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Research article

"Thanks for helping me find my enthusiasm for physics": the lasting impacts "research in schools" projects can have on students, teachers, and schools

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Abstract. Using 6 years of evaluation data, we assess the medium- and long-term impacts upon a diverse range of students, teachers, and schools from participating in a programme of protracted university-mentored projects based on cutting-edge space science, astronomy, and particle physics research. After having completed their 6-month-long projects, the 14–18-year-old school students report having substantially increased in confidence relating to relevant scientific topics and methods as well as having developed numerous skills, outcomes which are corroborated by teachers. There is evidence that the projects helped increase students' aspirations towards physics, whereas science aspirations (generally high to begin with) were typically maintained or confirmed through their involvement. Longitudinal evaluation 3 years later has revealed that these projects have been lasting experiences for students which they have benefited from and drawn upon in their subsequent university education. Data on students' destinations suggest that their involvement in research projects has made them more likely to undertake physics and STEM degrees than would otherwise be expected. Cases of co-created novel physics research resulting from Physics Research in School Environments (PRiSE) has also seemed to have a powerful effect, not only on the student co-authors, but also participating students from other schools. Teachers have also been positively affected through participating, with the programme having influenced their own knowledge, skills, and pedagogy, as well as having advantageous effects felt across their wider schools. These impacts suggest that similar "research in schools" initiatives may have a role to play in aiding the increased uptake and diversity of physics and/or STEM in higher education as well as meaningfully enhancing the STEM environment within schools.

1 Introduction

Independent research projects provide extended opportunities for school students to lead and tackle open-ended scientific investigations, with so-called "research in schools" programmes, which have been emerging in recent years, being a subset of these linked to current academic (STEM) research (e.g. Colle et al., 2007; M. O. Archer, 2017; Sousa-Silva et al., 2018; IRIS, 2020). It has been realised recently that, in general, more extended programmes of STEM interventions with young people are required to be effective in having lasting impact upon them compared to typical "one-off" approaches (see the review of M. O. Archer et al., 2021, and references therein). Independent research projects and "research in schools", when appropriately developed and supported by expert mentors from universities or industry, thus potentially align with this direction.

Bennett et al. (2016, 2018) reviewed the evidence of impact from independent research project endeavours globally. They found that impacts on students were most often investigated, with various outcomes being reported including improved understanding, practical and transferable skills, or attitudes and aspirations towards science. Dunlop et al. (2019)

further suggest there is value in students participating in independent research projects through developing their understanding about scientific research/researchers and allowing them to make more informed decisions about their future subject choices. It appears at present though that only a few programmes consider the impact on students from underrepresented groups, presenting emerging evidence that increased engagement with science can result from their involvement (Bennett et al., 2016, 2018). Finally, the review highlights that evaluations exploring the potential long-term impacts of project work on students, such as subsequent subject or career choices, are currently lacking.

While some studies into independent research projects use views from teachers, these tend to little explore the impact on the teachers themselves from their own participation in projects (Bennett et al., 2016, 2018). This aspect has recently been considered by Rushton and Reiss (2019) for teachers engaged in projects with IRIS (2020). Through in-depth interviews with 17 research-active science teachers, they report that through the projects they felt reconnected with science or research and had developed as teachers, including in their pedagogy, skills development, and recognition by school colleagues.

In general, however, Bennett et al. (2016, 2018) note that with little detail on the assessment criteria for independent research projects being reported, further work is required to improve the quality of evidence and to more fully explore the potential long-term benefits of teachers' and students' (particularly those from underrepresented groups) involvement in independent research projects. This paper draws on 6 years' worth of evaluation data from the Physics Research in School Environments (PRiSE) programme of independent research projects to explore the possible impacts on participating students, teachers, and schools.

2 PRiSE

PRiSE is a scalable framework for independent research projects based on current physics research that are mentored by active researchers (M. O. Archer et al., 2021). The programme aims to equip 14–18-year-old school students (particularly those from disadvantaged backgrounds) with the ability, confidence, and skills in order to increase/sustain their aspirations towards physics or more broadly STEM, ultimately enabling them to realise these at higher education and thus contributing to increased uptake and diversity of physics and to some extent STEM (cf. L. Archer et al., 2020a). Through working with teachers, PRiSE also aims to develop their professional practice and build long-term university–school relationships that raise the profile of science and mitigate biases/stereotypes associated with physics within these schools, generally making them environments which nurture and enhance all students' science capital (cf. IOP, 2014).

PRiSE was developed at Queen Mary University of London (QMUL) in 2014, where the four projects summarised in Table 1 currently exist. These projects run for approximately 6 months from the start of the UK academic year in September to just before the spring/Easter break in March, culminating with students presenting their work at a special conference held on university campus. Students typically spend 1–2 h per week throughout working on the project in groups, usually outside of lesson time. Support from the university is provided through workshops, school visits, monthly webinars, printed/multimedia resources, and ad hoc emails as required. The provision within the programme is explored in more detail in M. O. Archer et al. (2021). PRiSE has engaged a much more diverse set of school students and significantly more disadvantaged groups than is typical. Furthermore it has been found that students' success within the programme appears independent of background, which has been attributed by teachers as due to the extraordinary level of support offered (M. O. Archer, 2021).

The evaluation of PRiSE's pilot, which ran from 2014 to 2016 and involved six schools, suggested that students' awareness of current scientific research, understanding of the scientific method, and skills were enhanced by the programme and that teachers benefited through reconnecting with their subject at an academic level, being challenged, and being supported in their professional development (M. O. Archer, 2017). The programme has grown significantly since then, having involved 67 London schools by 2020. This paper expands the evaluation of PRiSE's potential impacts.

3 Methods

To evaluate the impact of the PRiSE programme, questionnaires were distributed to students and their teachers at each year's student conference held approximately 6 months after they started their PRiSE projects. We were also able to contact a subset of individuals 3 years after their participation. No control groups were established due to ethical considerations, further explored in M. O. Archer et al. (2021), which slightly limits this impact study. However, where possible we draw from publicly available benchmark data.

3.1 Instruments

Paper questionnaires were handed out to students and teachers at our student conferences each year (apart from 2020, when this was done online due to the COVID-19 pandemic), which assessed the impact on students and teachers at this 6-month stage. There were two questionnaires for students. One of these was project-specific, relating to students' confidence in scientific topics/practices relevant to their specific project, i.e. those in Table 1. The other applied to PRiSE in general, asking students about skills development, aspirations, and other ways they may have been affected by their involvement. Teachers only completed a PRiSE-wide

Table 1. A summary of the existing PRiSE projects at QMUL.

Project	Abbreviation	Years	Field	Description
Scintillator Cosmic Ray Experiments into Atmospheric Muons	SCREAM	2014–2020	Cosmic rays	Scintillator–photomuliplier tube detector usage
Magnetospheric Undulations Sonified Incorporating Citizen Scientists	MUSICS	2015–2020	Magnetospheric physics	Listening to ultra-low frequency waves and analysing in audio software
Planet Hunting with Python	PHwP	2016–2020	Exoplanetary transits	Learning computer programming, applying this to NASA Kepler and TESS data
ATLAS Open Data	ATLAS	2017–2020	Particle physics	Interacting through online tool with LHC statistical data on particle collisions

questionnaire, which not only asked for their observations of impacts upon students, but also how involvement in the project has affected their own knowledge, skills, practice, and wider school environments. The questions posed to both students and teachers varied slightly from year to year and are found in Appendix A. The PRiSE-wide questionnaires also included feedback on participants' experience of the programme, with these data forming the focus of a separate paper (M. O. Archer et al., 2021).

These instruments were chosen in order to collect data from as wide a range of students and teachers as possible as well as to respect the limited time/resources of all involved (both on the school and university sides). All data gathered were anonymous, with students and teachers only indicating their school and which project they were involved with. We have further anonymised the data by using pseudonyms for the schools. More detailed information about the schools involved can be found in M. O. Archer (2021). No protected characteristics (such as gender or race) or sensitive information (such as socio-economic background) were recorded. Our ethics statement on the forms informed participants that the data were being collected for evaluation purposes to determine the programme's impact and that they could leave any question they felt uncomfortable answering blank (also true of the online form).

For longer-term evaluation, students were also asked on a separate paper form at our conference to share their personal email addresses so that we could follow up with them a few years later, in order to explore potential lasting impacts of the programme. As with the main questionnaires, this was presented as optional with an ethics statement and description of how their data would be used clearly presented. It was decided to contact cohorts of PRiSE students 3 years after they started the project for this follow-up, so that students would either be studying at university or at least (in the case of the youngest PRiSE students) making university applications, hence giving us insight into university destinations/plans. The students were emailed and asked to fill out an online form, detailed in Appendix B. The form contained primarily open-ended questions to enable us to understand PRiSE students' long-term attitudes to the programme, their higher education destinations, and what may have affected these decisions. These sorts of contextual data would not be available by simply obtaining destination data from services such as the Higher Education Access Tracker (HEAT, https://heat.ac.uk, last access: 20 July 2020) or requesting that schools provide it as a condition of their participation. Doing so would have also risked schools declining to participate. However, we do acknowledge that our approach reduces the number of responses that could realistically be collected.

3.2 Participants

Data were collected from 153 students (aged 14–18) and 45 teachers across 37 London schools. A breakdown of the number of responses per year and how many schools these responses came from is given in Table 2, where the total number of participants (and their schools) in attendance at our conferences are also indicated. We note that, due to the COVID-19 pandemic, the 2019/20 programme was disrupted, so we do not have reliable information on how many students, teachers, and schools would have successfully completed the programme that year. There is no indication that the respondents differed in any substantive way from the wider cohorts participating in the programme.

3.3 Analysis

Both qualitative and quantitative approaches were utilised in data analysis, as the open- and closed-ended questions in the surveys generated different types of data.

Table 2. Response rates to questionnaires at PRiSE student conferences.

		2015	2016	2017	2018	2019	2020
Students	Project-specific		13/26 (50 %)	30/70 (43 %)	45/92 (49 %)	40/97 (41 %)	
	PRiSE-wide		13/26 (50 %)	21/70 (30 %)	46/92 (50 %)	38/97 (39 %)	35/?
Teachers	PRiSE-wide	1/1 (100 %)	6/6 (100 %)	6/11 (55 %)	9/16 (56 %)	6/16 (38 %)	17/?
Schools		1/1 (100 %)	6/6 (100 %)	11/ 11 (100 %)	13/15 (87 %)	11/15 (73 %)	19/?

For all quantitative (numerical) data, uncertainties presented represent standard (i.e. 68 %) confidence intervals. For proportions/probabilities these are determined through the Clopper and Pearson (1934) method, a conservative estimate based on the exact expression for the binomial distribution, and therefore represent the expected variance due to counting statistics only. Several statistical hypothesis tests are used with effect sizes and two-tailed p values being quoted, with a statistically significant result being deemed as $p < 0.05$. In general we opt to use nonparametric tests as these are more conservative and suffer from fewer assumptions (e.g. normality, interval scaling) than their parametric equivalents such as t tests (Hollander and Wolfe, 1999; Gibbons and Chakraborti, 2011). When comparing unpaired samples a Wilcoxon rank-sum test is used, which tests whether one sample is stochastically greater than the other (often interpreted as a difference in medians). The Wilcoxon signed-rank test is used to compare both a single sample to a hypothetical value or data from paired samples to one another. Both versions test whether differences in the data are symmetric about zero in rank. Finally, for proportions we use a binomial test, an exact test based on the binomial distribution of whether a sample proportion is different from a hypothesized value (Howell, 2007). For ease of reference, further details about the quantitative analyses are incorporated into the relevant sections of the findings.

Thematic analysis (Braun and Clarke, 2006) was used to analyse the textual (qualitative) responses. Instead of using pre-determined qualitative codes to categorise the data, our analyses drew on a grounded theory approach (Robson, 2011; Silverman, 2010), letting the themes emerge from the data themselves. This process involved the following steps.

1. Familiarisation. Responses are read and initial thoughts noted.

2. Induction. Initial codes are generated based on review of the data.

3. Thematic review. Codes are used to generate broad themes (which we refer to as dimensions) and identify associated data.

4. Application. Codes are reviewed through application to the full dataset.

5. Reliability. Codes are applied to a subset of data by a second coder to check reliability.

6. Final coding. Final codes are applied to the data.

7. Analysis. A thematic overview of the data is confirmed, with examples chosen from the data to illustrate the themes (dimensions).

Overall there was 92 ± 2 % agreement between the two coders, which corresponds to a Cohen's kappa of 0.836 (Cohen's kappa is unity minus the ratio of observed disagreement to that expected by chance and hence ranges from 0 to 1, e.g. McHugh, 2012). Disagreements were resolved by discussion to arrive at the final coding presented in the paper. Our analyses examine the impact on students and teachers from schools which completed the programme, as it was not possible to gather evidence from schools which dropped out during the year. Future work could attempt to investigate this, subject to funding and ethical approval.

4 Impact on students

This first section of the findings examines the impact of PRiSE on students at the 6-month (captured at our student conferences) and 3-year (captured online) stages. Impact on students through the co-production of research is also briefly discussed.

4.1 6-month stage evaluation

We assess the impact on students in three broad areas related to the aims of the programme: their confidence in scientific topics and methods; their skill sets; and their aspirations towards pursuing physics or STEM.

4.1.1 Confidence

At our conferences from 2016 to 2019 students ($n = 127$) were asked to rate their confidence (using a six-point Likert scale) in topics and practices relevant to their projects (see Table 3). Additionally they were asked to retrospectively assess their confidence before having undertaken the project. Given that the options varied by project, this was performed on separate paper questionnaires to the more general PRiSE-wide questionnaire that applied to all projects; however, the

same level of anonymity and ethical considerations were afforded to students here too. While for a subset of students M. O. Archer (2017) also surveyed students before undertaking projects, we opted not to continue this. This is firstly because surveys taken on different days necessarily include natural intraindividual variability (Eid and Diener, 1999), which cannot be separated out from any real stable change with only two survey points. Secondly, a retrospective assessment following the project also means that an apparent decrease in confidence, known as the Kruger and Dunning (1999) effect, is avoided because prior to the interventions confidence may have been artificially high as individuals are not aware of what they do not know. Given that many other repeated STEM intervention programmes have resulted in no overall changes from before to after (e.g. Jeavans and Jenkins, 2017; Hope-Stone Research, 2018), we set the benchmark to be a statistically significant positive change.

We test the paired before and after data for each topic and practice, omitting any where students listed either as unsure, using a Wilcoxon signed-rank test. The results show statistically significant increases for all the topics and practices, with the range of two-tailed z scores by project listed in square brackets in Fig. 1 ($z \geq 1.96$ corresponds to 95 % confidence or more). To give an overall measure of these changes, we take an average for each student across all topics and practices (again omitting unsures as before), and these are plotted in Fig. 1 showing 96 ± 2 % of students have increased in confidence. The median overall change across all projects was 0.92 ± 0.04 points, indicated as the black bar in Fig. 1 along with interquartile range (grey area), whereas the mean was slightly higher at 1.08 ± 0.06 due to a positive skewness (the uncertainty refers to the standard error in the mean). The overall results show positive changes across all projects to a high level of confidence, as indicated in the figure, with no real variation in results between the different projects or between schools. Therefore, students' confidence in scientific topics and methods seems to have substantially increased as a result of PRiSE, and almost all students reported this benefit. This gain in confidence has also been noted in teachers' comments:

> They have become more confident in communicating their ideas and realised that they are not too young to do research. (Teacher 1, Hogwarts, SCREAM 2015)

> This has been a challenging experience for the students taking part. Students have gained a better appreciation of real science and built confidence. (Teacher 3, Xavier's Institute for Higher Learning, MUSICS 2016)

4.1.2 Skills

From 2016 onwards we asked students ($n = 140$) to list which skills, if any, they felt they had developed through their PRiSE project. Teachers ($n = 40$) were also asked to indicate their observations on skills that their students had developed during the programme. We extracted keywords from any prose responses and sifted through the data performing keyword clustering. This latter step involved identifying synonymous skills and relabelling them so there was a consistency of terminology throughout. This processing resulted in a dataset of 79 unique skills. Students tended to identify on average around two distinct skills each, whereas teachers typically listed three, though the responses per person ranged up to five and six respectively. Figure 2 shows the skills identified as a word cloud, where students and teachers have been given equal weight by normalising their counts by their respective totals. Colours indicate from whom the words originated, showing a large amount of agreement between the two groups. All the skills listed are highly relevant to being a scientist, with the most cited being (in descending order) teamwork, research, data analysis, programming, and presentation skills. These results remain fairly consistent with those from the pilot and arguably indicate areas where university/research physics differ substantially from the regular school experience. Skills development was not mentioned in any of the PRiSE projects' resources (e.g. there was no list of "skills to be developed"), so we are confident in the validity of these results, though we cannot rule out that teachers may have influenced students' answers. Therefore, through experiencing and being involved in research-level physics, it seems likely students have gained new, or further developed existing, skills, constituting a positive impact upon them. This has been further expanded upon in the teacher feedback:

> They have developed presenting skills, they do get that [at school] but not for academic poster sessions. The unique skills from the project were the exposure to the physics, analysis, independence; it has allowed them to access the world. (Teacher 1, Hogwarts, SCREAM 2015)

> Challenging opportunity [for students] to broaden skills and experience. (Teacher 23, Smeltings, ATLAS 2019)

> Great for developing pupil research skills and getting confident in cross referencing scientific articles, a very important skill for them in post-college education. (Teacher 42, Hill Valley High School, ATLAS 2020)

4.1.3 Aspirations

To assess whether students' aspirations were affected at the 6-month stage, we first undertook a qualitative analysis in 2018–2019 asking in an open question how students' thoughts about future subject choices or careers might have been affected through doing the project. A thematic analysis of the 63 responses revealed three distinct dimensions,

Table 3. The scientific topics and practices used in assessing students' confidence.

Topics				Practices
SCREAM	MUSICS	PHwP	ATLAS	
Neutrinos	Plasma	Planets	Fundamental Particles	Mathematical Models
Muons	Magnetic Fields	Stars	Fundamental Forces	Experiment Design
Cosmic Rays	Space	Gravity	Particle Detectors	Calibration (SCREAM)
Particle Detectors	Magnetosphere	Exoplanet Detection	Particle Interactions	Statistical Analysis
Anti-particles	Waves			Error Analysis
Special Relativity	Resonance			Drawing Conclusions
				Collaborating
				Presenting
				Writing
				Reviewing Literature
				Programming (PHwP)

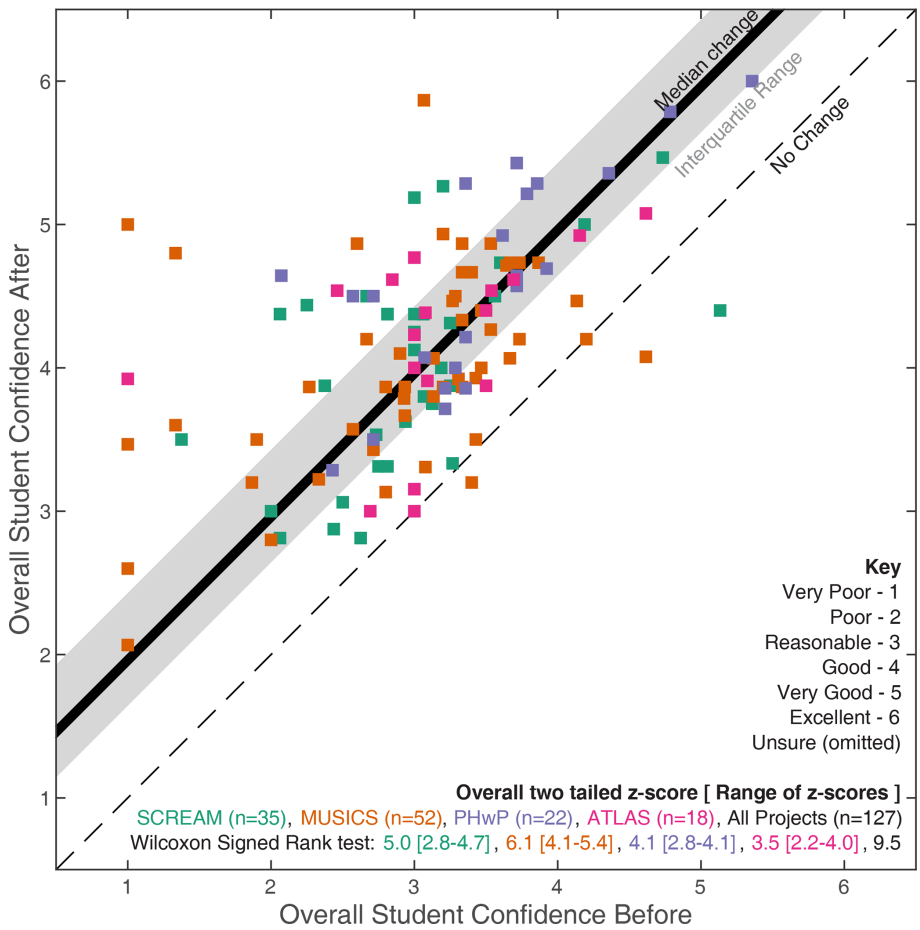

Figure 1. Overall student confidence in relevant scientific topics/methods before and after taking part in PRiSE ($n = 127$). Data points are coloured by project. Overall changes are also indicated through the interquartile range (grey area) and standard confidence interval in median (black bar). Overall and ranges of z scores in two-tailed Wilcoxon signed-rank tests are also listed by project.

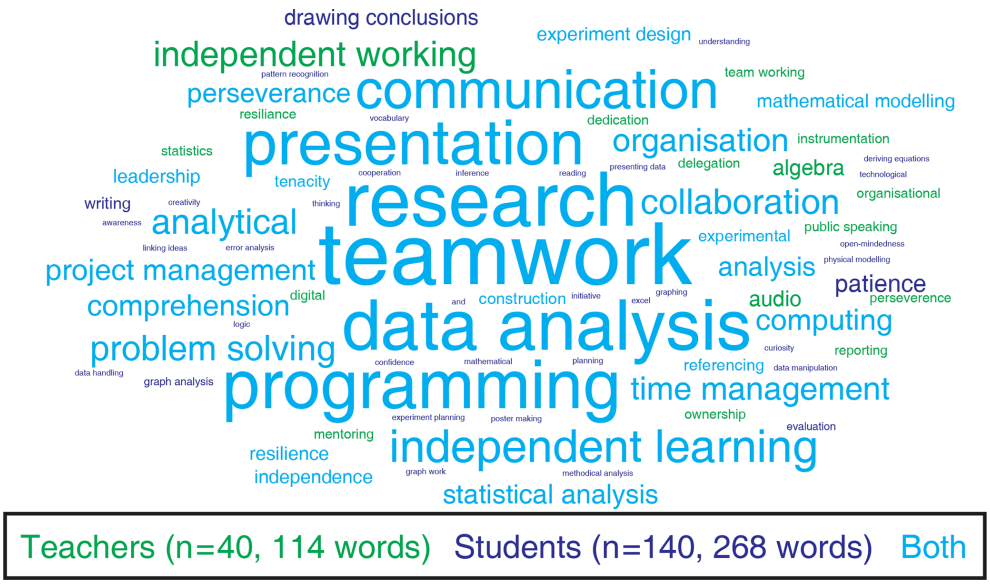

Figure 2. Word cloud of skills developed by students. Colours indicate words identified by students (blue), teachers (green), or both (cyan). Students and teachers have been given equal total weight.

each with their own set of underlying codes. The first of these concerned how much the students felt that they had wanted to study either physics or a STEM subject before even undertaking the project ($n = 22$), which tended to be raised if they already wanted to pursue this route or if they were not interested in these subjects. The second dimension covers the students' aspirations following the project ($n = 13$), revealing that students were either now wanting to pursue physics/STEM, were considering these as potential options, or were simply unsure. Finally, the third dimension was an expression of change as a result of their involvement in PRiSE ($n = 22$), which typically stated that it had confirmed their subject choice, made them more likely to pursue physics/STEM, had not affected them, or (in a small number of cases) had deterred them from continuing with physics/STEM. These themes align with the findings of Dunlop et al. (2019) on how independent research projects can affect students' aspirations.

We show the dimensions and codes in Table 4, also giving counts of the number of responses which fall within them (cf. Sandelowski, 2001; Sandelowski et al., 2009; Maxwell, 2010). We note that some students' responses covered more than one of the dimensions, but none spanned all three. Out of the 63 responses to this question, 11 did not fit into any of these three dimensions, instead highlighting aspects of the programme they enjoyed (research, teamwork, real applications of physics, and what physics at university is like) but not explicitly stating their subject aspirations or how they may have been changed by the project. From these counts, it is clear that in both dimensions 2 and 3 the totals indicating positive effects from PRiSE are greater than the neutral or negative responses. However, given that these numbers are rather small and derived from a qualitative coding, we do not attempt to make a statistical interpretation of the impact of PRiSE on students' physics/STEM aspirations based on them.

Instead, informed by these promising preliminary results, we implemented in 2020 a quantitative approach to assessing how PRiSE may have affected students' aspirations. In a similar manner and with similar justification to our evaluation of students' confidence, we asked students ($n = 35$) to assess their likelihood (using a five-point Likert scale) of continuing with physics and STEM as well as retrospectively assessing these from before the project. We shall call this the "absolute scale", since it pertains to students' absolute likelihood of continuing these subjects, and code it to values of 1–5 as shown in Fig. 3a–b. In addition, we asked how working on the project affected their thoughts on physics and STEM as future subject choices using a different five-point scale, where the wording of the options used was informed by the previous qualitative results in Table 4. We refer to this as the "relative scale", since it concerns whether the students feel their thoughts changed as a result of PRiSE, and code it to values from -2 to $+2$, as shown in Fig. 3c. One student only answered these questions relating to physics but not for STEM.

When considering physics aspirations, there was no clear positive bias towards the subject beforehand (see horizontal distribution in Fig. 3a), with a mean value on the absolute scale of 3.23 ± 0.21 ($p = 0.264$ in a one-sample Wilcoxon signed-rank test against a null hypothesis of 3). The vertical distribution shows some shift towards greater values on the absolute scale after the projects, now exhibiting overall positive results (mean of 3.69 ± 0.20, $p = 0.006$). From the

Table 4. Qualitative coding of students' responses concerning their future aspirations along with counts ($n = 52$ of 63).

Dimension 1: likeliness of wanting to study physics/STEM before the project				
Codes	Wanted to already	Unrelated to future choices		
Count	16	6		
Dimension 2: likeliness of wanting to study physics/STEM after doing project				
Codes	Now wants to	Now considering as option	Unsure on future choices	
Count	4	3	6	
Dimension 3: change in likeliness of wanting to study physics/STEM due to project				
Codes	Confirmed as subject choice	More likely	Didn't change mind	Deterred
Count	6	6	8	2

paired data, $40 \pm 10\,\%$ of students increased in likelihood of studying physics on the absolute scale (though no students who were very unlikely before showed any increase), and only one student's likelihood decreased (to a neutral stance), with the mean change being $+0.46 \pm 0.12$. While this indicates only moderate changes in students' absolute physics aspirations, they are statistically significant ($p = 8 \times 10^{-4}$ in a Wilcoxon signed-rank test). On the relative scale displayed in the top panel of Fig. 3c, however, $69 \pm 9\,\%$ of students report that the projects either made them more likely to continue with physics or confirmed it, with again only one student becoming less likely to pursue physics. The average was $+0.89 \pm 0.13$, greater than zero with high confidence ($p = 2 \times 10^{-5}$). No trends were present by project or school. Since we colour the data points in Fig. 3a based on the students' responses on the relative scale (panel c), it is clear that most of the students whose absolute physics aspirations increased attribute this in some way to PRiSE, while around half of those whose aspirations did not increase on the absolute scale still claim positive influence by PRiSE.

Students' STEM aspirations, unlike physics, were already incredibly high before the projects as shown in Fig. 3b, with a mean value on the absolute scale of 4.53 ± 0.14. Because of this, a large proportion ($67 \pm 9\,\%$) of students would be unable to increase in value on the absolute scale due to already giving the highest rating. No students decreased in likelihood on the absolute scale and only 6 students out of the 34 increased, though this constituted around half of the students who could possibly increase (gave a 4 or below beforehand). This slight change in the paired data (average $+0.18 \pm 0.07$ across all students) was still statistically significant ($p = 0.031$). The bottom panel of Fig. 3c reveals a bimodal distribution on the relative scale of whether PRiSE affected students' STEM aspirations, with the largest peak at $+2$ (it confirmed their subject choice) and a smaller one at 0 (no change). No students reported being less likely to pursue STEM due to PRiSE; $68 \pm 9\,\%$ of students indicated PRiSE's likely positive influence on their STEM aspirations (a result similar to physics aspirations), with the mean being 1.15 ± 0.15, which is again a clear positive result ($p = 1 \times 10^{-5}$). As before there was no real variation in these results by project or school. All students who increased on the absolute scale attribute this to PRiSE, whereas a majority who did not change still indicate PRiSE had a positive effect on their STEM aspirations.

Ideally one would benchmark the likelihoods before PRiSE against larger surveys of similarly aged students' aspirations to test whether PRiSE students were more likely to continue with physics/STEM anyway. Unfortunately, direct comparisons are not possible due to the differing ways the relevant questions have been structured across national surveys. However, such research has shown that STEM degree aspirations amongst all students remain similar to the makeup of STEM vs. non-STEM A-Level subject choices, implying that almost all students studying at least one STEM A-Level likely aspire towards a STEM degree (Hamlyn et al., 2020). Furthermore, science aspirations are highly correlated with "science capital" and begin to form at an early age (Moote et al., 2020). Therefore, it is not surprising that PRiSE students' likelihood of wanting to continue with STEM was high beforehand.

The follow-up qualitative question, asking students to explain how or why their thoughts about subject choices had been affected by the project, typically mentioned how their interest, enjoyment, or understanding had been enhanced, e.g.:

> Before working on Planet Hunting With Python, I was already quite focused on studying in a STEM field, and the main reason I signed up for the project was because of my interest in physics. After the project, I felt as though my decision to pursue such an area was only further cemented. (Student 120, Octavian Country Day School, PHwP 2020)

The one student who reported being less likely to pursue physics (but was not affected with regards to STEM) noted that

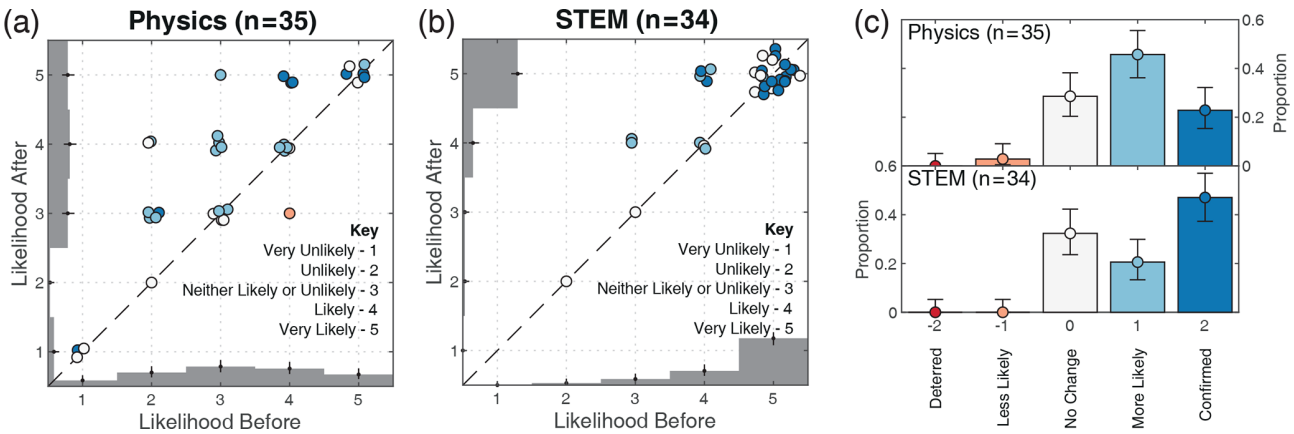

Figure 3. Likelihood before and after of PRiSE students continuing with **(a)** physics and **(b)** STEM education. Data points have been jittered for visibility. Marginal distributions (grey areas) are also shown for both before and after. How PRiSE specifically has affected students' aspirations is shown in **(c)** for physics (top) and STEM (bottom), where the colours used are also reflected in **(a)** and **(b)**. Error bars denote the standard (1σ) Clopper and Pearson (1934) interval.

> I already had my mind set on doing STEM subjects at university, but now I am less interested in physics as I have come to see how some areas are more challenging than others and I wouldn't want to specialise in those areas. (Student 136, Jedi Academy, ATLAS 2020)

In light of this response, arguably the project enabled this student to make a more informed decision (cf. Dunlop et al., 2019) rather than necessarily causing harm. Some students raised the idea of their science identity affecting their likelihood beforehand, a known key factor in students' aspirations (e.g. L. Archer et al., 2013, 2020b), with PRiSE showing mixed results in affecting this:

> I never really saw Physics as a choice for me, as I did not want to do it, and the project hasn't changed my mind about this. (Student 133, Imperial Academy, ATLAS 2020)

> I am not very great at physics but this project made me more interested and invested. (Student 135, Xavier's Institute for Higher Learning, SCREAM 2020)

Another theme that emerged in response to this question was that PRiSE added something not usually accessible to them in school, the research, which helped cement students' subject choices and potentially influenced their career aspirations (cf. L. Archer et al., 2020a):

> Because I've always wanted to go into research and this project showed me that I enjoy it. (Student 138, Jedi Academy, ATLAS 2020)

> I've always assumed that I would work towards studying physics since GCSE; this project was very useful in seeing what research may be like if I took that path after education. (Student 143, Sunnydale High School, MUSICS 2020)

> I was always interested in maths and physics, especially maths. However this project showed me what we do not do in physics lessons, the research. For me this is one of the most important things in physics. (Student 145, Sunnydale High School, MUSICS 2020)

Students' aspirations have been found to be extremely resilient and very difficult to change, with most (even protracted series of) interventions yielding no statistically significant overall effects (L. Archer et al., 2013, 2014; M. O. Archer et al., 2021). With this in mind, the moderate increase in physics and the slight positive change in STEM absolute aspirations are considerable compared to the sector and what is realistically achievable with the resources afforded. The relative scale indicates that students feel that PRiSE has influenced their subject choices, typically either confirming or making them more likely to follow either physics or STEM, with 80 ± 8 % of students indicating a positive effect in either or both.

4.2 3-year stage evaluation

To date we have undertaken long-term evaluation for three cohorts of PRiSE students who had participated in the academic years 2015/16 (cohort 1), 2016/17 (cohort 2), and 2017/18 (cohort 3). At our student conferences 72 students from these three cohorts left contact details with us for this purpose, which were well spread across the different schools involved. Across the three cohorts, the bounce rate was 46 ± 7 % (predominantly due to now inactive school email addresses being given) and the emails were opened by 24 PRiSE students (a rate of 62 ± 9 % from non-bouncing

emails, again well spread across different schools), with 14 filling out the survey though we purposely cannot identify individuals from responses. While this is a relatively small number of responses, longitudinal evaluation is notoriously difficult for under-resourced engagement programmes (e.g. M. O. Archer et al., 2021), and there are still significant and useful results from the data, which we present in this section. The evaluation covers the perceived legacy of PRiSE for these students as well as the students' higher education destinations and the factors which may have affected these.

4.2.1 Legacy

Most of the 14 PRiSE students who responded were aged 16–17 when they undertook their projects, with two students aged 15–16 and one student each in the ranges 14–15 and 17–18. All of them remembered undertaking a physics research project with the university. When asked what experiences they remembered from the project, the 11 open responses provided (three students did not answer this or the following question) could be categorised as concerning the underlying science.

> [It] helped us to really solidify our understanding of harmonics. (Student 2, cohort 1)
>
> Learning about how the magnetosphere works and its importance. (Student 8, cohort 2)
>
> [I] learned about exoplanets. (Student 14, cohort 3)

The process of undertaking university/research style work

> It was very intriguing to have played with actual data and have an attempt at analysing the sound wave forms that we were given. (Student 2, cohort 1)
>
> Setting up the experiments and working through problems as they arose. (Student 7, cohort 2)
>
> Working with other students on a project we did not know much about before and presenting it in front of a lot of people. (Student 11, cohort 3)
>
> Creating a formula to use in order to calculate [the] surface area of a scintillator which is hit directly by muons, [and] observing building schematics to find how much matter muons pass through during travel into [the] building. (Student 12, cohort 3)
>
> I remember getting to experience some more advanced practical physics that was more reminiscent of university lab work than school lab work. (Student 13, cohort 3)

The skills they developed through their involvement

> [I] learned how to analyse sound in audacity. (Student 5, cohort 2)
>
> I built good teamworking and project management skills (Student 11, cohort 3)
>
> Learning to code in Python. (Student 14, cohort 3)

As well as having enjoyed the overall experience

> having a great time and meeting some lovely people (Student 13, cohort 3)

When asked how they have used the experiences since, if at all, of the same 11 respondents all bar 2 provided examples. These concerned their skill development

> [It] really helped to develop our teamwork skills, which I have used frequently in most things that I do in my academic education. Also there is a huge element problem-solving and how to undertake the project/study is fundamental in my Engineering degree for electronics, I have used it a lot. (Student 2, cohort 1)
>
> Now I [have] used python in my computational physics module at university. (Student 3, cohort 1)
>
> I am currently at university doing many group projects. Taking part in the Queen Mary magnetosphere project has helped me improve my team building and communication skills. (Student 8, cohort 2)
>
> The presentation helped me improve my public speaking and speaking confidence. (Student 13, cohort 3)

As well as activities they have done since

> It was a good introduction to conducting experiments. I carried out a CREST gold research project after this experience. (Student 7, cohort 2)
>
> I've tried to be confident to defend a project in front of people and to show an inquisitive attitude. (Student 11, cohort 3)
>
> I now study architecture, so the observing building schematics and 3D mathematics were both useful experiences. (Student 12, cohort 3)
>
> The lab work was useful as it gave me an idea of how to work in a uni lab, which is particularly helpful now that I am at uni. (Student 13, cohort 3)

Of the two negative responses, both stating "I haven't", one caveated though that "but that's just because I haven't had to do a group project since" (Student 9, cohort 3). Overall, students' responses suggest that their PRiSE projects were lasting and beneficial experiences that they have been able to draw from in their subsequent educational activities and development.

4.2.2 Destinations

All the PRiSE students reported that they were studying at university when the survey was conducted, apart from one who due to their age (they were 14–15 when involved in PRiSE) intended to. We asked the students what subject they were studying at university (or planned to study in the case of the one student), giving the options of physics (or a combination including physics), another STEM subject, or a non-STEM degree. The results of this are shown in blue in Fig. 4, where we compare these to the degree destinations of physics A-Level students nationally (McWhinnie, 2012) in orange (these data only include students that went on to higher education). The 7 out of 14 PRiSE students going on to study a physics degree is considerably higher than the national rate of 9.7 % ($p = 1 \times 10^{-4}$ in a binomial test). While the number of students going on to study other STEM subjects (6 out of 14) is consistent with the national statistics, the increased uptake of physics leads to the overall STEM-degree proportion (13 out of 14) also being significantly greater than found nationally (59.3 %, $p = 0.012$). Given the diversity of schools involved (discussed in-depth in M. O. Archer, 2021) and the known barriers to STEM higher education for underrepresented groups (e.g. Campaign for Science and Engineering, 2014; Hamlyn et al., 2020), it is highly unlikely that these results can be explained simply by PRiSE schools tending to produce more physics and STEM students anyway. Another consideration may be that PRiSE students were already highly likely to continue their physics education beforehand anyway. While this did not appear to be the case for the 2019/20 cohort discussed in Sect. 4.1.3, with it being shown that PRiSE led to some increased physics and STEM aspirations, the destination results here came from different cohorts, so this remains a possibility. However, given that PRiSE has been a consistent framework (both in terms of schools targeting and delivery) throughout, it is reasonable to assume that the 2019/20 cohort is representative of the others used here and thus may be used as comparable samples. This then suggests that students' involvement in PRiSE may very well make them more likely to pursue physics and STEM degrees.

The students' reasons behind choosing their degree subjects and what influenced them varied. We note that 1 student out of the 12 that responded to these questions referenced the research project (which was not prompted in the question).

> I did the sounds of space project that you organised a couple of years ago and am now pursuing a physics degree from Cambridge. Thanks for helping me find my enthusiasm for physics! (Student 4, cohort 1)

However, in general the responses were quite brief and did not give much insight into the likely many factors which may have played a role in their subject choices (cf. L. Archer et al., 2013, 2020b). While for cohorts 2 and 3 we added questions that explicitly asked about PRiSE's influence on the students' degree choices, the small number of responses and brief answers simply highlight the need for more in-depth qualitative longitudinal evaluation, though this is challenging to undertake. We note that there is little research into engagement programmes' effectiveness at influencing students' destinations, both correlative and causal, as raised in a recent review (Robinson and Salvestrini, 2020). However, given that PRiSE shows some statistically significant positive effects on students' aspirations, which are known to be highly resilient, at the 6-month stage as well as PRiSE students being more likely to study physics and STEM degrees than would otherwise be expected (further statistically significant effects), the results of this empirical enquiry into PRiSE's potential effect on students' destinations are perhaps promising.

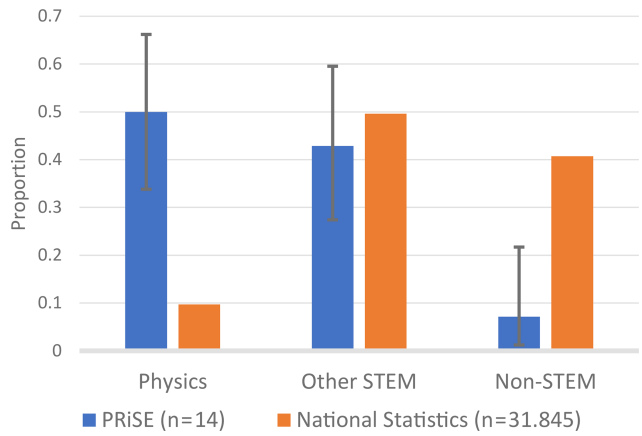

Figure 4. Degree destinations of PRiSE students (blue) compared to UK national statistics of A-Level physics students (orange). Error bars denote the standard (1σ) Clopper and Pearson (1934) intervals.

4.3 Co-production of research

Co-producing publishable physics research between researchers and school students is not an explicit aim of PRiSE, unlike for instance the more researcher-driven ORBYTS programme (Sousa-Silva et al., 2018). The rationale behind this is explored further in M. O. Archer et al. (2021). Nonetheless, in a few instances genuinely novel preliminary results have come from students' independently motivated work on the MUSICS project (the other PRiSE projects are unlikely to result in publishable physics research). The first of these originated from the 2016/17 cohort, where a group from a girls' school in an area of particularly high deprivation discovered a series of decreasing-pitch "whistle" sounds which lasted several seconds (corresponding to 5 d in reality). Through collaboration with the students and further investigation by professional scientists, it was discovered that these unexpected sounds corresponded to the natural oscillations of Earth's magnetic field lines following a solar storm. Such wave events had been deemed rare previously but, due to the

accessibility of exploring the sonified data, were found to in fact be quite common thanks to the students' discovery. The work was presented at several international scientific conferences and eventually published in the journal *Space Weather* with the students and their teacher listed as co-authors (M. O. Archer et al., 2018). Information about these developments resulting from the students' project work was continually passed on via their teacher, who in turn responded with the students' comments:

> It was a very rewarding experience which allowed us an insight into the research conducted at university level. This helped us to develop crucial skills needed in the next years of our studies. It was truly amazing to hear how significant the event we found was and that it will be forming the basis of a proper scientific paper.
>
> Being a part of the university's research and the subsequent paper published is truly an amazing opportunity. It was really interesting to find such a significant event and we gained so much experience and developed many skills during our research that will be useful in our university careers.

The publication garnered widespread media attention, for example featuring on BBC Radio 4's "Inside Science". Unfortunately we were unable to find out how the news of the publication had been shared across the school involved and affected other students' thoughts about physics. However, through publicising the result across all schools involved in PRiSE via teachers, it appears to have had a powerful effect on PRiSE students at other schools:

> Hearing that other kids at other schools have actually produced a paper, it just gives you hope that it's actually something I can do. (Student, mixed state school in area of particularly high deprivation, MUSICS, BBC Radio 4 interview, October 2018)

This potentially highlights through demonstration by their peers that (research-level) physics is something which is accessible to "people like me", thereby breaking down known barriers to participation in physics and science generally.

While no other publications have resulted as of yet, a group of students (from a selective boys' academy) in 2018/19 identified undocumented instrumental noise present in the data which researchers and satellite operators were unaware of. Another group (from a non-selective mixed academy with particularly high free school meal percentages and in an area of particularly high deprivation) in 2019/20 decided to investigate the relationship between the recently discovered aurora-like STEVE (strong thermal emission velocity enhancement) phenomenon (MacDonald et al., 2018) and magnetospheric ULF waves, finding some differences in wave activity during published STEVE events to typical levels, which might lead to promising results with significant additional work. Finally, two more groups in 2019/20 (a non-selective mixed academy and a partnership between an independent girls' school and three mixed state schools, one with particularly high free school meal percentages and in an area of particularly high deprivation) working on a follow-up campaign to the previous students' co-authored paper uncovered other wave events during solar storms with novel features that are currently being investigated further by professional scientists and may be publishable in the future.

5 Impact on teachers and schools

Possible impacts upon teachers and schools from PRiSE were first explored using qualitative responses to open-ended questions and then further investigated with quantitative data gathered in 2019–2020.

5.1 Thematic analysis

From a thematic analysis of all the qualitative data from open-ended questions collected across 4 years (2015–2018) from 21 teachers, we identified eight distinct areas (indicated in italics) in which teachers and schools seem to have been positively affected by their involvement in PRiSE. These codes have subsequently been applied to responses across all years of data (2015–2020, 45 teachers). Expressions of negative impact were rare, with only one teacher (Teacher 15, Tree Hill High School, MUSICS 2018) noting that the project had caused them "a small amount of extra stress"; nonetheless, this teacher continued to engage with the programme in subsequent years. The first theme identified related to teachers *gaining new physics knowledge* based around the content of the projects:

> [It] added to [my] knowledge of standing waves giving more real-life examples of waves. (Teacher 8, Coal Hill School, MUSICS 2017)
>
> [It] introduced me to an area of physics where I have little experience. I have yet to teach the particles side of A-level physics. However, this project and the knowledge accumulated will be valuable when I do. (Teacher 20, Hogwarts, SCREAM 2018)

In turn, this has made them *more confident in discussing research* with students in general:

> [It has] given me confidence to explore physics beyond my areas of expertise/beyond the school specs. (Teacher 15, Spence Academy for Young Ladies, MUSICS 2018)
>
> It has re-ignited my interest in current research, and reminded me that complicated, cutting edge research can be more accessible than I sometimes

> think! (Teacher 36, Starfleet Academy, MUSICS 2020)
>
> [I have] re-engaged with research and research methods. (Teacher 41, Xavier's Institute for Higher Learning, SCREAM 2020)

Elements of the research projects have also been *implemented or referred to in teachers' regular lessons*:

> [I have been] able to use the detector with classes when teaching Year 12 particles. (Teacher 13, St Trinians, SCREAM 2016)
>
> It has been referred to [in lessons] in terms of what scientists do and the research process. (Teacher 15, Spence Academy for Young Ladies, MUSICS 2018)
>
> [It has given me] context when talking about Earth's magnetic field [in lessons]. (Teacher 16, Tree Hill High School, MUSICS 2018)
>
> It has consolidated my understanding and teaching of exoplanets. I used some of the techniques in teaching detection of exoplanets in the astro topic of AQA's A-level going beyond the syllabus. (Teacher 19, Boston Bay College, PHwP 2018)

Another theme concerned teachers gaining *confidence in mentoring and/or supporting extra curricular activities*, such as developing their "patience" [and] "encouragement" (Teacher 6, Hogwarts, SCREAM 2016):

> [I have developed in] motivating students to attempt challenging problems. (Teacher 11, Prufrock Preparatory School , SCREAM 2017)

They also report developing a *variety of other skills* including algebra, data analysis, reviewing academic posters, using software such as Audacity and Excel, and computer programming:

> I have also enjoyed the personal challenge to my own coding abilities. (Teacher 39, Bending State College, PHwP 2020)

Students' project work has been shared across the schools such as via assemblies, displaying students' posters in classrooms or halls within the school, and publishing news stories on the school's website or in local papers (references not included so as to preserve the anonymity of schools, teachers, and students). We note though that this was communicated to us informally either via email or during subsequent school visits rather than through the paper questionnaire. Nonetheless it seemed of sufficient note to include as a theme. Following on from this, some teachers report in the survey that their school's involvement with the project has *raised the profile of physics or STEM within their school*:

> [Students in lessons] were impressed to hear of our 'muon project' and knowing we were involved with a university physics department helped them engage with us. If they think they and their teachers can be involved in research they are more motivated. (Teacher 1, Hogwarts, SCREAM 2015)
>
> [It] gave prestige to the Physics department at the college. (Teacher 9, Xavier's Institute for Higher Learning, MUSICS 2017)

Finally, some teachers feel that they and their schools have *developed a relationship with the university*:

> [It] created a link to HE. (Teacher 15, Spence Academy for Young Ladies, MUSICS 2018)
>
> We feel involved in a very interesting [research] project. (Teacher 27, Hogwarts, SCREAM 2019)

This is further backed up by the significant repeated buy-in of teachers and schools after completing the project, with 70 ± 10 % returning for multiple years of PRiSE projects, further explored in M. O. Archer (2021), thereby changing how they interact with universities (e.g. not just attending one-off events) and solidifying the above-mentioned impacts:

> I am more confident in my second year. (Teacher 21, Hogwarts, SCREAM 2018)
>
> Now I've done one project I feel better equipped to get things going myself. (Teacher 39, Bending State College, PHwP 2020)

We use these eight areas of impact on teachers and schools for subsequent quantitative analysis in the next section. However, we note with further teacher survey responses in 2019–2020 that we have identified an additional theme. This pertains to *teachers' preconceptions of their students' ability*:

> I am now more aware of what our students are capable of – not just listening to visiting speakers but being actively engaged in real-world research! (Teacher 10, Prufrock Preparatory School, SCREAM 2017)
>
> [It has] made me more enthusiastic to engage students in real research. (Teacher 17, Sunnydale High School, MUSICS 2018)
>
> The project allowed me to identify students that were genuinely interested and committed to Physics. It also gave me evidence that my students should study science further at university. I was able to pass this on to parents and universities. (Teacher 31, Quirm College for Young Ladies [and partner schools], MUSICS 2020)
>
> It has been inspiring to see my students self-organising so well together. (Teacher 43, Sunnydale High School, MUSICS 2020)

5.2 Quantitative analysis

Based on the areas of impact on teachers and schools emerging from the qualitative data (from 2015 to 2018), from 2019 onwards we sought to quantitatively assess how prevalent they might be. Teachers ($n = 23$) were asked to identify for each of the eight themes whether they felt that they (or their school) had been affected by the project in that area, using the closed options of "I have", "I will eventually", "I have not", and "Unsure". This scale was chosen over a five-point Likert due to an expected low level of responses. We exclude any blank or unsure answers (which were rare) and divide the remaining 172 responses across the eight themes into negatives ("I have not") and positives, with the latter being subdivided into planned ("I will") and definite ("I have") impacts. We acknowledge that some may consider the "I will" response to be neutral, and thus our analysis takes both interpretations into account.

Figure 5a shows the distributions of these results for each impact area along with the overall results obtained from totalling all responses. We find that all areas, apart from mentoring ($p = 0.115$), have statistically significant positive majorities in binomial tests ($p < 0.03$). Only learning new physics and developing a relationship with QMUL have majority definite responses ($p < 0.011$). Coding the responses as values of 1 (negative) to 3 (definite), the overall average is 2.52 ± 0.06, which is greater than 2 to a very high level of confidence. In fact, all categories, apart from mentoring ($p = 0.108$) and sharing outcomes ($p = 0.119$), are statistically significant in one-sample Wilcoxon signed-rank tests against null hypotheses of 2. However, all categories' distributions are consistent with the overall results in Wilcoxon rank-sum tests; thus, while there are differences between the distributions, such as slightly more teachers feeling they have not developed mentoring skills or having not yet shared their students' work across their schools (understandable given the question was posed at the student conference), these variations are moderate and not statistically significant.

Figure 5b shows the distribution of the number of positive impacts claimed per teacher. No teachers responded negatively in all categories, and thus all seem to have been positively affected in some way. The average number of positive categories indicated by teachers was 6.2 ± 0.4 out of 8. The bivariate distribution of definite impacts per teacher as a function of the number of positive impacts they indicated is shown inset, revealing teachers tended (apart from in one case) to indicate the majority of positive impacts claimed had already occurred. The average number of definite impacts was 5.2 ± 0.5. Out of the 23 teachers, only 5 gave the same answer in all categories (in these cases all definite responses), suggesting the results are largely reliable and likely did not fall prey to unreflective responses. Therefore, it appears that the identified areas of impact upon teachers and schools as a result of PRiSE may indeed be quite widespread.

6 Conclusions

We have investigated the medium- and long-term impacts on students, teachers, and schools who have participated in a 6-month-long programme of physics "research in schools" projects, open-ended investigations for school students based around cutting-edge STEM research. This programme, Physics Research in School Environments (PRiSE), has involved a diverse range of London schools, and we have used evaluation data captured from questionnaires across its entire 6-year duration to date.

Medium-term impacts on the participating 14–18-year-old school students were assessed after they had completed their 6-month-long projects. Students' confidence in relevant scientific topics and methods seems to have substantially increased as a result of PRiSE, with nearly all students reporting this benefit. Furthermore, through experiencing and being involved in research-level physics, students report having gained new, or further developed existing, skills. Both of these impacts upon students have been corroborated by teachers' observations. While the students involved with PRiSE were fairly committed to STEM in general beforehand, our data suggest that they had no clear bias in aspirations towards the subject of physics in particular. Following the programme it appears that students' attitudes towards pursuing STEM were typically maintained or confirmed through their involvement, and physics aspirations seem to have been moderately enhanced. We find no evidence that these impacts varied by the different projects or schools. These results should be deemed successful, as a drop-off in STEM aspirations is often seen at this age (Davenport et al., 2020), with these issues being particularly pertinent in physics (L. Archer et al., 2020a). Thus at this stage of a student's educational journey they are likely to require interventions that sustain and support their science identity, which, in turn, has an influence on their educational choices (L. Archer and DeWitt, 2016).

Longitudinal evaluation has also been performed for three cohorts of PRiSE students 3 years after they commenced their projects. While a relatively small sample, the evidence suggests that these projects have been memorable and beneficial experiences that students have been able to draw upon in their later educational activities and development. The data on PRiSE students' degree destinations show increased uptake of physics and STEM at degree level than would typically be expected, suggesting that their involvement in the research projects has helped transform their aspirations into destinations – a key aim of the programme. Further in-depth qualitative research, such as interviews or focus groups, could provide richer and more reflective information on how students' thoughts and feelings about their association with physics and STEM may have been affected by participating in PRiSE, given the nuance and multiple factors at play with students' aspirations in general, which are diffi-

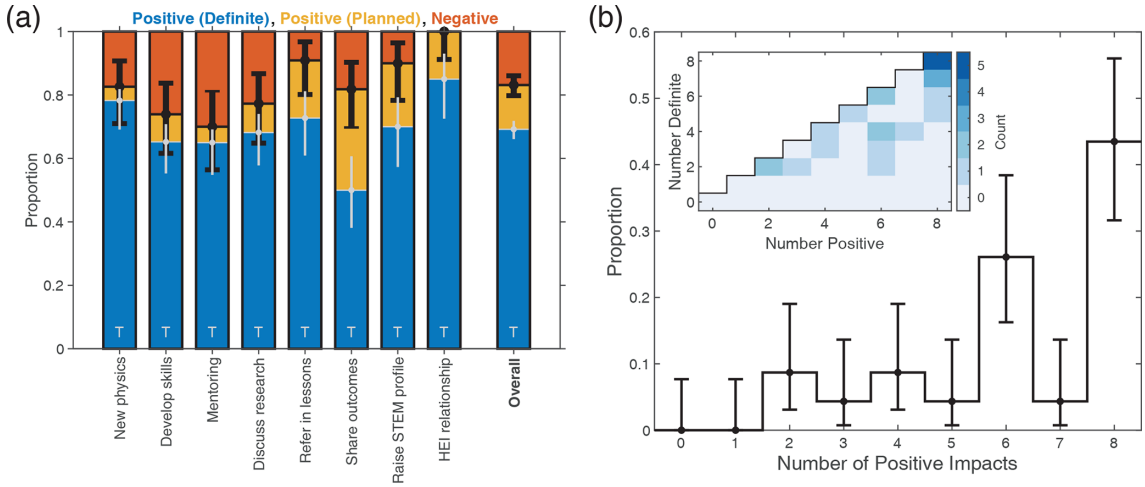

Figure 5. Quantitative results of impacts on teachers and schools ($n = 23$). **(a)** Distribution of teachers' responses for each impact category. Results are divided (black lines and associated error bars) into negative (red) and positive responses, with the latter subdivided (grey lines and error bars) into "definite" (blue) and "planned" (yellow). **(b)** Distribution of the number of positive impact categories reported per teacher, with the bivariate distribution of the number of definite impacts vs. positive ones shown inset. Error bars denote standard (1σ) Clopper and Pearson (1934) intervals.

cult to capture and interpret with questionnaire data alone (L. Archer et al., 2013, 2020b).

The impacts upon students reported in this paper only relate to those who completed the 6-month programme. However, as should be expected for any extended programme, there is some drop-off in participation with PRiSE. This has been explored in more detail in M. O. Archer (2021), demonstrating that students' success with PRiSE appears to be independent of background and thus not clearly patterned by societal biases present within the field (e.g. Campaign for Science and Engineering, 2014). Currently though we have no data on what impact the programme has on those students who drop out. While no teachers have communicated any negative effects on students who do not continue, with some highlighting informally their students' attitudes towards the projects, this requires further formal investigation. Such work is required to ensure that no negative effects are being felt by these students and potentially discover what positives, if any, may result from even partial participation. Furthermore, we have no evidence that the PRiSE approach would be effective for students who are generally uninterested or unengaged with STEM. Indeed, it seems unlikely that such students would want to persist with an extended and challenging extra-curricular physics programme. Young people's aspirations towards science begin to form at an early age (L. Archer et al., 2013, 2020b), and therefore interventions throughout their educational journey need to align with their needs and wants, from initial inspiration and positive associations to informing on career-focused aspects and finally sustaining those built aspirations (Davenport et al., 2020). PRiSE only aims to address that final part of the chain, since no single programme can fit all stages.

Evaluation of the impacts on teachers and schools has identified several themes. By collaborating on PRiSE, teachers can gain new physics knowledge, become more confident in discussing research, and integrate aspects of the research projects into their regular lessons. Teachers also report developing various technical skills, gaining confidence in mentoring, and reassessing their preconceptions of students' potential. While all these positive changes to teachers' practice will likely be felt across their wider schools, there is more direct evidence of the school environment being affected, such as through students' project work being championed, the profile of physics or science being raised, and a university–school relationship being established with significant repeated buy-in from schools over several years. These impacts appear to be fairly widespread across the teachers and schools involved in PRiSE. We note that these results share many similarities with those reported by Rushton and Reiss (2019) for IRIS (2020) from interviews with 17 teachers. The PRiSE programme features much greater diversity in schools, with an overrepresentation of disadvantaged groups in many metrics considered (M. O. Archer, 2021). Furthermore, as discussed in M. O. Archer et al. (2021), PRiSE does not rely on such a teacher-driven model, instead providing a wealth of resources and interventions to support teachers' and schools' participation. The similar impacts thus highlight that, with the right support, teachers and schools from a variety of contexts can benefit from "research in schools" projects. Further research could investigate the validity of the participating teachers' remarks on the impact on the schools' environments, for instance through in-depth interviews or focus groups with other teachers in the schools.

The impacts upon participating students, teachers, and schools discussed in this paper show real promise for the emerging field of “research in schools” initiatives. They suggest that with more similarly designed and supported programmes at other institutions, we may be able to start to address a key part of the chain of the wider issue of uptake and diversity, not just in physics, but potentially STEM also. We stress, however, that multi-faceted approaches from a variety of different stakeholders and organisations are required to implement real change in this entire issue, but “research in schools” may be able to form one piece of the puzzle.

Appendix A: 6-month stage evaluation questions

Here we list the questions considered within this paper posed in the PRiSE-wide questionnaires at the 6-month stage evaluation. We detail the phrasing used, how participants could respond, and which years the question was asked. Follow-on questions are indicated by indentation and a down-right arrow (↳).

Table A1. Questions posed to students.

Question	Response type	Year(s)
In what way has this project affected you	Open Text	2016–2020
What skills, if any, has the project helped you develop	Open Keywords	2016–2020
How has doing the project affected your thoughts about future subject choices/careers	Open Text	2018–2019
Before working on the project, how likely were you to continue with the following (Physics/STEM) in the future	Five-point Likert	2020
↳ After working on the project, how likely are you now to continue with the following (Physics/STEM) in the future	Five-point Likert	2020
↳ How has working on the project affected your thoughts about these future subject choices (Physics/STEM)	Five-point Likert	2020
↳ Please explain how or why?	Open Text	2020

Table A2. Questions asked of teachers.

The questions asked of teachers were the following.		
Question	Response type	Year(s)
In what way has this project affected your students	Open Text	2015–2020
In what way has this project affected you	Open Text	2015–2018
What skills, if any, has the project helped your students develop	Open Keywords	2016–2020
What skills, if any, has the project helped you develop	Open Text	2016–2018
Have you found the project useful in your lessons	Five-point Likert	2015–2018
↳ Please tell us why / why not	Open Text	2015–2018
Do you feel you have been affected by the project in any of the following ways (8 categories)	Closed Options	2019–2020
↳ Are there any other ways you feel you've been affected	Open Text	2019–2020

Appendix B: 3-year stage evaluation questions

Table B1. The following questions were asked of students in the 3-year stage evaluation via an online form.

Section	Question	Response type	Required	Go to section	Cohort(s)
1	What school year would you have been in during the academic year [cohort year]	Closed Options	Y		1–3
	Do you remember undertaking a Queen Mary Physics & Astronomy research project that year	Yes/No	Y	Yes: 2 No: 3	1–3
2	What experiences do you remember from the project	Open Text	N		1–3
	How have you used those experiences since, if at all	Open Text	N	3	1–3
3	Are you studying at a Higher Education Institution (HEI) e.g. a University	Closed Options	Y	Yes: 4 Intend to: 5 No: Submit	1–3
4	Which HEI are you studying at	Open Text	N	5	1–3
5	What subject are you studying or plan to study at a HEI	Closed Options	Y		1–3
	What are/were your reasons for studying that subject	Open Text	N		1–3
	What influenced you to study that subject	Open Text	N	6	1–3
6	Did the research project in any way influence your subject choice	Closed Options	Y		2–3
	How would you say the research project affected your subject choice (if applicable)	Open Text	N	Submit	2–3

Data availability. Data supporting the findings of this study that are not already contained within the article or derived from listed public domain resources are available on request from the corresponding author. These data are not publicly available due to ethical restrictions based on the nature of this work.

Author contributions. MOA conceived the programme and its evaluation, performed the analysis, and wrote the paper. JdW contributed towards the analysis, validation, and writing.

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