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Science teaching and students' attitudes and aspirations: The importance of conveying the applications and relevance of science

Richard Sheldrake*, Tamjid Mujtaba, Michael J. Reiss

UCL Institute of Education, University College London, 20 Bedford Way, London WC1H 0AL, United Kingdom

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ABSTRACT

More people studying and working within science are desired in numerous countries, although it remains less clear how educators can help. Analysis considered nationally-representative samples of students in England, aged 15 (Year 11), from 2006 and 2015. On both occasions, accounting for students' background and other views, students' perceived utility of science most strongly and positively associated with their science-related career aspirations, while students' reports of encountering different teaching approaches had smaller or no associations. Conveying the wider applications of science to students was the only teaching approach to consistently and positively associate with students' utility and other attitudes. Developing students' attitudes, and hence their aspirations, through highlighting the applications and relevance of science to everyday life may be beneficial.

1. Introduction

Understanding students' aspirations to study and work within science continues to be a central concern for science educators in England and other countries (EACEA, 2011; NSTC, 2013; Royal Society, 2014). More students studying science-related subjects have been desired as a means to foster greater quantitative skills, to meet an expected demand for increased numbers of science-related professionals, and to address under-representation and promote equity (CASE, 2014; OECD, 2015; Royal Society, 2008; WISE, 2014).

In England, in common with many other countries, studying science subjects at upper-secondary school is generally necessary to study science courses at university, and studying science at university is generally necessary for a science career. Accordingly, experiences in school may be especially important in facilitating or precluding future careers in science. Primary and secondary education have indeed been found to be important times for developing students' interest in science (Maltese, Melki, & Wiebke, 2014), and students' interest in science and their perceived utility of science (students valuing science through thinking that science leads to various benefits such as fostering their skills and facilitating careers) have been found to be closely associated with their studying and career aspirations (Regan & DeWitt, 2015). Students' attitudes and aspirations to study science reported during secondary school have indeed predicted whether they subsequently gained science-related degrees at university (Maltese & Tai, 2011; Morgan, Gelbgiser, & Weeden, 2013; Tai, Qi Liu, Maltese, & Fan, 2006). However, it remains somewhat unclear what educators can or should do in order to foster attitudes such as interest in science and to promote aspirations towards science, especially with regard to applying particular teaching approaches such as using practical work or debates within classrooms.

Numerous teaching approaches are possible within science education, and historical attention on selecting approaches to increase attainment, and/or on approaches that are assumed to reflect what scientists do, has increasingly expanded to also consider how teaching may influence students' attitudes (Osborne and Dillon, 2008; Savelsbergh et al., 2016). Students' classroom experiences in

* Corresponding author.
E-mail address: rsheldrake@ioe.ac.uk (R. Sheldrake).

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secondary school have been found to associate with their interest in science, for example, but any direct associations between specific teaching approaches and students' aspirations remains somewhat unclear (Abrahams, 2009; Hampden-Thompson & Bennett, 2013; Wang, 2012).

Accordingly, the research presented here focused on revealing the associations between students' reports of encountering different teaching approaches and students' reported science-related career aspirations, while accounting for students' different background characteristics. In more detail, the research considered associations between teaching approaches and theorised antecedents of aspirations (including students' interest and perceived utility), and then considered what factors (including teaching approaches, interest, utility, and other factors) actually associated with students' reported aspirations, in order to gain greater practical insight. The analysis considered nationally-representative samples of students (aged 15) from the Programme for International Student Assessment (PISA) from 2006 and from 2015 in order to consider the consistency of any findings to enhance the overall insight. The analysis focused on students in England in order to maximise its local contextual relevance.

1.1. Science aspirations and choices

The numbers of students studying science-related subjects at upper-secondary school and at university in England have historically varied, and have often been lower than other subjects and imbalanced with respect to students' gender and home backgrounds (Homer, Ryder, & Banner, 2014; Royal Society, 2006, 2008; Smith, 2011). These differences in studying choices have often been explained by students' different attitudes and beliefs (DeWitt, Archer, & Osborne, 2014; Mujtaba & Reiss, 2014). Essentially, various aspects of students' lives, such as their parents' beliefs (DeWitt et al., 2011) and classroom experiences (Wang, 2012), may influence their attitudes about science, which may then primarily influence their aspirations.

Considered in review across multiple studies, students' interest in science and their perceived utility of science have most strongly associated with their studying and career aspirations, to greater extents than other attitudes, measures of their attainment, and various other indicators related to their homes and backgrounds (Bøe & Henriksen, 2015; Regan and DeWitt, 2015; Tripney et al., 2010). Recent research in England has reaffirmed the relevance of interest and utility to students' prospective aspirations towards studying and working in science, together with further factors including the personal value of science to their identities, their current confidence, their confidence in their future attainment, and influences from their parents (DeWitt & Archer, 2015; Mujtaba & Reiss, 2014; Sheldrake, 2016). Similarly, students in England have retrospectively reported that their studying choices have followed from their interest, perceived utility, and confidence (Bates, Pollard, Usher, & Oakley, 2009; Jensen & Henriksen, 2015; Mellors-Bourne, Connor, & Jackson, 2011; Vidal Rodeiro, 2007). Studies undertaken outside of England, such as in the United States of America (e.g. Maltese and Tai, 2011; Tai et al., 2006) and in continental European countries (e.g. Bøe & Henriksen, 2013; Bøe, 2012), have revealed broadly similar findings, especially regarding the importance of students' interest and perceived utility.

It remains unclear whether any one factor is the most influential, however. Studies highlighting that students cited interest as the primary reason for their choices (Bates et al., 2009; Mellors-Bourne et al., 2011), for example, may contrast with studies that highlighted the primary importance of students' perceived utility of science (Mujtaba & Reiss, 2014; Vidal Rodeiro, 2007). Any number of methodological differences may be relevant, given that studies have variously considered students' prospective studying aspirations (e.g. Mujtaba & Reiss, 2014) or their retrospective recollections about their choices (e.g. Jensen & Henriksen, 2015). While many studies have been large in scale, and broadly generalizable to students across England given particular attainment characteristics (e.g. DeWitt et al., 2014; Mujtaba and Reiss, 2014), they have not necessarily considered precisely nationally-representative samples.

Overall, while students' attitudes towards science have been found to associate with their aspirations, greater clarity would be beneficial, especially as to whether any teaching approaches also associate with students' aspirations and/or with any attitudes that may in turn associate with aspirations. In general, it remains less clear as to what might associate with (and hence potentially influence) students' interest in science and perceived utility of science.

1.2. Teaching approaches

Students' studying and career aspirations have been found to be difficult to directly change (Archer, DeWitt, & Dillon, 2014). Pragmatically, in order to increase the numbers of students aspiring towards science careers, educators could instead attempt to foster students' attitudes, such as their perceived utility of science, and/or apply various different teaching and learning approaches or activities in order to inspire or engage students.

Various interventions have explicitly focused on fostering students' attitudes towards science (Rosenzweig & Wigfield, 2016). Numerous approaches have been applied to help increase students' interest in science, such as emphasising the relevance of science and explaining the experiences and work of scientists (Bernacki, Nokes-Malach, Richey, & Belenky, 2016; Hong & Lin-Siegler, 2012; Hulleman & Harackiewicz, 2009). Similarly, promoting the relevance and utility of science to students and their parents has been found to associate with higher science interest and attainment in students, and with students selecting courses in science (Harackiewicz, Rozek, Hulleman, & Hyde, 2012; Rozek, Hyde, Svoboda, Hulleman, & Harackiewicz, 2015). In general terms, educators may be able to explain science careers or the wider applications of science in various ways, perhaps during and/or to supplement other teaching approaches or activities.

Various teaching approaches have been historically applied or recommended within science education. Practical work (often experimental laboratory work) remains valued within science education, for example, due to practical work being assumed to reflect the empirical nature of science, but other justifications and contrasting views are possible (Abrahams & Reiss, 2012; Hodson, 1993;

Millar, 1998). More broadly, 'inquiry-based' teaching of science focuses on student-led rather than teacher-led activities (but with some guidance and support from teachers), often via observation and experimentation (and so can overlap with practical work), and where students broadly apply a scientific approach or method (Furtak, Seidel, Iverson, & Briggs, 2012; Minner, Levy, & Century, 2010; Schroeder, Scott, Tolson, Huang, & Lee, 2007). Further teaching approaches, such as fostering 'argumentation' or debates, are also assumed to both develop and reflect practices that scientists apply in their work, such as critical reasoning and justification (Cavagnetto, 2010; Erduran & Jiménez-Aleixandre, 2007). Alternately, 'context-based' teaching focuses more on enhancing students' interest and perceived relevance of science, through using applied contexts as avenues to learn scientific skills and ideas (Bennett, Lubben, & Hogarth, 2007).

Teaching approaches have often been considered in the context of attainment, essentially in order to determine optimal or efficient practices. Considered in review across multiple studies, inquiry-based learning has generally associated with increased attainment, with the most benefits arising from including some degree of support from teachers (Furtak et al., 2012; Savelsbergh et al., 2016; Schroeder et al., 2007). The benefits of argumentation approaches appear less clear or less explicitly quantified (Cavagnetto, 2010; Rönnebeck, Bernholt, & Ropohl, 2016). Context-based approaches have appeared broadly equivalent to other teaching approaches in relation to developing students' understanding, while appearing to help increase students' attitudes to science (Bennett et al., 2007; Vaino, Holbrook, & Rannikmäe, 2012). More specifically, both inquiry-based and context-based approaches (and also using computers to enrich learning, collaborative learning, and providing extra-curricular activities) have generally associated with students' interest in science (Savelsbergh et al., 2016).

Most evidence has come from (and/or reviews have focused mostly on) the United States of America (e.g. Furtak et al., 2012; Schroeder et al., 2007). Specifically in England, practical work has sometimes appeared less effective than expected in developing students' understanding of underlying scientific ideas, and may not necessarily help foster a process of inquiry and 'working like a scientist'; nevertheless, students have found practical work interesting, although it has been unclear whether this has helped foster wider interests in science (Abrahams & Millar, 2008; Abrahams, 2009; Toplis, 2012). Interventions in England to develop students' scientific argumentation/justification have appeared effective in promoting particular patterns of argumentation, but this appeared to have no clear impact on students' science attainment (Osborne, Erduran, & Simon, 2004; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). In England, context-based learning of chemistry has appeared equivalent to other approaches in terms of developing students' scientific understanding while also appeared to be interesting to students (Bennett & Lubben, 2006; Ramsden, 1997).

Overall, it may be difficult to justify any particular teaching approach as clearly being ideal or optimal. Variable findings have arisen from research, which is perhaps complicated due to potentially differing conceptualisations or operationalisations of the underlying ideas (e.g. Rönnebeck et al., 2016). Justifying a particular teaching approach may also require considering which justifications are favoured, necessary, and/or sufficient for a recommendation, such whether teaching approaches should reflect practices within science, follow from theories of learning, be empirically identified as increasing attainment or other measures of understanding, and/or for any other reasons. Fundamentally, and to pragmatically avoid such issues, further clarification would be beneficial into whether and how specific teaching approaches influence students' aspirations and/or attitudes, especially within England.

1.3. Research aims

Research has highlighted that students' attitudes are especially relevant to their science-related career aspirations, particularly their interest in science and their perceived utility of science (Bøe & Henriksen, 2015; Regan & DeWitt, 2015).

Research has increasingly considered these attitudes within motivational theories, and has especially focused on the expectancy-value model of motivated behavioural choices within social-cognitive theory (Bøe & Henriksen, 2015; Bandura, 1997; Eccles, 2009). The expectancy-value model proposes that science studying and career choices are closely related to someone's 'expectations for success' (their confidence in their current abilities and/or future capabilities in science) and the 'subjective values' attached to their various options (specifically including someone's interest and perceived utility regarding science); these beliefs are developed within someone's wider environment, such as their family and learning contexts (Eccles, 2009). These assumptions have been broadly supported by studies that have found that contextual aspects of students' lives have associated with the students' expectations (confidence) and subjective values (interest and utility) about science, which have then associated with their studying intentions or choices (e.g. DeWitt et al., 2011; Wang, 2012). Nevertheless, it remains less clear whether or which particular teaching approaches associate with students' attitudes and/or career aspirations within such models.

Accordingly, this study aimed to (1) clarify how various teaching approaches associated with theorised antecedents of choices from the expectancy-value model (interest, utility, confidence, and also attainment), and then (2) clarify which factors (including teaching approaches) actually associated with students' science-related career aspirations.

Given the assumptions of the expectancy-value model and prior studies (e.g. Eccles, 2009; Wang, 2012), it was hypothesised that teaching approaches would not necessarily directly associate with students' aspirations, but might instead associate with interest and utility (and hence potentially indirectly associate with aspirations). Specifically, given prior research, it was hypothesised that approaches representing inquiry-based teaching, context-based teaching, and/or providing general explanations of the wider context or applications of science would associate with students' interest and potentially with their perceived utility of science (e.g. Savelsbergh et al., 2016; Straw and Macleod, 2015). Additionally, given prior research, it was hypothesised that students' interest and perceived utility of science (key elements from the expectancy-value model) would have the strongest associations with students' aspirations (e.g. Mujtaba & Reiss, 2014; Sheldrake, 2016).

2. Methods

2.1. Samples

The Programme for International Student Assessment (PISA) consists of various surveys undertaken by the Organisation for Economic Co-operation and Development (OECD), targeting students aged 15 (Year 11 in England) within full-time education. Recently, PISA focused on science in 2006 (OECD, 2007) and in 2015 (OECD, 2016). On both occasions, schools were systematically sampled (with probabilities proportional to their size) within strata (with separate sampling of schools within geographical regions and other strata), and around 35 students were then randomly-sampled within each school (OECD, 2007, 2016).

Sample-weighting was calculated by the OECD to allow the complex samples to reflect the wider populations of students in England at the time of the surveys (OECD, 2009b). The various results presented here include sample-weighting, excepting that numbers of students are reported as unweighted numbers for intuitive clarity.

In England, PISA surveyed 4935 students (across 171 schools) in 2006 and 5194 students (across 206 schools) in 2015. The majority of the surveyed students in England were indeed in Year 11 (99.7% in 2006 and 98.8% in 2015) with an average age of 15.7 years on both occasions. The samples were relatively equally split between boys and girls, with 49.4% being boys in 2006 and 50.8% being boys in 2015 (without sample-weighting: 2403 boys being 48.7% of the unweighted sample in 2006, and 2719 boys being 52.3% of the unweighted sample in 2015).

2.2. Student questionnaires

Students in PISA 2006 and PISA 2015 completed questionnaires that measured their aspirations and attitudes towards science, information about their backgrounds, and their performance across various science tasks.

Comprehensive processes of questionnaire development were applied by the OECD, and the various items/factors represent established attitudes within educational research (OECD, 2007; OECD, 2016; Wigfield and Cambria, 2010). For example, students' interest and their perceived utility of science are integral to the expectancy-value model of motivational choices (being aspects of students' 'subjective values'; Eccles, 2009), and/or can be contextualised as intrinsic and extrinsic motivation (Ryan & Deci, 2000). Similarly, students' self-efficacy beliefs (concerning their perceived capabilities in science) reflect their expectancies/confidence within the expectancy-value model and within social-cognitive theory itself, where higher confidence is considered motivational and where lower confidence may be limiting (Bandura, 1997; Bong & Skaalvik, 2003; Eccles, 2009).

The theorised assignment of items to factors has been internationally validated by the OECD (OECD, 2009a, 2017), and was also verified for England alone as part of the current study through confirmatory factor analysis (via maximum-likelihood estimation, i.e. factor by factor) and through exploratory factor analysis (via principal-components analysis, i.e. considering emergent factors from all available items). The factors showed acceptable reliability (internal consistency via Cronbach's alpha coefficients). For brevity, given the number of items/factors across both surveys, the reliability coefficients are appended (Supplementary material: Table A).

In order to maximise their interpretability and consistency across both surveys, factors were calculated as the average of the relevant individual items, reverse-scoring items when necessary to maintain consistency (i.e. higher factor-scores reflected higher interest, utility, etc.). Accordingly, the items/factors then reflected the underlying response-scales. For most items/factors, this involved agreement-scales from (1) 'Strongly disagree', (2) 'Disagree', (3) 'Agree', to (4) 'Strongly agree'. The frequency of students receiving or encountering different teaching approaches when learning science was measured from (1) 'Never or hardly ever', (2) 'In some lessons', (3) 'In most lessons', to (4) 'In all lessons'. The frequency of engagement with home/extra-curricular science activities was measured from (1) 'Never or hardly ever', (2) 'Sometimes' (3) 'Regularly', to (4) 'Very often'. The key items/factors used within the analysis are described in the following sections.

2.2.1. Science aspirations

In PISA 2006 and PISA 2015, students were asked what kind of job they expected to have when they were around 30 years old. Following the current OECD guidance (OECD, 2016, pp. 282–283), the analysis involved coding these into 'science-related career aspirations' that encompassed occupations in: science and engineering; medicine/health; and information/technology. Previously published results from PISA 2006 (OECD, 2007) have included various other occupations as science-related, such as architects, social workers, sociologists, and psychologists, which were classified as non-science-related within the current analysis.

2.2.2. Science attitudes and context

Various science-specific attitudes and beliefs were similarly measured across both surveys. From the expectancy-value model (Eccles, 2009), students' 'expectancies' were measured as their **self-efficacy** for undertaking various applied science tasks (their confidence in being able to e.g. 'Describe the role of antibiotics in the treatment of disease'). Students' 'subjective values' were measured as their generalised **interest in science** (interest/intrinsic value of science, e.g. 'I am interested in learning about science') and their perceived **utility of science** (utility/extrinsic value of science, e.g. 'Studying my science subjects is worthwhile for me because what I learn will improve my career prospects'). Additionally, both surveys also measured students' **interest across specific science areas and topics** (covering topics across physics, chemistry, and biology), students' **engagement in home/extra-curricular science activities** (frequencies of e.g. '[Watching] TV programmes about science'), and the frequencies of encountering various teaching approaches. Further factors were measured in only one survey (for brevity, these are detailed, together with example items, in the Supplementary material; Supplementary material: Table A).

Teaching approaches were similarly measured across both surveys, and specifically covered students reporting the frequency of receiving or encountering: '**interaction/debate**' (e.g. 'Students are given opportunities to explain their ideas', 'There is a class debate about investigations'); '**practical/hands-on activities**' (e.g. 'Students spend time in the laboratory doing practical experiments', 'Students are asked to draw conclusions from an experiment they have conducted'); '**student-led investigations**' (e.g. 'Students are allowed to design their own experiments', 'Students are asked to do an investigation to test out their own ideas'); and teaching that focused on the '**applications of science**' or the wider relevance of science (e.g. 'The teacher clearly explains the relevance of science concepts to our lives', 'The teacher explains how a science idea can be applied to a number of different phenomena').

The students' background and home context were similarly measured in both surveys via their: gender; home possessions (reflecting their general family affluence, and including the number of books at home); whether their parents worked within science-related occupations (coded in the same way as the students' career aspirations as part of the analysis); their parents' level of education; and their parents' level of occupation (i.e. broadly reflecting inferred income/'socio-economic status', given their occupation). Students' ethnicity was not measured within PISA for students in England.

2.2.3. Science task-scores

The students' science task-scores reflected their performance across various sets of applied tasks that were not necessarily curricula-based, and the OECD indicators ('plausible-values') were used in the analysis (OECD, 2009b). PISA task-scores have been found to be positively associated with students' subsequent examination attainment with small to moderate magnitudes, and so may reflect (to some extent) their curricula-based classroom attainment (Fischbach, Keller, Preckel, & Brunner, 2013; Parker, Marsh, Ciarrochi, Marshall, & Abduljabbar, 2014).

2.3. Analytical approaches

PISA 2006 and PISA 2015 were considered separately, given that almost ten years occurred between the surveys. This offered potential replication or disconfirmation within the overall study: the consistency of any emerging findings across both surveys could enhance any insight, while differences could highlight a need for caution when forming conclusions. Accordingly, analysis focused on the items/factors that were covered within both surveys, in order to enhance potential comparability.

On a wider level, the analysis focused on students' reported experiences and beliefs for consistency, and given their centrality within motivational theory and prior studies (Bøe & Henriksen, 2015; Eccles, 2009). All the items/factors were therefore on the student-level, rather than also including school-level or wider contextual indicators, which could be matched or calculated in diverse ways (such as forming indicators of school-average task-scores) but which were outside of the current research aims and scope.

2.3.1. Missing values/responses

Students may not necessarily report their experiences and beliefs for every questionnaire item. Calculating factors as averages across multiple items helped to minimise, but not eliminate, any impact of missing responses. However, statistical analysis such as predictive modelling often only considers those students with responses/scores for every modelled item/factor; this would entail only considering 2981 of 4935 students from PISA 2006 and 2072 of 5194 students from PISA 2015. Essentially, using many single-item indicators (such as parental education), and using many predictors in general, increases the risk of reducing the number of considered students; such students may differ in views/profile from the entire sample, and fewer students reduces the power of statistical tests to reveal significant differences.

Accordingly, aspirations (and parental occupations) were coded as 'science-related' or 'non-science-related, missing, unsure, and/or unclear'. Estimates of other missing values/scores were produced using full-information maximum-likelihood via expectation-maximisation, which is considered one of the best contemporary approaches to handling missing values/scores (IBM, 2014; Peugh & Enders, 2004). This allowed all students to be consistently considered (4935 in PISA 2006 and 5194 in PISA 2015), regardless of the type of analysis (e.g. correlations or predictive modelling) and/or the number of items/factors being modelled (e.g. used as predictors).

Preliminary analysis highlighted that the same results/conclusions emerged regardless of the aspiration/occupation coding approach and whether missing values/scores were estimated or not. The presented results include estimates of missing values/scores in order to maximise the considered student numbers.

2.3.2. Statistical analysis

Preliminary analysis applied various analytical approaches, including single-level linear regression (via ordinary least-squares estimation) and also multi-level linear regression (via maximum-likelihood estimation with variable intercepts per school) to account for students being clustered within schools (Snijders & Bosker, 2012). Parameter estimates were similar across different approaches, and the results/conclusions remained constant (examples are appended in the Supplementary material for brevity; Supplementary material: Table B for PISA 2006 and Supplementary material: Table C for PISA 2015). Given the preliminary results/conclusions, single-level modelling was reported for efficiency/parsimony, and to best accommodate the complexity of the OECD design through official software (using 'Balanced Repeated Replication' elements of sample-weighting to help account for the stratified/clustered sample design; OECD, 2009a, 2017). The presented analysis therefore used SPSS with the IEA IDB Analyzer, specifically designed to handle PISA data. This accommodated the complex sample-weighting, with 'Balanced Repeated Replication' elements, and analytically aggregated the multiple (plausible-value) indicators of students' task-scores (Rubin, 1987).

The standard criterion ($p < 0.05$) was used for statistical significance. For linear outcomes, predictive associations ('effect sizes')

Table 1
Sample summary.

Item/factor (scale)	PISA 2006 Mean	PISA 2006 Std. Dev.	PISA 2015 Mean	PISA 2015 Std. Dev.
Science-related career aspirations (1=Y)	.18	.38	.30	.46
Working in science, mother (1=Y)	.04	.20	.10	.30
Working in science, father (1=Y)	.08	.28	.10	.29
Education level, mother (1-6)	4.01	1.35	4.38	1.33
Education level, father (1-6)	3.88	1.47	4.31	1.38
Gender (1=boy)	.49	.50	.51	.50
Home/extra-curricular activities (1-4)	1.44	.44	1.57	.55
Teaching: interaction/debate (1-4)	2.53	.66	1.72	.73
Teaching: hands-on/practical activities (1-4)	2.50	.54	2.29	.61
Teaching: applications of science (1-4)	2.41	.64	2.60	.80
Teaching: student-led investigations (1-4)	1.71	.65	1.85	.64
Interest/intrinsic value (1-4)	2.56	.66	2.71	.73
Utility/extrinsic value (1-4)	2.81	.72	2.97	.74
Task-score (OECD scale)	515.63	117.76	512.17	116.04
Interest in science areas/topics (1-4)	2.48	.60	2.59	.70
Self-efficacy for tasks/areas (1-4)	2.86	.59	2.90	.61
Students (number)	4935		5194	

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Means and standard deviations ('Std. Dev.') are reported. Parental education was scaled by the OECD via the International Standard Classification of Education with 4 reflecting upper-secondary education, 5 reflecting vocational university-equivalent education, and 6 reflecting (non-vocational) university education. The OECD's home possessions and parental occupation scales were not directly comparable in means across surveys (due to the OECD amending how these scale indicators were calculated over time), but similarly operated as linear indicators and via the underlying items; in predictive modelling, preliminary analysis provided similar results/conclusions regardless of re-scaling/re-calculating the factors and via alternate approaches such as only using the single-item indicator of the number of books at home. Teaching factors are shaded for clarity.

were reported as standardised coefficients: how many standard deviations of increase/decrease would occur in the outcome, given one standard deviation increase in the predictor. For binary outcomes (students' science-related aspirations), predictive associations were reported as odds ratios: the change in odds given one unit increase in the predictor, where values below one reflected decreased odds of the outcome and values above one reflected increased odds. For conciseness, decreased odds ratios were referred to as negative associations while increased odds ratios were referred to as positive associations.

3. Results

3.1. Summary statistics

In England (Table 1), 18.6% of students in PISA 2006 aspired to science-related careers compared to 29.7% of students in PISA 2015. Greater proportions of parents were also categorised as working in science-related careers in PISA 2015, despite the analysis applying the same categorisation scheme to both surveys. Given that the two samples covered different students, any potential differences do not describe individual changes over time and may not necessarily reflect wider trends or changes in society (which might require approaches such as surveying Year 11 students every year in order to reveal trends over time).

In PISA 2006 (Table 1), students most frequently reported experiencing 'interaction/debate', 'hands-on/practical activities', and 'applications of science' (with relatively similar frequencies), then 'student-led investigations' within science teaching. In PISA 2015 (Table 1), students most frequently reported experiencing science teaching that highlighted the 'application of science', then 'hands-on/practical activities', and then 'student-led investigations' and 'interaction/debate'.

For the comparable items/factors across PISA 2006 (Table 2) and PISA 2015 (Table 3), students' aspirations most strongly correlated with their perceived utility and general interest in science (with small to moderate magnitudes, given indicative thresholds; Cohen, 1988). More extensive correlations with aspirations, including items/factors specific to one survey but not the other, are appended in the Supplementary material for brevity (Supplementary material: Table D).

In both surveys (Tables 2 and 3), all indicators of teaching approaches positively correlated with students' interest, perceived utility, and self-efficacy beliefs; across the different teaching approaches, the 'applications of science' consistently had the highest (but still small) correlations with these factors. However, in PISA 2006 (Table 2), 'student-led investigations' negatively correlated with task-scores while 'interaction/debate' had no significant association with task-scores. In PISA 2015, reported 'interaction/debate' and 'student-led investigations' in teaching both negatively correlated with students' task-scores (Table 3).

3.2. Modelling theorised antecedents and students' aspirations (PISA 2006)

The independent associations between the various teaching approaches ('interaction/debate', 'hands-on/practical activities', 'applications of science', and 'student-led investigations') and students' interest, perceived utility, self-efficacy, and task-scores were considered for PISA 2006, while accounting for students' background characteristics (Table 4). Students' science-related aspirations

Table 2
Correlation summary (PISA 2006).

Item/factor	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Science-related career aspirations (1=Y)	1												
2. Working in science, mother (1=Y)	**.044**	1											
3. Working in science, father (1=Y)	**.119**	**.135**	1										
4. Gender (1=boy)	.018	-.008	-.009	1									
5. Home/extra-curricular activities	**.242**	.026	**.067**	**.106**	1								
6. Teaching: interaction/debate	**.045**	-.007	.011	**.031**	**.194**	1							
7. Teaching: hands-on/practical activities	**.051**	.001	.000	**.054**	**.217**	**.525**	1						
8. Teaching: applications of science	**.088**	.011	.007	**.103**	**.278**	**.600**	**.556**	1					
9. Teaching: student-led investigations	-.017	-.024	**-.034**	**.115**	**.184**	**.487**	**.475**	**.503**	1				
10. Interest/intrinsic value	**.290**	**.036**	**.082**	**.124**	**.537**	**.249**	**.237**	**.303**	**.114**	1			
11. Utility/extrinsic value	**.377**	**.035**	**.070**	**.068**	**.406**	**.249**	**.244**	**.326**	**.184**	**.567**	1		
12. Task-score	**.236**	**.091**	**.184**	**.051**	**.209**	-.014	**.045**	**.056**	**-.205**	**.359**	**.220**	1	
13. Interest in science areas/topics	**.242**	.003	**.056**	**.083**	**.513**	**.236**	**.227**	**.300**	**.155**	**.672**	**.538**	**.243**	1
14. Self-efficacy for tasks/areas	**.205**	**.054**	**.119**	**.134**	**.378**	**.135**	**.154**	**.215**	.018	**.472**	**.338**	**.536**	**.436**

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Pearson correlations coefficients are reported. Significant coefficients ($p < 0.05$) are highlighted in bold. Parental education and employment level factors have been omitted for brevity (see the Supplemental Material for more correlations). Teaching factors are shaded for clarity.

were similarly predicted for comparability (Table 4), and were then predicted through more detailed models for greater insight (Table 5).

In PISA 2006, when accounting for the students' different background characteristics (and the other teaching approaches), the students' reports of encountering different teaching practices had varying independent associations with the different outcomes (Table 4). The 'applications of science' was the only teaching factor to consistently and positively independently associate with each outcome, including students' science-related aspirations (Table 4).

Students' science-related aspirations were then predicted through sequential steps, which offered more comprehensive insights (Table 5). The models considered: students' home and background (Table 5, step 1); teaching approaches (Table 5, step 2, mirroring Table 4); students' interest, utility, and task-scores (Table 5, step 3); students' self-efficacy for undertaking science areas/tasks and their interest in science areas/topics (Table 5, step 4); and then the remaining predictors that were only measured in PISA 2006 and not PISA 2015 (Table 5, step 5).

Students' home and background characteristics only explained a modest amount of variance in students' aspirations, but this revealed the relevance of home/extra-curricular activities and fathers working within science, which independently positively associated with aspirations (i.e. increasing the odds of students aspiring to science-related careers; Table 5, step 1). Including the teaching factors produced little change in explained variance; the 'applications of science' positively associated with aspirations (i.e. increasing the odds of students aspiring to science-related careers) while 'student-led investigations' negatively associated with aspirations (i.e. decreasing the odds; Table 5, step 2). Including students' general interest, perceived utility, and task-scores highlighted that these all positively associated with aspirations (while the teaching factors lost significance; Table 5, step 3). Including students' interest in science areas/topics and self-efficacy beliefs highlighted that these were not significantly associated with intentions, when also accounting for students' interest, utility, and task-scores (Table 5, step 4). Finally, accounting for the most

Table 3
Correlation summary (PISA 2015).

Item/factor	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Science-related career aspirations (1=Y)	1												
2. Working in science, mother (1=Y)	**.072**	1											
3. Working in science, father (1=Y)	**.058**	**.112**	1										
4. Gender (1=boy)	-.014	**.029**	.001	1									
5. Home/extra-curricular activities	**.154**	**.047**	**.052**	**.113**	1								
6. Teaching: interaction/debate	-.013	-.016	.004	**.161**	**.260**	1							
7. Teaching: hands-on/practical activities	**.028**	**.027**	**.035**	**.050**	**.205**	**.477**	1						
8. Teaching: applications of science	**.083**	-.003	.000	**.098**	**.253**	**.465**	**.445**	1					
9. Teaching: student-led investigations	.024	-.007	.021	**.085**	**.255**	**.599**	**.573**	**.481**	1				
10. Interest/intrinsic value	**.221**	**.095**	**.051**	**.068**	**.438**	**.149**	**.187**	**.309**	**.164**	1			
11. Utility/extrinsic value	**.345**	**.049**	**.044**	.012	**.335**	**.134**	**.152**	**.243**	**.152**	**.454**	1		
12. Task-score	**.163**	**.143**	**.073**	.002	**.086**	**-.200**	.010	**.085**	**-.102**	**.318**	**.157**	1	
13. Interest in science areas/topics	**.185**	**.077**	**.031**	**.109**	**.419**	**.127**	**.161**	**.275**	**.144**	**.633**	**.380**	**.318**	1
14. Self-efficacy for tasks/areas	**.162**	**.075**	**.044**	**.098**	**.370**	**.121**	**.177**	**.283**	**.166**	**.473**	**.352**	**.373**	**.449**

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Pearson correlations coefficients are reported. Significant coefficients ($p < 0.05$) are highlighted in bold. Parental education and employment level factors have been omitted for brevity (see the Supplemental Material for more correlations). Teaching factors are shaded for clarity.

comprehensive array of factors, students' science-related career aspirations in PISA 2006 most strongly associated with the students' perceived utility of science, personal value of science, perceived provision of careers information, fathers working within science-related careers, and engagement in home/extra-curricular science activities (Table 5, step 5).

In summary, students who reported experiencing more teaching that conveyed the 'applications of science' generally reported higher science aspirations, when accounting for the other teaching approaches and their background characteristics (Table 4). Students who reported higher 'applications of science' also generally reported higher interest, utility, and had higher attainment (Table 4); when accounting for these factors, the 'applications of science' had no associations with aspirations (Table 5; i.e. higher aspirations primarily associated with higher utility, rather than from experiencing higher 'applications of science' in itself). Expressed simply, the results suggest that conveying the 'applications of science' may not necessarily foster science aspirations directly, but may primarily help foster students' perceived utility (Table 4), which may then primarily foster aspirations (Table 5). However, given the cross-sectional nature of the survey, any such processes can only be inferred and not proven.

3.3. Modelling theorised antecedents and students' aspirations (PISA, 2015)

The analysis was repeated for PISA 2015 to consider a more contemporary perspective, and to consider whether any results were similarly observed in both PISA 2006 and in PISA 2015.

In PISA 2015 (Table 6), the 'applications of science' was the only teaching factor to consistently and positively associate with students' interest, perceived utility, task-scores, self-efficacy, and aspirations, when accounting for the other teaching approaches and differences in students' background characteristics (which mirrored the earlier results from PISA 2006).

In more detailed models (Table 7), students' aspirations were initially positively associated with the students' engagement in

Table 4
Summary of models predicting interest, utility, task-scores, self-efficacy, and science-related career aspirations (PISA 2006).

	Interest/intrinsic value (linear)		Utility/extrinsic value (linear)		Task-score (linear)		Self-efficacy (linear)		Science-related career aspirations (logistic)	
Item/factor	Std. Effect	Sig.	Std. Effect	Sig.	Std. Effect	Sig.	Std. Effect	Sig.	Exp.	Sig.
Intercept/constant	**NA**	**<.001**	**NA**	**<.001**	**NA**	**<.001**	NA	**<.001**	**(-) .013**	**<.001**
Gender (1=boy)	**.066**	**<.001**	.012	.345	**.042**	**.009**	**.094**	**<.001**	(-) .969	.696
Home possessions	.018	.297	.029	.066	**.115**	**<.001**	**.132**	**<.001**	(-) .992	.873
Working in science, mother (1=Y)	.008	.511	.021	.083	.006	.636	.002	.874	1.056	.777
Working in science, father (1=Y)	.010	.430	**.035**	**.004**	**.037**	**.021**	**.026**	**.025**	**1.674**	**<.001**
Education level, mother	**-.031**	**.043**	**-.038**	**.019**	.015	.424	.026	.089	1.006	.858
Education level, father	.044	.027	**.065**	**<.001**	-.004	.849	.028	.118	1.014	.704
Occupational level, mother	.008	.552	-.015	.226	**.135**	**<.001**	**.041**	**.003**	**1.006**	**.027**
Occupational level, father	**.054**	**.007**	-.010	.578	**.199**	**<.001**	**.073**	**<.001**	**1.009**	**.007**
Home/extra-curricular activities	**.470**	**<.001**	**.325**	**<.001**	**.170**	**<.001**	**.305**	**<.001**	**3.401**	**<.001**
Teaching: interaction/debate	**.110**	**<.001**	**.062**	**.003**	.003	.875	**.039**	**.016**	1.035	.696
Teaching: hands-on/practical activities	**.059**	**.001**	**.048**	**.008**	**.079**	**<.001**	**.042**	**.016**	1.024	.791
Teaching: applications of science	**.121**	**<.001**	**.174**	**<.001**	**.086**	**<.001**	**.123**	**<.001**	**1.286**	**.004**
Teaching: student-led investigations	**-.118**	**<.001**	-.018	.302	**-.296**	**<.001**	**-.137**	**<.001**	**(-) .691**	**<.001**
Explained variance	34.2%		22.5%		25.9%		23.3%		11.8%	

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Linear modelling was used to predict interest, utility, self-efficacy, and task-scores; standardised coefficients ('Std. Effect') and significance ('Sig.'; *p*-values) are reported. Logistic modelling was used to predict science-related career aspirations; exponential coefficients ('Exp.') and significance ('Sig.'; *p*-values) are reported. Exponential coefficients are 'odds ratios'; for one unit change in the predictor, an exponential coefficient above 1 reflects increased odds of the student intending a science career, while an exponential coefficient below 1 reflects decreased odds (minus signs have been added in brackets for additional clarity in these cases). Significant coefficients ($p < 0.05$) are highlighted in bold. Explained variance shows adjusted R^2 for linear models and Nagelkerke R^2 for logistic models. Teaching factors are shaded for clarity.

home/extra-curricular science activities, and with their parents working in science-related fields (Table 7, step 1). Including teaching approaches highlighted that 'interaction/debate' was negatively associated with aspirations while conveying the 'applications of science' was positively associated with aspirations, accounting for the other modelled factors (Table 7, step 2). Including the students' general interest, perceived utility, and task-scores highlighted that these positively associated with aspirations, while earlier factors lost significance (Table 7, step 3): home/extra-curricular activities, the 'applications of science' in teaching, and parents working in science all lost significance at this stage. Including students' self-efficacy for undertaking science areas/tasks and students' interest in science areas/topics revealed that these were not significantly associated with aspirations, when accounting for the other factors (Table 7, step 4). Including further factors, measured in PISA 2015 but not in PISA 2006, revealed that expecting to undertake higher levels of education (measured on a scale from the minimum compulsory level at secondary school, through upper-secondary education, through to university, and including equivalent vocational levels within the response options) was the only other relevant factor to aspirations (Table 7, step 5). Finally, when accounting for the most comprehensive array of factors, the students' science-related career aspirations in PISA 2015 positively associated with their perceived utility of science, their expected level of education, their general interest in science, and their science task-scores, and negatively associated with 'interaction/debate' in teaching (Table 7, step 5).

In summary, considered together, these results again suggested that students with higher interest, utility, and/or task-scores were

Table 5
Detailed models predicting science-related career aspirations (PISA 2006).

	Step 1		Step 2		Step 3		Step 4		Step 5	
Item/factor	Exp.	Sig.	Exp.	Sig.	Exp.	Sig.	Exp.	Sig.	Exp.	Sig.
Intercept/constant	**(-) .014**	**<.001**	**(-) .013**	**<.001**	**(-) <.001**	**<.001**	**(-) <.001**	**<.001**	**(-) <.001**	**<.001**
Gender (1=boy)	(-) .950	.518	(-) .969	.696	(-) .911	.285	(-) .916	.313	(-) .932	.424
Home possessions	1.010	.841	(-) .992	.873	(-) .919	.163	(-) .922	.178	(-) .914	.149
Working in science, mother (1=Y)	1.070	.726	1.056	.777	(-) .910	.658	(-) .915	.676	(-) .918	.694
Working in science, father (1=Y)	**1.667**	**<.001**	**1.674**	**<.001**	**1.532**	**.003**	**1.533**	**.003**	**1.496**	**.007**
Education level, mother	1.006	.862	1.006	.858	1.027	.499	1.028	.492	1.032	.435
Education level, father	1.014	.713	1.014	.704	(-) .977	.552	(-) .978	.570	(-) .966	.373
Occupational level, mother	**1.007**	**.010**	**1.006**	**.027**	1.005	.053	1.005	.057	1.004	.085
Occupational level, father	**1.010**	**.005**	**1.009**	**.007**	1.006	.111	1.006	.116	1.006	.098
Home/extra-curricular activities	**3.380**	**<.001**	**3.401**	**<.001**	**1.441**	**<.001**	**1.440**	**<.001**	**1.238**	**.046**
Teaching: interaction/debate			1.035	.696	(-) .954	.611	(-) .956	.625	(-) .927	.418
Teaching: hands-on/practical activities			1.024	.791	(-) .897	.269	(-) .895	.265	(-) .909	.335
Teaching: applications of science			**1.286**	**.004**	(-) .934	.449	(-) .934	.447	(-) .909	.309
Teaching: student-led investigations			**(-) .691**	**<.001**	(-) .838	.073	(-) .838	.071	**(-) .791**	**.014**
Interest/intrinsic value					**1.263**	**.023**	**1.247**	**.045**	1.137	.248
Utility/extrinsic value					**4.490**	**<.001**	**4.474**	**<.001**	**3.587**	**<.001**
Task-score					**1.003**	**<.001**	**1.003**	**<.001**	**1.004**	**<.001**
Interest in science areas/topics							1.064	.527	(-) .985	.876
Self-efficacy for tasks/areas							(-) .925	.328	**(-) .830**	**.034**
Self-concept									1.091	.410
Personal value									**1.804**	**<.001**
General value									(-) .757	.062
School career preparation									(-) .939	.588
School career information									**1.524**	**<.001**
Explained variance	10.9%		11.8%		29.9%		29.9%		31.5%	

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Exponential coefficients ('Exp.') and significance ('Sig.'; *p*-values) are reported. Exponential coefficients are 'odds ratios'; for one unit change in the predictor, an exponential coefficient above 1 reflects increased odds of the student intending a science career, while an exponential coefficient below 1 reflects decreased odds (minus signs have been added in brackets for additional clarity in these cases). Significant coefficients ($p < 0.05$) are highlighted in bold. Explained variance shows Nagelkerke R^2. Teaching factors are shaded for clarity.

more likely to report science aspirations (Table 7). The initially observed positive association between 'applications of science' and aspirations could be inferred to follow from underlying positive associations between 'applications of science' and interest, utility, and task-scores (which then positively associated with aspirations; Table 6 and Table 7). This mirrored the earlier results from PISA 2006, although again, given the cross-sectional nature of the survey, any such processes can only be inferred and not proven.

4. Discussion

The presented results highlighted the importance of students' perceived utility of science, and to a lesser extent their interest in science, in relation to their science-related career aspirations, even when accounting for extensive arrays of other factors. The clearest new insight for science education was that conveying the 'applications of science' was the only measured teaching approach to

Table 6
Summary of models predicting interest, utility, task-scores, self-efficacy, and science-related career aspirations (PISA 2015).

Item/factor	Interest/intrinsic value (linear)		Utility/extrinsic value (linear)		Task-score (linear)		Self-efficacy (linear)		Science-related career aspirations (logistic)	
	Std. Effect	Sig.	Std. Effect	Sig.	Std. Effect	Sig.	Std. Effect	Sig.	Exp.	Sig.
Intercept/constant	**NA**	**<.001**	**NA**	**<.001**	**NA**	**<.001**	**NA**	**<.001**	**(-) .120**	**<.001**
Gender (1=boy)	.010	.466	**-.035**	**.008**	.022	.211	**.056**	**<.001**	(-) .881	.196
Home possessions	**.043**	**.016**	.019	.240	**.170**	**<.001**	**.120**	**<.001**	1.011	.776
Working in science, mother (1=Y)	**.049**	**.001**	**.035**	**.025**	.017	.260	.017	.216	**1.377**	**.020**
Working in science, father (1=Y)	.012	.404	.022	.193	-.011	.474	-.019	.215	**1.350**	**.013**
Education level, mother	-.025	.181	**-.037**	**.020**	**.043**	**.004**	.033	.100	(-) .968	.357
Education level, father	**.045**	**.019**	**.076**	**<.001**	-.038	.069	.027	.087	1.046	.131
Occupational level, mother	.021	.213	-.038	.105	**.176**	**<.001**	.021	.239	1.002	.303
Occupational level, father	.012	.476	.009	.691	**.075**	**<.001**	**.043**	**.026**	1.000	.952
Home/extra-curricular activities	**.379**	**<.001**	**.291**	**<.001**	**.071**	**<.001**	**.295**	**<.001**	**1.777**	**<.001**
Teaching: interaction/debate	**-.054**	**.001**	-.029	.105	**-.270**	**<.001**	**-.078**	**<.001**	**(-) .774**	**<.001**
Teaching: hands-on/practical activities	**.045**	**.006**	.033	.079	**.044**	**.027**	.030	.137	(-) .990	.888
Teaching: applications of science	**.232**	**<.001**	**.171**	**<.001**	**.200**	**<.001**	**.213**	**<.001**	**1.286**	**<.001**
Teaching: student-led investigations	-.042	.056	-.005	.784	**-.098**	**<.001**	.001	.941	.981	.838
Explained variance	25.1%		14.7%		21.4%		21.7%		5.5%	

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Linear modelling was used to predict interest, utility, self-efficacy, and task-scores; standardised coefficients ('Std. Effect') and significance ('Sig.'; *p*-values) are reported. Logistic modelling was used to predict science-related career aspirations; exponential coefficients ('Exp.') and significance ('Sig.'; *p*-values) are reported. Exponential coefficients are 'odds ratios'; for one unit change in the predictor, an exponential coefficient above 1 reflects increased odds of the student intending a science career, while an exponential coefficient below 1 reflects decreased odds (minus signs have been added in brackets for additional clarity in these cases). Significant coefficients ($p < 0.05$) are highlighted in bold. Explained variance shows adjusted R^2 for linear models and Nagelkerke R^2 for logistic models. Teaching factors are shaded for clarity.

consistently and positively associate with students' perceived utility, interest, and task-scores in science, accounting for the other teaching approaches and students' background characteristics. Essentially, conveying the wider relevance of science to everyday life and to wider contexts may help foster students' perceived utility of science, which may then help foster students' aspirations towards science careers.

4.1. Teaching approaches in science

Addressing the first research aim, from across the indicators of students experiencing different frequencies of teaching approaches (engagement in 'interaction/debate', undertaking 'hands-on/practical activities', undertaking 'student-led investigations', and teachers conveying the 'applications of science'), conveying the 'applications of science' was the only approach to consistently and positively associate with theorised antecedents of aspirations from the expectancy-value model (specifically, students' interest, perceived utility, self-efficacy beliefs, and their task-scores in science), when accounting for the other teaching approaches and students' background characteristics. These results were consistently observed in both PISA 2006 and PISA 2015.

The results supported the hypothesis that explaining the wider context or applications of science would associate with students' interest and perceived utility of science, which accordingly coheres with implications from existing research (Savelsbergh et al., 2016; Straw and Macleod, 2015). However, the results did not clearly support the hypothesis that inquiry-based teaching approaches

Table 7
Detailed models predicting science-related career aspirations (PISA 2015).

	Step 1		Step 2		Step 3		Step 4		Step 5	
Item/factor	Exp.	Sig.	Exp.	Sig.	Exp.	Sig.	Exp.	Sig.	Exp.	Sig.
Intercept/constant	**(-) .144**	**<.001**	**(-) .120**	**<.001**	**(-) .003**	**<.001**	**(-) .003**	**<.001**	**(-) .005**	**<.001**
Gender (1=boy)	(-) .862	.128	(-) .881	.196	(-) .928	.474	(-) .923	.446	1.028	.807
Home possessions	1.023	.570	1.011	.776	(-) .958	.340	(-) .958	.336	(-) .943	.209
Working in science, mother (1=Y)	**1.361**	**.023**	**1.377**	**.020**	1.275	.106	1.272	.107	1.310	.067
Working in science, father (1=Y)	**1.333**	**.017**	**1.350**	**.013**	1.302	.059	1.305	.057	1.305	.058
Education level, mother	(-) .965	.314	(-) .968	.357	(-) .979	.545	(-) .979	.554	(-) .966	.332
Education level, father	1.048	.118	1.046	.131	1.012	.698	1.011	.718	(-) .993	.817
Occupational level, mother	1.003	.212	1.002	.303	1.002	.507	1.002	.493	1.001	.685
Occupational level, father	1.000	.924	1.000	.952	(-) .999	.613	(-) .999	.614	(-) .999	.538
Home/extra-curricular activities	**1.755**	**<.001**	**1.777**	**<.001**	1.121	.121	1.109	.182	1.088	.275
Teaching: interaction/debate			**(-) .774**	**<.001**	**(-) .850**	**.018**	**(-) .850**	**.019**	(-) **.858**	**.029**
Teaching: hands-on/practical activities			(-) .990	.888	(-) .923	.306	(-) .924	.310	(-) .922	.311
Teaching: applications of science			**1.286**	**<.001**	1.017	.754	1.014	.797	1.005	.935
Teaching: student-led investigations			.981	.838	1.047	.649	1.048	.641	1.064	.535
Interest/intrinsic value					**1.198**	**.008**	**1.163**	**.046**	**1.153**	**.050**
Utility/extrinsic value					**3.045**	**<.001**	**3.039**	**<.001**	**2.936**	**<.001**
Task-score					**1.002**	**<.001**	**1.002**	**<.001**	**1.001**	**.030**
Interest in science areas/topics							1.079	.337	1.095	.238
Self-efficacy for tasks/areas							(-) .983	.817	(-) .962	.615
Highest expected level of education									**1.176**	**<.001**
Teaching: perceived fairness of teacher									1.040	.466
Teaching: disciplinary climate									1.078	.244
Teaching: student support									1.038	.610
Teaching: feedback									(-) .929	.351
Teaching: adaptive instruction									1.039	.557
Teaching: teacher-directed instruction									(-) .936	.280
Parental encouragement in education									(-) .981	.805
Anxiety (absence of)									(-) .952	.427
Team working									1.023	.827
Achievement motivation (ambition)									(-) .921	.281
School belonging									(-) .960	.622
Epistemic beliefs about science									(-) .976	.794
Explained variance	4.4%		5.5%		20.2%		20.2%		21.6%	

Notes: Missing responses were estimated by expectation-maximisation; task-scores (plausible-values) were aggregated via multiple-imputation. Exponential coefficients ('Exp.') and significance ('Sig.'; *p*-values) are reported. Exponential coefficients are 'odds ratios'; for one unit change in the predictor, an exponential coefficient above 1 reflects increased odds of the student intending a science career, while an exponential coefficient below 1 reflects decreased odds (minus signs have been added in brackets for additional clarity in these cases). Significant coefficients ($p < 0.05$) are highlighted in bold. Explained variance shows Nagelkerke R^2. Teaching factors are shaded for clarity.

(assumed to be identified through the 'hands-on/practical activities' and 'student-led investigations' indicators) would associate with higher interest (Savelsbergh et al., 2016). When accounting for the other teaching approaches and students' background, in both PISA 2006 and PISA 2015, 'hands-on/practical activities' had positive but minimal associations with students' interest. However, when accounting for the other factors, 'student-led investigations' negatively associated with students' interest in PISA 2006 and had no significant association with interest in PISA 2015.

The analysis considered indicators of teaching approaches that have variously been explored and applied within science education. Applying 'hands-on/practical activities' has often been assumed to reflect the empirical nature of science (Millar, 1998). Practical work and 'student-led investigations' both occur within wider ideas of inquiry-based learning of science, which again aim to reflect overall processes of scientific inquiry (Furtak et al., 2012). Fostering 'interaction/debate' or argumentation has similarly been assumed to reflect aspects of scientific inquiry, such as reasoning and justification (Erduran & Jiménez-Aleixandre, 2007). Alternately, conveying the 'applications of science' does not necessarily require an underlying assumption that students must learn by doing what scientists do. Conveying the 'applications of science' may potentially link with wider teaching/learning approaches where students learn scientific skills and ideas specifically through considering applied contexts, but does not necessarily imply or require this (Bennett et al., 2007). Conveying the 'applications of science' could supplement any other teaching approaches, practical or otherwise.

On a wider level, the presented results highlight the potential benefit of continuing to explore how students perceive their teaching/learning context, rather than focusing on applying theoretical or conceptual ideas of (or various other rationales for) how students could or should learn science. Assumptions that students must learn by doing what scientists do may appear reasonable, but may risk science education focusing only on professional development, and may inadvertently perpetuate an idealised or discouraging version of who or what a scientist is (Archer, Dawson, DeWitt, Seakins, & Wong, 2015; Claussen & Osborne, 2013; Osborne & Dillon, 2008). For example, research in England has highlighted that girls who strongly aspired towards physics often preferred the theoretical elements and 'big ideas' of physics rather than practical work (Archer, Moote, Francis, DeWitt, & Yeomans, 2016). Widening foci may then also help consider or address differences in the numbers of students aspiring towards science.

4.2. Science-related career aspirations

Addressing the second research aim, students' perceived utility of science (valuing science through thinking that science leads to various benefits such as increased skills and facilitating careers) had the strongest positive independent association with their science-related career aspirations. This finding was consistent across PISA 2006 and PISA 2015. This supported the earlier hypothesis, and coheres with recent studies undertaken within England (DeWitt & Archer, 2015; Mujtaba & Reiss, 2014; Sheldrake, 2016). Students' interest in science also associated with aspirations, although at a lower magnitude than utility in PISA 2015, and was not significantly associated with aspirations in PISA 2006 when accounting for the comprehensive array of other factors. Accordingly, further research into any differing effects of utility, interest, and/or other factors at different times, educational stages, and/or choices may be beneficial.

In contrast to the assumptions of the expectancy-value model (Eccles, 2009), students' confidence, expressed as self-efficacy beliefs, was not associated with their aspirations when accounting for the other modelled factors. This may follow from the OECD measuring self-efficacy as students' confidence to undertake applied tasks (their confidence in being able to, for example, 'Recognise the science question that underlies a newspaper report on a health issue' and 'Predict how changes to an environment will affect the survival of certain species'). Students' confidence in their capabilities to accomplish other, more contextually-relevant and/or attainment-based, tasks may be more relevant to their studying or career decisions. For example, recent research in England has measured self-efficacy beliefs through students' confidence in being able to gain particular grades in upper-secondary school science examinations (A-Levels), which indeed associated with their aspirations (Sheldrake, 2016). Researchers may need to remain mindful that insights from PISA may be implicitly constrained by the nature of its particular questionnaires (specifically, what is measured and how it is measured). As another example, in PISA 2006, students' personal value of science to their own identity (agreement with items such as 'Science is very relevant to me') had the second-strongest association with aspirations (after the students' perceived utility of science), but personal value was not measured in PISA 2015. Future research may benefit from measuring and/or exploring the implications of students perceiving science to be an inherent aspect of personal identity and/or as a means to convey an identity to other people (Carlone & Johnson, 2007; Sheldrake, 2016).

The results also highlighted few associations between teaching approaches and students' aspirations, when accounting for the full arrays of other factors. In the final models, 'student-led investigations' negatively associated with aspirations but only in PISA 2006, while 'interaction/debate' negatively associated with aspirations but only in PISA 2015. These varying results suggest that more research may be beneficial (perhaps measuring teaching approaches in other ways and/or in more detail), and/or that such associations are unavoidably somewhat dependent on particular cohorts of students. One set of results was consistent across PISA 2006 and PISA 2015, however: teaching the 'applications of science' initially positively associated with students' aspirations, but lost significance once students' interest and utility were modelled (which positively associated with aspirations and with the 'applications of science'). It was plausible to infer that this pattern of results reflected the 'applications of science' positively associating with interest and utility, which then positively associated with aspirations (i.e. where the teaching approach has an indirect rather than a direct association with aspirations). This partially supported the earlier hypothesis and hence coheres with implications from prior research (e.g. Eccles, 2009; Wang, 2012). However, future research, occurring with the same students over time, remains necessary in order to provide conclusive evidence of causes and effects.

From the indicators of students' home and background (including their gender), engagement in home/extra-curricular science activities (which measured frequencies of watching science programmes, reading science books, magazines, and web-sites, and attending science clubs) had the strongest positive association with their aspirations. This coheres with research highlighting the potential influence of extra-curricular activities (Aschbacher, Li, & Roth, 2010; Bennett, Lubben, & Hampden-Thompson, 2013; Straw & Macleod, 2015). However, in PISA 2015, home/extra-curricular activities had no significant association with aspirations, when accounting for students' interest, utility, and task-scores, which coheres with existing research that has suggested that students' context may help foster (or limit) their attitudes to science (DeWitt & Archer, 2015; Mujtaba & Reiss, 2014). While educators cannot easily influence students' home activities, some extra-curricular activities may be facilitated within schools, such as providing science clubs and/or ambassadors from science-related fields who visit schools to give career talks, provide advice, and deliver demonstrations (Straw & Macleod, 2015).

On a wider level, given the overall importance of students' perceived utility of science, it may be beneficial to explore in more detail how and why science is considered indirectly valuable, for example perhaps as 'use value' (e.g. studying science to gain skills for a specific career, not necessarily within science) and/or as 'exchange value' (e.g. studying science to gain qualifications that are generically valued) (Black & Hernandez-Martinez, 2016). Studying science may also be (both indirectly and directly) valued through being part of an expected or unavoidable progression to become a scientist, which is ultimately what is valued and aimed for. Increased clarification may be beneficial, since otherwise highlighting that science can be used as a means to achieve many different careers may not necessarily inspire students to actually become scientists, although this may help reassure students that studying science can pragmatically keep their options open.

4.3. Limitations

PISA studies cover nationally-representative samples of students. Despite the similarities across the PISA 2006 and PISA 2015 results, the differences suggest that some results may be sample-dependent. Specifically, even nationally-representative samples are grounded in particular sampling methodologies that occur at a particular time. Future research may need to consider whether and/or how choices are influenced by wider social or cultural contexts that might change over time. This might be achieved through integrating any such indicators within statistical models of longitudinal samples, and/or through surveying 'the current Year 11' or another specific cohort every year and hence considering how different cohorts might systematically change (or be similar) in their thinking, and/or through qualitative approaches that may reveal far more detail into students' experiences and beliefs than abstracted statistical models are able to.

Measurement in PISA studies is planned and implemented by the OECD rather than by different researchers addressing their own specific aims/questions. Future research may therefore benefit from considering further and/or different indicators of students' attitudes, beliefs, and choices. Additionally, as in any other research, the presented results only apply to the items/factors as measured. For example, the reported frequency of experiencing 'interaction/debate' (measured through items such as experiencing 'class debate about investigations'), may cover discussion into how best to undertake an investigation, how to engage in evidencing or justifying conclusions, to address misconceptions about results/conclusions, and/or any number of other areas, potentially within or outside of theoretical ideas of 'argumentation' (Erduran & Jiménez-Aleixandre, 2007).

The perceived frequencies of encountering different teaching approaches as reported by students might differ from frequencies as reported by teachers. The presented research focused on students' perceptions and beliefs, broadly following from motivational theory (Eccles, 2009), but other perspectives and/or analytical approaches remain possible (although limited in this case by the data available within PISA surveys).

Students' 'science-related career aspirations' can also be defined in numerous ways. When planning and implementing new surveys, researchers may also need to consider students' aspirations towards studying science at the next educational stage(s) as well as working within a science career, and consider whether results vary from those seen here. Additionally, research in science education in England has often considered aspirations as degrees of agreement or disagreement (e.g. DeWitt & Archer, 2015; Mujtaba & Reiss, 2014), while the research presented here unavoidably considered a binary/dichotomous aspirations indicator (where students either intended a career in science or did not). Research may benefit from also exploring whether and how particular thresholds of agreement are relevant, in order to help link both approaches.

Fundamentally, the analysis only considered associations between concurrently-reported items/factors. Longitudinal explorations would be beneficial to clarify whether specific items/factors are indeed antecedents to particular outcomes, and formalised structural models could then be applied (e.g. path analysis and/or structural equation modelling), which are less meaningful with cross-sectional data. This is perhaps best illustrated through the positive association between higher expected levels of education and science-related aspirations that was observed in PISA 2015. It is possible that higher expected levels of education somehow foster science-related aspirations (e.g. someone first decides that they want to study at university, and then thinks that they might as well study science since they would be at university; the process of someone's decision-making remains somewhat unclear within this interpretation). Conversely, it is possible that students recognise that science-related aspirations require higher levels of education, and any causality is actually reversed (e.g. someone first decides that they want a career in science, and then recognises that they need to study at university for this). Alternately, there may not necessarily be simple cause-effect relations, and science-related aspirations and expected levels of education may develop concurrently and/or rely on wider assumptions or beliefs (i.e. measuring further factors may be necessary for increased insight).

In prior research, students have retrospectively reported that their studying choices followed from their interest and perceived utility (e.g. Jensen & Henriksen, 2015; Vidal Rodeiro, 2007), so it may nevertheless be plausible to infer that fostering interest and utility can help foster someone's aspirations (i.e. in contrast to other factors such as someone's expected level of education, where relations may be less clear). Nevertheless, it generally remains less clear how attitudes form (and/or influence aspirations) over time; it remains possible that students' attitudes, beliefs, and choices associate and form in complex ways, and future longitudinal research into the area would be beneficial.

4.4. Conclusions

Analysis of PISA 2006 and PISA 2015 for students in England highlighted that teaching the 'applications of science' (conveying the wider applications and/or relevance of science to students' lives) was the only measured teaching approach to consistently and positively associate with students' interest and perceived utility of science, accounting for other teaching approaches and students' background characteristics. Additionally, in PISA 2006 and in PISA 2015, the 'applications of science' initially positively associated with students' science-related career aspirations, but lost significance once students' interest, utility, and other factors were modelled.

Students' perceived utility of science (students valuing science through thinking that science leads to various benefits such as fostering their skills and facilitating careers) consistently had the strongest positive association with their science-related career aspirations, in PISA 2006 and in PISA 2015, accounting for extensive arrays of other factors. Students' interest in science also appeared relevant to their aspirations in PISA 2015.

Overall, these patterns of results suggested that conveying the wider relevance of science to everyday life and to wider contexts may help foster students' interest in science and perceived utility of science, which may then help foster students' aspirations towards science careers.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijer.2017.08.002.

References

Abrahams, I., & Millar, R. (2008). Does Practical Work Really Work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education*, *30*(14), 1945–1969. http://dx.doi.org/10.1080/09500690701749305.

Abrahams, I., & Reiss, M. J. (2012). Practical work: Its effectiveness in primary and secondary schools in england. *Journal of Research in Science Teaching*, *49*(8), 1035–1055. http://dx.doi.org/10.1002/tea.21036.

Abrahams, I. (2009). Does Practical Work Really Motivate? A study of the affective value of practical work in secondary school science. *International Journal of Science Education*, *31*(17), 2335–2353. http://dx.doi.org/10.1080/09500690802342836.

Archer, L., DeWitt, J., & Dillon, J. (2014). 'It didn't really change my opinion': exploring what works, what doesn't and why in a school science, technology, engineering and mathematics careers intervention. *Research in Science & Technological Education*, *32*(1), 35–55. http://dx.doi.org/10.1080/02635143.2013.865601.

Archer, L., Dawson, E., DeWitt, J., Seakins, A., & Wong, B. (2015). Science capital: A conceptual, methodological, and empirical argument for extending Bourdieusian notions of capital beyond the arts. *Journal of Research in Science Teaching*, *52*(7), 922–948. http://dx.doi.org/10.1002/tea.21227.

Archer, L., Moote, J., Francis, B., DeWitt, J., & Yeomans, L. (2016). The exceptional physics girl: A sociological analysis of multimethod data from young women aged 10–16 to explore gendered patterns of post-16 participation. *American Educational Research Journal*, 1–39. http://dx.doi.org/10.3102/0002831216678379.

Aschbacher, P., Li, E., & Roth, E. (2010). Is science me? high school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564–582. http://dx.doi.org/10.1002/tea.20353.

Bøe, M. V., & Henriksen, E. K. (2013). Love it or leave it: Norwegian students' motivations and expectations for postcompulsory physics. *Science Education*, *97*(4), 550–573. http://dx.doi.org/10.1002/sce.21068.

Bøe, M. V., & Henriksen, E. K. (2015). Expectancy-Value perspectives on choice of science and technology education in late-Modern societies. In E. K. Henriksen, J. Dillon, & J. Ryder (Eds.), *Understanding student participation and choice in science and technology education* (pp. 17–29). Dordrecht: Springer. http://dx.doi.org/10.1007/978-94-007-7793-4_2.

Bøe, M. V. (2012). Science choices in norwegian upper secondary school: What matters? *Science Education*, *96*(1), 1–20. http://dx.doi.org/10.1002/sce.20461.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Bates, P., Pollard, E., Usher, T., & Oakley, J. (2009). *Who is heading for HE? young people's perceptions of, and decisions about, higher education*. London: Department for Business, Innovation and Skills.

Bennett, J., & Lubben, F. (2006). Context-based chemistry: The salters approach. *International Journal of Science Education*, *28*(9), 999–1015. http://dx.doi.org/10.1080/09500690600702496.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education*, *91*(3), 347–370. http://dx.doi.org/10.1002/sce.20186.

Bennett, J., Lubben, F., & Hampden-Thompson, G. (2013). Schools that make a difference to post-compulsory uptake of physical science subjects: Some comparative case studies in england. *International Journal of Science Education*, *35*(4), 663–689. http://dx.doi.org/10.1080/09500693.2011.641131.

Bernacki, M., Nokes-Malach, T., Richey, J. E., & Belenky, D. (2016). Science diaries: A brief writing intervention to improve motivation to learn science. *Educational*

Psychology, *36*(1), 26–46. http://dx.doi.org/10.1080/01443410.2014.895293.
Black, L., & Hernandez-Martinez, P. (2016). Re-thinking science capital: The role of ‘capital’ and ‘identity’ in mediating students’ engagement with mathematically demanding programmes at university. *Teaching Mathematics and Its Applications*, *35*(3), 131–143. http://dx.doi.org/10.1093/teamat/hrw016.
Bong, M., & Skaalvik, E. (2003). Academic self-concept and self-efficacy: How different are they really? *Educational Psychology Review*, *15*(1), 1–40. http://dx.doi.org/10.1023/A:1021302408382.
CASE [Campaign for Science and Engineering] (2014). *Improving diversity in STEM*. London: Campaign for Science and Engineering.
Carlone, H., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218. http://dx.doi.org/10.1002/tea.20237.
Cavagnetto, A. (2010). Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts. *Review of Educational Research*, *80*(3), 336–371. http://dx.doi.org/10.3102/0034654310376953.
Claussen, S., & Osborne, J. (2013). Bourdieu's notion of cultural capital and its implications for the science curriculum. *Science Education*, *97*(1), 58–79. http://dx.doi.org/10.1002/sce.21040.
Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, New Jersey: Lawrence Earlbaum Associates.
DeWitt, J., & Archer, L. (2015). Who Aspires to a Science Career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education*, *37*(13), 2170–2192. http://dx.doi.org/10.1080/09500693.2015.1071899.
DeWitt, J., Archer, L., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2011). High aspirations but low progression: The science aspirations-careers paradox amongst minority ethnic students. *International Journal of Science and Mathematics Education*, *9*(2), 243–271. http://dx.doi.org/10.1007/s10763-010-9245-0.
DeWitt, J., Archer, L., & Osborne, J. (2014). Science-related aspirations across the primary–secondary divide: Evidence from two surveys in england. *International Journal of Science Education*, *36*(10), 1609–1629. http://dx.doi.org/10.1080/09500693.2013.871659.
EACEA [Education, Audiovisual and Culture Executive Agency] (2011). *Science education in europe: National policies, practices and research*. Brussels: European Commission [10.2797/7170].
Eccles, J. (2009). Who am I and what am I going to do with my life? Personal and collective identities as motivators of action. *Educational Psychologist*, *44*(2), 78–89. http://dx.doi.org/10.1080/00461520902832368.
Erduran, S., & Jiménez-Aleixandre, M. P. (Eds.), (2007). *Argumentation in science education: Perspectives from classroom-Based research*Dordrecht/London: Springer. http://dx.doi.org/10.1007/978-1-4020-6670-2.
Fischbach, A., Keller, U., Preckel, F., & Brunner, M. (2013). PISA proficiency scores predict educational outcomes. *Learning and Individual Differences*, *24*, 63–72. http://dx.doi.org/10.1016/j.lindif.2012.10.012.
Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. *Review of Educational Research*, *82*(3), 300–329. http://dx.doi.org/10.3102/0034654312457206.
Hampden-Thompson, G., & Bennett, J. (2013). Science teaching and learning activities and students’ engagement in science. *International Journal of Science Education*, *35*(8), 1325–1343. http://dx.doi.org/10.1080/09500693.2011.608093.
Harackiewicz, J., Rozek, C., Hulleman, C., & Hyde, J. (2012). Helping parents to motivate adolescents in mathematics and science: An experimental test of a utility-value intervention. *Psychological Science*, *23*(8), 898–906. http://dx.doi.org/10.1177/0956797611435530.
Hodson, D. (1993). Re-thinking old ways: Towards a more critical approach to practical work in school science. *Studies in Science Education*, *22*(1), 85–142. http://dx.doi.org/10.1080/03057269308560022.
Homer, M., Ryder, J., & Banner, I. (2014). Measuring determinants of post-compulsory participation in science: A comparative study using national data. *British Educational Research Journal*, *40*(4), 610–636. http://dx.doi.org/10.1002/berj.3106.
Hong, H.-Y., & Lin-Siegler, X. (2012). How learning about scientists’ struggles influences students’ interest and learning in physics. *Journal of Educational Psychology*, *104*(2), 469–484. http://dx.doi.org/10.1037/a0026224.
Hulleman, C., & Harackiewicz, J. (2009). Promoting interest and performance in high school science classes. *Science*, *326*(5958), 1410–1412. http://dx.doi.org/10.1126/science.1177067.
IBM (2014). *IBM SPSS missing values 22*. IBM [Retrieved July 1, 2017, from ftp://public.dhe.ibm.com/software/analytics/spss/documentation/statistics/22.0/en/client/Manuals/IBM_SPSS_Missing_Values.pdf].
Jensen, F., & Henriksen, E. K. (2015). Short stories of educational choice: In the words of science and technology students. In E. K. Henriksen, J. Dillon, & J. Ryder (Eds.), *Understanding student participation and choice in science and technology education* (pp. 135–151). Dordrecht: Springer. http://dx.doi.org/10.1007/978-94-007-7793-4_9.
Maltese, A., & Tai, R. (2011). Pipeline persistence: Examining the association of educational experiences with earned degrees in STEM among U.S. students. *Science Education*, *95*(5), 877–907. http://dx.doi.org/10.1002/sce.20441.
Maltese, A., Melki, C., & Wiebke, H. (2014). The nature of experiences responsible for the generation and maintenance of interest in STEM. *Science Education*, *98*(6), 937–962. http://dx.doi.org/10.1002/sce.21132.
Mellors-Bourne, R., Connor, H., & Jackson, C. (2011). *STEM graduates in non-STEM jobs*. London: Department for Business, Innovation and Skills.
Millar, R. (1998). Rhetoric and reality: What practical work in science is really for. In J. Wellington (Ed.), *Practical work in school science. Which way now?* (pp. 16–31). London: Routledge.
Minner, D., Levy, A. J., & Century, J. (2010). Inquiry-Based science Instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. http://dx.doi.org/10.1002/tea.20347.
Morgan, S., Gelbgiser, D., & Weeden, K. (2013). Feeding the pipeline: Gender, occupational plans, and college major selection. *Social Science Research*, *42*(4), 989–1005. http://dx.doi.org/10.1016/j.ssresearch.2013.03.008.
Mujtaba, T., & Reiss, M. J. (2014). A survey of psychological, motivational, family and perceptions of physics education factors that explain 15-year-old students’ aspirations to study physics in post-compulsory english schools. *International Journal of Science and Mathematics Education*, *12*(2), 371–393. http://dx.doi.org/10.1007/s10763-013-9404-1.
NSTC [National Science and Technology Council] (2013). *Federal science, technology, engineering, and mathematics (STEM) education: 5-Year strategic plan*. Washington, DC: Executive Office of the President of the United States.
OECD [Organisation for Economic Co-operation and Development] (2007). *PISA 2006 science competencies for tomorrow's world. volume 1: analysis*. Paris: OECD Publishinghttp://dx.doi.org/10.1787/9789264040014-en.
OECD (2009a). *PISA 2006 Technical Report*Paris: OECD Publishinghttp://dx.doi.org/10.1787/9789264048096-en.
OECD (2009b). *PISA data analysis manual: SPSS* (2nd ed.). Paris: OECD Publishing.
OECD (2015). *Universal basic skills: What countries stand to gain*. Paris: OECD Publishinghttp://dx.doi.org/10.1787/9789264234833-en.
OECD (2016). *PISA 2015 results (Volume I): excellence and equity in education*. Paris: OECD Publishinghttp://dx.doi.org/10.1787/9789264266490-en.
OECD (2017). *PISA 2015 technical report*Paris: OECD Publishing [Retrieved July 1, 2017, from http://www.oecd.org/pisa/data/2015-technical-report].
Osborne, J., & Dillon, J. (2008). *Science education in europe: Critical reflections*. London: The Nuffield Foundation.
Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020. http://dx.doi.org/10.1002/tea.20035.
Osborne, J., Simon, S., Christodoulou, A., Howell-Richardson, C., & Richardson, K. (2013). Learning to argue: A study of four schools and their attempt to develop the use of argumentation as a common instructional practice and its impact on students. *Journal of Research in Science Teaching*, *50*(3), 315–347. http://dx.doi.org/10.1002/tea.21073.
Parker, P., Marsh, H., Ciarrochi, J., Marshall, S., & Abduljabbar, A. S. (2014). Juxtaposing math self-efficacy and self-concept as predictors of long-term achievement outcomes. *Educational Psychology*, *34*(1), 29–48. http://dx.doi.org/10.1080/01443410.2013.797339.
Peugh, J., & Enders, C. (2004). Missing data in educational research: A review of reporting practices and suggestions for improvement. *Review of Educational Research*, *74*(4), 525–556. http://dx.doi.org/10.3102/00346543074004525.
Rönnebeck, S., Bernholt, S., & Ropohl, M. (2016). Searching for common ground – A literature review of empirical research on scientific inquiry activities. *Studies in*

Science Education, *52*(2), 161–197. http://dx.doi.org/10.1080/03057267.2016.1206351.

Ramsden, J. (1997). How does a context-based approach influence understanding of key chemical ideas at 16 + ? *International Journal of Science Education*, *19*(6), 697–710. http://dx.doi.org/10.1080/0950069970190606.

Regan, E., & DeWitt, J. (2015). Attitudes, interest and factors influencing STEM enrolment behaviour: An overview of relevant literature. In E. K. Henriksen, J. Dillon, & J. Ryder (Eds.), *Understanding student participation and choice in science and technology education* (pp. 63–88). Dordrecht: Springer. http://dx.doi.org/10.1007/978-94-007-7793-4_5.

Rosenzweig, E., & Wigfield, A. (2016). STEM motivation interventions for adolescents: A promising start, but further to go. *Educational Psychologist*, *51*(2), 146–163. http://dx.doi.org/10.1080/00461520.2016.1154792.

Royal Society (2006). *A degree of concern? UK first degrees in science, technology and mathematics*. London: The Royal Society.

Royal Society (2008). *A higher degree of concern*. London: The Royal Society.

Royal Society (2014). *Vision for science and mathematics education*. London: The Royal Society.

Rozek, C., Hyde, J., Svoboda, R., Hulleman, C., & Harackiewicz, J. (2015). Gender differences in the effects of a utility-value intervention to help parents motivate adolescents in mathematics and science. *Journal of Educational Psychology*, *107*(1), 195–206. http://dx.doi.org/10.1037/a0036981.

Rubin, D. (1987). *Multiple imputation for nonresponse in surveys*. New York: John Wiley & Sonshttp://dx.doi.org/10.1002/9780470316696.

Ryan, R., & Deci, E. (2000). Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology*, *25*(1), 54–67. http://dx.doi.org/10.1006/ceps.1999.1020.

Savelsbergh, E., Prins, G., Rietbergen, C., Fechner, S., Vaessen, B., Draijer, J., et al. (2016). Effects of innovative science and mathematics teaching on student attitudes and achievement: A meta-analytic study. *Educational Research Review*, *19*, 158–172. http://dx.doi.org/10.1016/j.edurev.2016.07.003.

Schroeder, C., Scott, T., Tolson, H., Huang, T.-Y., & Lee, Y.-H. (2007). A meta-analysis of national research: Effects of teaching strategies on student achievement in science in the United States. *Journal of Research in Science Teaching*, *44*(10), 1436–1460. http://dx.doi.org/10.1002/tea.20212.

Sheldrake, R. (2016). Students' intentions towards studying science at upper-secondary school: The differential effects of under-confidence and over-confidence. *International Journal of Science Education*, *38*(8), 1256–1277. http://dx.doi.org/10.1080/09500693.2016.1186854.

Smith, E. (2011). Women into science and engineering? Gendered participation in higher education STEM subjects. *British Educational Research Journal*, *37*(6), 993–1014. http://dx.doi.org/10.1080/01411926.2010.515019.

Snijders, T., & Bosker, R. (2012). *Multilevel analysis: An introduction to basic and advanced multilevel modeling* (2nd ed.). London: SAGE Publications.

Straw, S., & Macleod, S. (2015). *Evaluation of STEMNET's operations and impacts 2011–2015: Summary report*Slough: National Foundation for Educational Research.

Tai, R., Qi Liu, C., Maltese, A., & Fan, X. (2006). Planning early for careers in science. *Science*, *312*(5777), 1143–1145. http://dx.doi.org/10.1126/science.1128690.

Toplis, R. (2012). Students' views about secondary school science lessons: The role of practical work. *Research in Science Education*, *42*(3), 531–549. http://dx.doi.org/10.1007/s11165-011-9209-6.

Tripney, J., Newman, M., Bangpan, M., Niza, C., MacKintosh, M., & Sinclair, J. (2010). *Factors influencing young people (Aged 14–19) in education about STEM subject choices: A systematic review of the UK literature*. London: Wellcome Trust.

Vaino, K., Holbrook, J., & Rannikmäe, M. (2012). Stimulating students' intrinsic motivation for learning chemistry through the use of context-based learning modules. *Chemistry Education Research and Practice*, *13*(4), 410–419. http://dx.doi.org/10.1039/C2RP20045G.

Vidal Rodeiro, C. (2007). *A level subject choice in England: Patterns of uptake and factors affecting subject preferences*. Cambridge: Cambridge Assessment.

WISE (2014). *Not for people like me? Under-represented groups in science, technology and engineering*. Bradford: WISE.

Wang, M.-T. (2012). Educational and career interests in math: A longitudinal examination of the links between classroom environment, motivational beliefs, and interests. *Developmental Psychology*, *48*(6), 1643–1657. http://dx.doi.org/10.1037/a0027247.

Wigfield, A., & Cambria, J. (2010). Students' achievement values, goal orientations, and interest: Definitions, development, and relations to achievement outcomes. *Developmental Review*, *30*(1), 1–35. http://dx.doi.org/10.1016/j.dr.2009.12.001.