The process evaluation will address the following questions:

- Was the intervention implemented with fidelity for the intervention schools?
- What was practice as usual in the control schools?
- What appear to be the necessary conditions for success of the intervention?
- What were the barriers to delivery including the impact of COVID-19?

We have developed a multi-stage mixed-methods IPE data collection plan. We will collect data through monitoring data, surveys for all schools in the trail (intervention and control), in addition to a documentary review, interviews and school visits (to observe science displays) for selected case study schools (see **Error! Reference source not found.**). Upon detailed review of PSQM's logic model it was felt that visits to schools were a way to observe some of the key PSQM intended changes.

Update: A focus on the impact of COVID-19 will be added to IPE guiding questions following revisions to the design of the trial.

Pre-intervention

Non-enrolment and drop-outs

While it is not possible to identify the characteristics of the schools that do not participate in the trial, the PSQM team will monitor the contact with schools and the general sign-up rate in order to get a sense of non-enrolment. If a school drops out from the programme, the hub leader will be responsible for notifying the PSQM team with accompanying reasons for why the drop-out occurred.

During intervention phase

Motivations for joining the study

The baseline headteacher online surveys (September – October 2019) will examined the motivations for joining the trial and the current practice related to science teaching. It is important to note that two other recent research efforts (CFE 2017; 2019) also describe the existing practices regarding science teaching in primary schools in England.

Completion of intervention activities by intervention schools

We will assess the attendance rate at PSQM training sessions. Attendance of trainings by teachers is mandatory and will be tracked by the PSQM team through attendance logs. We do not anticipate non-attendance to be a substantial problem given that by signing-up, schools have committed to send teachers to training sessions – however, attendance is still an important metric to capture. PSQM will put together milestones to measure successful programme implementation and participant involvement. Other data collected by PSQM to monitor implementation fidelity includes logging onto VLE, uploading action plans, the upload of core documents, reflections and submission. Implementation fidelity will be analysed for all intervention schools through a compliance measure (see Study Analysis Plan). In addition, an in-depth analysis of the described documents will be conducted for the selected case study schools.

Based on information provided by the PSQM team, we will also report on the number of schools that are successful in gaining the quality mark they aimed for, and the numbers of cases when a submission was sent for a second review, a school was asked to submit additional evidence to get the quality mark and/or when a school had a deferral/extension.

POST-INTERVENTION

Exploring programme implementation and changes in practice

Online surveys

Online surveys for headteachers, teachers, subject leaders and hub-leaders will be rolled out as part of the IPE activities.

One of the aims of the post-intervention headteacher survey (in June 2021) will be to capture any potential changes in science practice (in both intervention and control schools). Any such identified changes will be highlighted in the evaluation report.

There is a possibility that staff members from various intervention and control schools discuss the intervention amongst themselves, thereby potentially leading to chances in science practices in the control schools (phenomenon known as “spillover” or “contamination”). However, given that this is a school-based intervention, we do not anticipate the likelihood of this occurring to be large.

In June 2021 online surveys will be distributed to two staff members per school (the subject leader and the nominated classroom teacher).[15] The focus of the surveys will be on usual practice, attitudes, perceptions and science-related activities in the classroom. The majority of survey items will be the same in both surveys for control and intervention schools, examining practices and attitudes around teaching of science and science-specific CPD activities. The questions will be based on relevant expected outcomes as defined by PSQM, and will draw from the Wellcome State of the Nation surveys for teachers and subject leaders where appropriate (CFE, 2017). The survey will also ask about how COVID-19 affected running science-related activities. In addition, in the intervention arm, intervention-specific questions will be included based on the expected intervention outcomes outlined in the logic model. Descriptive quantitative analyses will be used to analyse survey data using Stata.

[15] Initial plans were to administer these surveys on paper at the same time as pupils would be tested. Due to COVID-19 trial adaptation it was decided to administer these surveys online.

Hub leader surveys will focus on their experiences of working with schools and any barriers and facilitators to implementation. We expect that it will take no more than 10-15 minutes to complete the online surveys. The text for the survey will be prepared, compiled and distributed by RAND Europe.

Update: Initially two rounds of surveys were planned. Round 1 of the surveys was planned for 2020 (originally June, then December) with head teachers, science leads, Year 5 teachers and hub leaders – these were cancelled. Round 2 of data collection is maintained as well as its focus.

Case studies

- *Interviews with staff in case study schools*

Original plans were to approach five intervention schools representing a diverse set of characteristics (i.e. region, school size, type of qualification) for in-depth case studies. These were going to involve interviews with school teaching staff and headteachers, as well as– where possible – school governors. There were going to be two rounds of interviews, one in December 2020, another in June 2021. For the latter, initial plans were for a member of the Evaluation Team to conduct school visits to carry the interviews in person and to observe whether there are any science boards displayed around the school and document this. This was also intended to increase the chances to interview other relevant school stakeholders such as governors.

Update: As a result of COVID-19 disruptions there will only be one round of interviews in June 2021. This has been expanded to cover twenty schools (ten from the intervention group and ten from the control arm). These will maintain the same focus as originally planned and target head teachers, science subject leads and year 5 teachers (as outlined next). No interviews with school governors will be conducted, nor stie visits conducted.

These interviews will allow the Evaluation Team to gain a more in-depth understanding of what PSQM involves in practice for participating teachers, subject leaders, and schools, and explore the mechanisms of change as a result of the intervention. This information is particularly important to understand what other schools need to do if they chose to participate in PSQM later. Bigger schools may find it more challenging to disseminate the impact. The dimensions that will be taken into account for sampling case study schools will be the type of award the school is working towards, whether they are single or multi-form, and location (hub). In the case of control schools, the same criteria will apply with the exception of award. In addition, Ofsted ratings of schools will also be considered during their selection. We will aim to have control and intervention case study schools with similar relevant characteristics (e.g., school size and region).

NVivo software will be used to facilitate the development of a coding matrix using the transcripts from these interviews, following framework principles, with built-in flexibility to allow identification of anticipated and emergent themes.

- *Documentary review*

Initially, documentation obtained through PSQM's VLE and provided by schools was going to be reviewed for case study schools only. Selected schools were going to be asked to provide documentation that captures their science-related activities such as, school development plans, school science policy plans (if available), Ofsted reports, lesson observation notes, feedback on school improvement plans (SIPs), reports for and communications with governors, and letters to parents. We were also going to seek to obtain pictures of science displays around the school.

Update: Following changes to the evaluation design it was decided to expand the review of PSQM submissions to include 10 submissions from the selected intervention case study schools, in addition to 20 randomly selected PSQM submissions (resulting in a total of 30 submissions to be reviewed). Intervention case study schools will no longer be asked to provide additional documentation. Since control schools will now be included in the case study data collection, it was decided to request they provide some documentation that captures their science-related activities (as outlined above). While

acknowledging that these documents may not translate to a direct comparison to PSQM submissions, they should provide approximate information that the evaluation team can use to assess differences and similarities between control and intervention case study schools around science practice.

Examining continuity of Year 5 teachers

We would expect programme effects to be strongest for Year 5 pupils in those schools where Year 5 teachers trained in PSQM continue teaching the next Year 5 cohort (Cohort B). To examine this, we will descriptively compare programme outcomes for those schools where the same teachers are working in Year 5 in 2020/21. The information on continuity will be based on self-report by teacher in Year 2 of the trial as part of their surveys.

Update: Given that no outcome data will be collected the above analysis can no longer be conducted. However, as part of the June 2021 surveys, information on Year 5 teacher continuity will still be collected.

Compliance measure

To enable a non-compliance analysis, compliance will be defined at the school level, based on completion of programme activities, as recorded by the PSQM team. This will be specified in the Statistical Analysis Plan.

Update: Compliance information will still be collected and summarised in the final report as descriptive statistics, however, analyses using this data will be foregone as no outcome data will be collected.

Cost evaluation

Cost data will be gathered through online surveys, as well as through the interviews in the implementation and process evaluation (see above). Questions will be targeted at assessing any pre-requisite costs (such as training costs and materials) and any direct and marginal costs directly attributable to schools' participation in the intervention (printing, staff time, cover, etc.). We will use this information to estimate cost per-pupil, following EEF guidelines (EEF, 2015).

The main costs of the intervention relate to training, materials, and the time of teachers and subject leaders to complete the programme activities. To calculate the cost of training and materials the Evaluation Team rely on data provided by the Delivery Team. RAND will also take into account the cost of the time of hub leaders, headteachers, teachers and other staff in delivering the programme.

We acknowledge that in the RCT, schools in the intervention arm of the trial will have £1,500 paid toward these costs and a further £120 for travel time and will take this into account.

We will use the information on direct and indirect costs to estimate cost per-pupil, following EEF guidelines (EEF, 2018).

Update: Given the fact that there is no impact estimate and that costs would not be representative of 'usual' delivery practices, data on costs will not be collected. This also helps reduce data collection burden on schools.

Ethics and registration

The trial has been registered on the ISRCTN registry, which stands for 'International Standard Randomised Controlled Trial Number' and is used to describe RCTs and efficacy trials at inception. The trial has been assigned an ID registration number: ISRCTN50771738.

The ethics and registration processes are in accordance with the ethics policies adopted by RAND Europe. The evaluation is currently reviewed by RAND U.S. Human Subjects Protection Committee (HSPC).

Parents or legal guardians act as decision-makers for individual pupils. This is because the intervention

will be delivered during the school day, where schools act in loco parentis, and the intervention does not substantially differ from standard practice in schools. Prior to pupil data being sent to the Delivery Team, parents will be sent information and withdrawal forms by the school and have the opportunity to return these. The parental information sheets and withdrawal forms will be sent out to parents by the schools after the school representative sign the Memorandum of Understanding (MoU) describing what is involved in the trial. Parents can withdraw their children at any time from the research, but the initial withdrawal forms can be returned by parents within two weeks.

If participants choose to withdraw their children from the study later on, their data will not be collected or will be deleted, as appropriate (see Privacy Notice at http://redocuments.org/PSQM/Privacy_Notice_Parents.pdf).

RAND Europe will collect consent forms for school staff, governors and parents who will volunteer to participate in an interview. Furthermore, the cover page for each survey will contain a privacy notice for respondents. It will inform respondents that participation in the survey is entirely voluntary.

None of the Evaluation Team has any conflicts of interest and all members of the study team have approved this protocol prior to publication.

Data protection

RAND will obtain personal data from schools and pupils as data controller. Basic pupil information will be obtained on the basis of legitimate interests from schools pursuant to brief data sharing undertakings or agreements with each school recruited. RAND shall obtain pupil baseline and outcome data from its subcontractor (e.g., NFER), who will act as a processor pursuant to appropriate data sharing terms in it subcontract. Data obtained by NFER is expected to be on the basis of legitimate interests and pupils and parents shall be provided with age-appropriate fair processing privacy notices that explain the use, storage and secure handling of the data.

Data sharing agreements between the parties will outline in detail how and which data will be securely shared between them using the secure platform “Syncplicity”. Data will only be saved on General Data Protection Regulation (GDPR) compliant, secure servers inside the EEA or UK. All processes will be handled in accordance with RAND’s Data Protection Policy. RAND is registered with Information Commissioner’s Office (ICO), registration number Z6947026 and is certified for adhering to ISO 9001:2015 quality management practices. In order to stratify the sample and adequately evaluate the intervention as outlined in this proposal, it is necessary to process special categories of data, namely FSM status of pupils. RAND Europe considers this endeavour to fall under GDPR, Chapter 2, Article 9, Paragraphs 2d) and 2g).

Personnel

DELIVERY TEAM: PSQM (UNIVERSITY OF HERTFORDSHIRE)

Project Leader and PSQM Director: Associate Professor Jane Turner (University of Hertfordshire)

PSQM Deputy Director: Helen Sizer (University of Hertfordshire)

PSQM team: Claire Harman (University of Hertfordshire)

EVALUATION TEAM: RAND EUROPE

Overall Project & Evaluation Lead: Elena Rosa Brown (took over Dr Emma Disley in November 2019; previous project lead was Dr Alex Sutherland until June 2019) (RAND Europe).

Project Manager: Miriam Broeks (took over from Amelia Harshfield in March 2020; previous project manager was Dr Yulia Shenderovich until April 2019) (RAND Europe)

Core fieldwork and analysis team: Miriam Broeks, Sashka Dimova Amelia Harshfield (all RAND Europe)

Risks

Risk	Assessment	Mitigation strategy
Recruitment failure	Likelihood: Low Impact: High	Remain in dialogue with the PSQM Delivery Team over any recruitment issues. Provide letters for schools explaining the research process. Seek support from the EEF to encourage recruitment.
Attrition	Likelihood: Moderate Impact: Moderate to high	Clear information about expectations and requirements provided to participating schools. MoU to be signed with participating schools. Attrition to be monitored and reported according to CONSORT guidelines (Campbell et al., 2010). Schools in control group will receive a proportion of their payment for participating in the trial after outcomes testing has been completed in year one and the second amount at the end of year two. This is an incentive to remain in the trial.
Different rates of attrition from control and intervention groups	Likelihood: Low Impact: Moderate	There is a risk that schools in the intervention group may face an extra burden in terms of time and resources to deliver the programme. This can be mitigated by regular liaison with hub leaders and schools to secure continued engagement in the trial. There is a risk that control group schools may decide to withdraw from the trial because they wish to take part in PSQM and signed up to the trial in the hope they would be in the intervention group Schools would have agreed to the terms of the MoUs, which include the commitment for data to be collected at various stages.
Missing data	Likelihood: Moderate Impact: Moderate	To limit the amount of missing data screening, testing will happen in an extended period (approximately a month).
Pupil mobility	Likelihood: Moderate Impact: Low	Pupils who migrate to non-study schools will be excluded from the analysis as these pupils will be tested with external tests. In the event that mobility to non-study schools exceeds 10% on average across all schools, then the evaluators will discuss with the EEF the possibility of additional funding to collect this information.
Low implementation fidelity	Likelihood: Low to moderate Impact: Moderate	Process evaluation to monitor and document fidelity of implementation. Remain in dialogue with the PSQM Delivery Team on finding solutions.
Cross-contamination	Likelihood: Low Impact: High	Clear instructions will be provided to participants about the trial to avoid contamination.
Evaluation team members absence or turn-over	Likelihood: Moderate Impact: Low	All RAND staff have a three month notice period to allow sufficient time for handover. The team can be supplemented by researchers with experience in evaluation from the larger RAND Europe pool.
Low response rates for online surveys	Likelihood: Moderate Impact: Moderate	Online surveys to be kept to a maximum of 5-15 minutes long. Respondents given the opportunity to complete survey online on multiple occasions if required. Sufficient data collection window given with real-time monitoring of response rates to allow for reminders to be targeted. This may be a more significant problem in the control group. To address this, control schools will receive a payment of £1,500 on completion of the study.

Lack of coordination across the EEF (funders), RAND Europe (evaluators) and the PSQM team (delivery team)	Likelihood: Moderate Impact: Moderate	Teams to attend initial meetings and agree on roles and responsibilities at the outset. Regular updates to be provided to the lead evaluators. Regular contact between senior team from each organisation.
Further disruptions to trial activities due to COVID-19 (or alike) pandemic	Likelihood: Moderate Impact: High	A new outbreak of the COVID-19 pandemic could further delay evaluation activities. Teams will maintain regular contact to coordinate and decide on any strategies to mitigate potential risks to the evaluation plans.

Timeline

Dates	Activity	Staff responsible/ leading
October 2018	IDEA workshop	RAND Europe
January – April 2019	Recruiting schools and teachers	University of Hertfordshire
January – April 2019	Opt out forms to be sent to parents	Schools
March – May 2019	Collection of pupil information	Schools
May - June 2019	School and pupil information to be collected sent to RAND	University of Hertfordshire
May – June 2019	Randomisation	RAND Europe
September – October 2019	Baseline survey of headteachers all schools	RAND Europe
September 2020	Completion of Statistical Analysis Plan	RAND Europe
September 2019 – February 2021*	Programme implementation	University of Hertfordshire
February – April 2021*	Compilation of CPD attendance records, task completion and other intervention data for compliance measure/IPE	University of Hertfordshire
May-July 2021	Interviews in case study schools (teachers, subject leaders, headteachers) and documentary review	RAND Europe
May – June 2021	Surveys of headteachers, subject leaders, Year 5 teacher (all schools) and hub leaders	RAND Europe
30 November 2021	Draft EEF report	RAND Europe
April 2022	Final EEF report	RAND Europe

***These milestones were revised following trial adaptations due to COVID-19**

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