Abstract

We previously proposed that science capital (science-related forms of cultural and social capital) can be used as a theoretical lens for explaining the patterned nature of aspirations and educational participation among young people aged 11-16. Building on these findings, the present paper investigates whether science capital is related to post-18 aspirations to pursue further STEM study and whether science capital can be extended to related disciplines including engineering, maths and technology. Specifically, we report on correlational analyses exploring the relationships between science, technology, engineering and maths attitudes and science capital. Drawing on data from a new survey of 7,013 17/18 year old English secondary school students, analyses showed that science capital, while strongly related to engineering and physical science future study aspirations, was not strongly related to the pursuit of either maths or technology post-secondary study. The findings also suggest that engineering and maths perceptions have a stronger relationship to science capital than perceptions relating to technology. We conclude with a discussion of the implications of these findings and propose that science capital might be more usefully applied to 'SEM', with links to technology fields and aspirations needing further exploration.

Keywords: attitudes, equity, interdisciplinary science, social justice

Introduction

In the UK, and internationally, the issue of how to improve (increase and broaden) post-compulsory participation in Science, Technology, Engineering and Mathematics (STEM) troubles governments, educators and industry alike. These concerns predominantly emanate from the view that STEM industries are vitally important parts of the current and future economy of many countries and that scientifically and technologically advanced nations will require an increasing supply of STEM qualified workers in order to maintain national economic wealth and competitiveness (BIS, 2011; Industry Strategy, 2017; NAO, 2018; RAEng, 2016). In such societies, calls have been made for individuals to have sufficient understanding and knowledge of science and technology in order to be able to participate as active citizens in democratic life (e.g. STEM SMART, 2014). For instance, in the UK there are widespread concerns among government departments and STEM professional societies that insufficient numbers of young people are leaving the education system adequately qualified to work in STEM fields (Industry Strategy, 2017; National Audit Office, 2018; Royal Academy of Engineering, 2012). Fears have been expressed regarding a current and growing STEM skills shortage, for instance employers in the UK have reported finding it difficult to recruit people with appropriate STEM skills and qualifications (e.g. UKCES, 2015) and the Royal Academy of Engineering (2016) predicted that the UK will need to produce around 100,000 STEM graduates per year in order to meet labour market demands. Similar concerns have been raised in other countries, such as the US, where more than half of businesses surveyed in 2014 reported a STEM skills gap, in that they were unable to recruit enough workers with required STEM qualifications to fill their available positions and/or support plans for growth (Business Roundtable, 2014).

Beyond these concerns with ensuring a sufficiently STEM literate workforce and citizenship, attention has also been drawn to the need to address the lack of diversity within post-compulsory STEM education and careers globally – but particularly in the physical sciences, technology and engineering, in which women, lower socio-economic and some minority ethnic communities remain under-represented (Campaign for Science and Engineering, 2014; Christie, O'Neill, Rutter, Young, & Medland, 2017; Kemp, Berry, & Wong, 2018; Millar, 1996; Millar & Osborne, 1998; Osborne 2007; Royal Academy of Engineering, 2016).

Taking gender imbalances as an example, in the UK the Institute of Physics (2014) found that four times as many male students study physics at A-Level as their female counterparts, a disparity reflected across engineering and technology. This imbalance carries through to STEM-based employment, with women occupying just 21% of STEM-based jobs in Britain (WISE, 2016). Women are particularly poorly represented in technology and engineering and the UK sustains the lowest rate of female employment in engineering across the whole of Europe (Perkins, 2013). This narrow demographic profile of the graduate population and workforce in these STEM areas is understood as being a social justice problem that requires addressing in its own right (IOP, 2015; NAO, 2018; Smith 2010 a, b) and as potentially constraining the effectiveness, quality and competitiveness of the STEM sector in general, given arguments about the wide ranging benefits deriving from a broader talent pool (Godwin, Potvin, Hazari, & Lock, 2016; Hong & Page, 2004; Raelin et al., 2014).

For almost half a decade now, feminist scholars have been working to explain the low participation of women in STEM professions and education (Ford & Wajcam, 2016; Long & Fox, 1995; Rossiter, 1982; Rothschild, 1983). Technology and maths have more recently been a focus of this work, with some researchers arguing that male bias exists in the way the disciplines are defined and developed (e.g. Ford & Wajcam, 2016, Mendick, 2006; Wajcam, 1991). Studies have drawn attention to how issues of gender (notably the alignment of STEM fields with masculinity) play a key role in deterring girls and young women from continuing with the mathematics (Mendick, 2005; 2006), science (Archer & DeWitt, 2014), engineering (Connell, 1987; Du, 2006; Tonso, 2006) and technology (Kemp & Wong, 2018; Wong, 2016). Similar arguments have also been made with respect to the perceived 'whiteness' of the respective disciplines (Bullock, 2017; Sammel, 2009). Yet there are still gaps in understanding about how and why some students from communities that have been historically excluded from STEM (such as women) do aspire to and participate in STEM, while the majority do not.. Our research seeks to contribute to a deeper understanding of these persistent problems by focusing on the factors which shape students' aspirations and post-compulsory choices. We use the term aspiration to refer to the future-orientated hopes and ambitions, recognizing that the nature and content of aspirations can vary widely between individuals and across time and place:

> From intensely held goals and desires to looser, more nebulous interests; from 'high' or lofty ambitions to more prosaic, mundane or realistic expectations; from 'already known' and concrete expectations to fragile dreams that are constantly mediated and shaped by external constraints (Archer, Hollingworth & Mendick, 2010, p.78).

Hence our research seeks to understand how and why comparatively few young people aspire to STEM and why those who do tend to come from relatively narrow (privileged) social demographics. As discussed below, our ten-year longitudinal research (tracking a cohort of young people from age 10-18) has identified a range of factors that shape the likelihood of a young person expressing science aspirations, one of the most useful of which has been the concept of 'science capital' (science-related knowledge, resources, behaviors, dispositions and social contacts, Archer, Dawson, DeWitt, Seakins, & Wong, 2015). As outlined below, for the purpose of this paper, aspirations are operationalized as a young person's intentions to study a subject post-18.

Our previous quantitative and qualitative analysis has shown that young people (aged 10-15) with high levels of science capital are significantly more likely to espouse a science identity, aspire to continue with science post-16 and express positive attitudes to science (Archer et al., 2015; Archer et al., 2012; DeWitt, Archer, & Mau, 2016). Moreover, this work has also shown that middle-class, White and South Asian boys are the most likely young people to record high levels of science capital. Our recent work replicates and extends these findings in older students (aged 17/18), showing that levels of science capital remain patterned by gender, ethnicity and cultural capital (see Moote, Archer, DeWitt, & MacLeod, 2019). But to what extent might the concept of science capital also explain wider STEM aspirations and attitudes? Is it specific to science, or might science capital also relate to and explain student aspirations and attitudes regarding technology, engineering and/or mathematics? The current paper seeks to address these questions, drawing on our quantitative survey data.

The rise of 'STEM'

The term STEM is used pervasively across policy and practice but particularly within debates about how to improve participation in science, technology, engineering and mathematics. Despite the widespread use of the term STEM – and despite recognition of areas of commonality and overlap between the distinct fields of knowledge (e.g. Vincenti, 1990) and long traditions of interdisciplinary working within and across the feeder disciplines - arguably research on the factors shaping post-compulsory STEM participation has tended to remain siloed within respective research on STEM education fields. This is perhaps symptomatic of wider divisions and distinctions between the disciplinary areas, which have traditionally been associated with different levels of 'status' (e.g. Carnegie Corporation of New York, 2009). Furthermore, historical development and recognition and have both been separated and/or sought to assert their own distinctiveness on each discipline (e.g. Bybee, 2013).

Debates continue as to the extent to which the areas are, or have been, separate (e.g. Cardwell, 1971, 1972; Musson & Robinson, 1969; Shapin, 1972). Within the constituent STEM education fields, critiques have been made that engineering and technology have often been considered and treated as 'afterthoughts' within scholarship and educational reforms. Indeed, it is notable that the UK's main social science research council, the Economic and Social Research Council's only major funded initiative in the field of STEM education in the last decade focused exclusively on science and mathematics education. Moreover, in England science and mathematics are compulsory core subjects until the age of 16, while 'computing', including coding lessons, is now a required component of the primary curriculum (but is not a core subject within secondary education) and engineering is largely absent from pre-18 education.

The situation with engineering is changing in the US, with a growing prevalence of educational standards in engineering, although it is estimated that only 10 percent of K–12 students are exposed to engineering-related coursework in schools (National Academy of Engineers, 2010). Further, evidence suggests that many students and even some teachers are confused about what engineering is (viewing engineers primarily as builders or construction workers) (National Academy of Engineers, 2010; Dabbagh & Menasc, 2006). Hence, despite increasing support for a more integrated approach to STEM (National Research Council, 2009; Farmer, Klein-Gardner, & Nadelson, 2014), there is a lack of scholarship which looks at how shared issues (such as understanding the factors which produce low and uneven patterns of post-compulsory participation in science, technology, engineering and mathematics) play out similarly or differently across the component disciplinary areas.

Research on STEM attitudes and aspirations

It has been noted that there is relatively little research on young people's technology/computing attitudes and career aspirations (Wong & Kemp, 2017) and while there is a growing body of research on factors shaping aspirations and attitudes in engineering and maths, this is largely focused on students in higher education (Godwin, et al., 2016; Marra et al., 2009; Min, Zhang, Long, Anderson, & Ohland, 2011). Research on maths aspirations and attitudes is also growing at both the secondary (Black et al., 2010; Brown, Brown, & Bibby, 2008; Kleanthous & Williams, 2010) and post-secondary levels (e.g. Hernandez-Martinez et al., 2008). In contrast there has been sustained and extensive work on aspirations and attitudes in the field of science education) - which suggests that the factors shaping aspirations are highly complex (e.g. Archer et al., 2010; Danielsson, 2009; Osborne, Simon, & Collins, 2003; Sheldrake, Mujtaba, & Reiss, 2017). The rare studies that have examined aspirations and attitudes across disciplinary domains (e.g. Else-Quest, Mineo, & Higgins, 2013; Mujtaba & Reiss, 2013; 2016) suggest that similar factors may be related to students' aspirations to continue with both maths and physics and that gender makes much more of a difference to students' aspirations (and the factors shaping these) than subject. For instance, Mujtaba and Reiss found similarities in the extent to which particular school experiences shaped student aspirations to continue with physics and/or maths. However, they found considerable differences between males and females in terms of aspirations for maths and physics and the factors shaping these. In particular, Mujtaba and Reiss (2016) found that female students had lower levels of self-belief and perceived inequalities relating to these subjects, including receiving less support from teachers compared to their male peers. Further, substantive previous work also highlights the role of parental support in students' pursuit of science study and work (e.g. Gilmartin, Li, & Ashbacher, 2006). Our own previous work (e.g. Archer et al., 2012; Archer & DeWitt, 2016) additionally reflects the way in which science social capital (e.g. knowing someone who work in a science-related job) can facilitate the development and maintenance of science aspirations.

The relationship between attitudes and aspirations in science has also been extensively studied (Gorard, See, & Davies, 2012; Osborne, Simon, & Collins, 2003), something that we too have addressed in previous work (e.g. Archer & DeWitt, 2013, 2016). Other studies have documented the important role that subject-specific attitudes play in shaping students' aspirations (e.g. see Else-Quest, Mineo, & Higgins, 2013, who show that students' gendered attitudes influence maths and science aspirations and participation). In this paper, we seek to understand the relationship between subject-specific aspirations and attitudes and science capital more closely.

As discussed next, our own work has drawn attention to the explanatory power of the concept of science capital with regard to understanding a young person's likelihood of aspiring to continue with science post-16/18 (see also Cooper and Berry 2020 with regards specifically to students' aspirations to study biology, chemistry, physics and earth sciences). While the ideas have been picked up and applied to understanding young people's choice of studying mathematics at degree level (e.g. Black & Herndandez-Martinez, 2016; Choudry, Williams, & Black, 2017; Williams & Choudry, 2016), young people's engineering aspirations (Moote, Archer, DeWitt, & MacLeod, 2019; IMechE, 2018; ~~Katchanov, Markova, & Shmatko, 201~~6; Royal Academy of Engineering, 2017) and technology career aspirations (e.g. Wong & Kemp, 2018), a comparative analysis of the potential relationship between science capital and young people's aspirations and attitudes with regards to technology, engineering and mathematics has not been specifically empirically explored to date. Through this paper we contribute to addressing this gap; our analyses indicate that the concept of 'STEM capital' can help explain why some students are more likely than others to continue with STEM and can be used to understand, and inform efforts to increase and diversify, aspirations and participation across all STEM disciplines. However, we also recommend that care should be taken not to apply STEM capital without consideration of the factors affecting each individual discipline as our data show that the concept applies less readily to some subjects compared to others.

Theoretical framework: A Science Capital lens

In the course of our research exploring young peoples' science aspirations (age 10-14) we proposed the term *science capital* as an analytic concept to help make sense of patterns relating to family science resources and students' science aspirations (e.g. Archer et al., 2015). Science capital is a conceptual device that seeks to hold together all of the science-related resources (*capital*) that a person might have. As explained below, it derives from Bourdieusian sociological theory (e.g. Bourdieu, 1984), in which social life is understood as produced through the interplay of *habitus*, *capital* and *field*. In particular, we use science capital as a conceptual tool for understanding inequalities (e.g. of gender, social class and ethnicity) in the formation and production of young people's science aspirations.

Bourdieu proposed that patterns and relations of social difference can be understood as produced through the interplay of what he termed *habitus*, *capital* and *field*. Habitus refers to an internal set of dispositions that are acquired over time through processes of socialization and which shape an individual's sense of what is possible and/or desirable (e.g. the feeling that science is 'for me'). Capital refers to the economic, cultural and social resources that an individual might possess which can support (or constrain) particular possibilities.. Habitus and capital are realized through interactions with the field, the latter referring to socio-spatial contexts that are constituted through relations of power. For instance, through the interplay of capital and habitus with field, middle-class families may foster particular values, attitudes and behaviours in children that resonate with and are valued and supported within the field of school/ education. This, in turn, results in high academic attainment and aspirations for (and achievement of) high status (e.g. degree level) post-compulsory educational participation (e.g., Israel et al., 2001; Martin, 2009). While Bourdieu formulated his theory primarily within the context of the arts – for instance, his conceptualization of cultural capital foregrounds consumption of *les beaux arts*, such as going to the opera - we have extended his work to recognize the value and importance of science-related forms of habitus and capital (e.g. Archer et al., 2012). Hence science capital refers to forms of habitus, cultural capital and social capital that relate specifically to science.

The concept of science capital has been developed conceptually, empirically and methodologically (Archer et al., 2015; DeWitt et al., 2016) as a way to better understand why comparatively small proportions of young people continue with science once it is no longer compulsory and why those who do continue into post-compulsory science (but especially in the physical sciences) tends to come from more socially privileged communities (e.g. male, white, middle-class).

While we could have termed the concept 'science habitus and capital', in the interests of more efficient (and comprehensible) terminology, we choose to use the terminology of science capital (see Archer et al., 2015 for full discussion). In this way, we understand 'science capital' as not being a separate 'type' of capital but rather as bringing together science-related forms of habitus and capital (economic, cultural and social capital). That is, it is intended as a conceptual device for collating various types of socialized and embodied attitudes, dispositions, social and cultural capital that specifically relate to science—notably those which have the potential to generate use or exchange value for individuals or groups to support and enhance their attainment, engagement and/or participation in science.

Our previous qualitative (e.g. Archer & DeWitt, 2016) and quantitative (DeWitt et al., 2016) work identified a link between science capital and science-related aspirations, exploring both the breadth and depth of this relationship. Specifically, we found that students with high levels of science capital were statistically more likely to aspire to (and participate in) science post-16 (Archer et al., 2012; Archer & DeWitt, 2016) and post-18 (Moote et al., 2019) and that the likelihood of having high (or low) science capital is strongly shaped by social inequalities of social class, gender and ethnicity (see Archer et al., 2015), with males and middle-class students being more likely to record high levels of science capital. Further research has also highlighted that different dimensions of science capital have varying independent associations with students' aspirations (DeWitt et al., 2016), which we suggest highlights the benefit of future exploration into how these and other factors associate with students' aspirations and subject-specific attitudes.

The concept of science capital has gained considerable traction in science education policy and practice and has been engaged with in some of the STEM education research, with new applications and refinements of the concept. For instance, Gokpinar and Reiss (2016) outline that for them, science capital is provided to students primarily at a ‘pre-reflexive’ level which can then translate into capabilities and functions through conversion factors (e.g. out of school family visits to science museums or helping with homework).

Work by Mujtaba, Sheldrake, Reiss, & Simon, (2018) has confirmed our theoretical framework through multi-level modelling results while other research has explored the stories of capital ‘conformist’ and ‘non-conformist’ situations, examining students who ‘rebel’ (i.e. students from high science capital families who develop non-science aspirations (Salehjee & Watts, 2015). Science capital has also been applied to explore engagement in informal science activities in historic visitor attractions (Essex & Haxton, 2018). It has also been applied to mathematics, with development of the concept of maths capital (Black & Herdandez-Martinez, 2016; Choudry, Williams, & Black, 2017; Williams & Choudry, 2016).

The present paper extends previous work through exploring the potential relationship between science capital and post-18 aspirations and attitudes in relation to not just science but also technology, engineering and mathematics. The paper seeks to contribute to knowledge that can help inform policy and practice in support of increased and diversified participation in STEM through an analysis of the extent to which science capital may relate, or not, to student aspirations with regard to technology, engineering and mathematics. Specifically, building on our previous work (e.g. Archer et al., 2015; Moote et al., 2019), the paper asks:

- To what extent (if any) does science capital relate to students’ aspirations to pursue a STEM subject post-18? Are there any differences in the strength of the relationship between science, technology, engineering and maths aspirations and science capital?
- To what extent does science capital relate to students’ broader attitudes to science, technology, engineering and/or mathematics? Are there any differences in the strength of the relationship between science, technology, engineering and maths attitudes and science capital?

Methods

Context and Sample

The ASPIRES 2 project is a 5-year longitudinal study funded by the UK's Economic and Social Research Council[i]. It follows on from the previous ASPIRES study, which investigated children's science and career aspirations from age 10-14, with the present study extending the tracking of this cohort from 14-19 years old. The overall project employs a mixed methods approach in order to generate both a breadth and depth of data. The ASPIRES studies involve a quantitative online survey of the cohort and repeat (longitudinal) interviews with a selected subsample of students and their parents. This paper reports on the final phase of the ASPIRES 2 study, which includes a survey and interviews with students age 17/18 years old (Year 13) collected Autumn 2016. However, the focus of the current paper is on a subset of quantitative survey data gathered during the final phase of this 5-year study.

Sample

Students from 265 schools completed the survey (237 government/publicly-funded; 28 privately-funded schools). This sample of schools (English sample, excluding Wales, Northern Ireland and Scotland) was roughly proportional to the overall national distribution of schools in England by geographic region ($\chi^2(8, 3450)=10.66$, $p=.22$, representing all 9 Government Office Regions in England) and gender ($\chi^2(2, 3450)=.801$, $p=.67$). In addition, the sample was comparable to the overall distribution of schools in England in terms of attainment ($\chi^2(5, 3450)=11.14$, $p=.049$), though with more in the middle band and fewer in the lowest band. In terms of school type, the sample contains relatively more 6th form Academies (53% vs 43% seen nationally, $\chi^2(4, 3450)=23.58$, $p<.001$). Index of Multiple Deprivation 2015 (IMD 2015) scores were also included as a measure of deprivation (see The English Indices of Deprivation 2015 Statistical Release 3 from The Department of Communities and Local Government for details on this measure). IMD 2015 scores were used over other measures (e.g. free school meals) as there is lack of a common measure of socioeconomic status across schools at this level in England. IMD deciles were roughly proportional to national distributions ($\chi^2(9, 3450)=10.71$, $p=.30$).

Of the 7,013 students, 39% identified as male and 61% as female[ii]. Students reported their ethnicities as follows: 76.5% White, 10.0% South Asian (Indian, Pakistani, Bangladeshi heritage), 4.3% Black (Black African, Black Caribbean heritage), 1.8% Chinese or East Asian, 5.8% mixed or other, and 1.6% preferred not to say. As the study focuses in part on the impact of ethnicity on students' aspirations, schools with higher populations of ethnic minority students were deliberately over-recruited to ensure sufficient numbers for analysis. Consequently, there are fewer White students in the sample than in primary and secondary schools across England.

We also calculated a measure of 'cultural capital' (based on parental university attendance, leaving school before 16, number of books in the home, and visits to museums). For simplicity and ease of interpretation we created five cultural capital groups, which had the following percentages of students within them: very low (6.4%), low (28.0%), medium (26.4%), high (20.3%), and very high (18.9%). For further justification for this scoring methodology please refer to DeWitt and Archer (2015).

Survey Overview and Recruitment

A questionnaire exploring students' aspirations and related science attitudes (DeWitt et al., 2011; 2014) was revised, validated and piloted with 200 students before being administered to a national sample of 7,900 17/18-year-old students. The piloting process involved adapting items to reflect educational changes for Year 13 students (e.g. science lessons separated by subject) and conducting principal components analyses to ensure that appropriate factor loadings were retained. Following data cleansing (which involved removal of duplicate and incomplete responses), 7,013 students remained in the sample for analysis presented here.

The overall project survey covered topics such as: aspirations (including a focus on science); subject preferences; participation in science activities in and out of school; parental and peer attitudes towards school and science; post-16 choices. It builds on previous surveys, the development and validation of which have been described elsewhere (e.g., DeWitt et al., 2011). DeWitt et al. (2014) also provides further detail on the reliability and validity of the survey instrument, as well as the specific items. The present analyses focus on a subset of this survey data, particularly relating to science capital, post-secondary aspirations and subject-specific attitudes, as outlined below.

Index of science capital

Details of how the science index was created and refined are detailed elsewhere (Archer et al., 2015; DeWitt et al., 2016), but, in brief, previously, we analyzed data from a more extensive science capital survey administered to 3,658 students aged 11-15 in schools in England. Logistic and linear regression analyses were performed and identified 14 items that most closely related to a dependent measure of future science affinity and science identity. These include dispositional items (i.e. relating to habitus, e.g. whether science is seen as useful and relevant to everyday life, whether science qualifications are transferable, or not), behavioral items (relating to habitus and capital, e.g. how often they engage in different science activities out of school, such as reading science books or visiting science museums), social capital items (e.g. friends or family members with science jobs or qualifications, explicit family support and/or teacher encouragement to continue with science) and science knowledge (relating to habitus and cultural capital, e.g. understanding of scientific method). Due to the conceptual closeness between habitus and capital, some items can be interpreted as comprising aspects of both habitus and capital. For instance, talking regularly with others at home about science reflects both habitus (a socialized disposition to value and talk regularly about science) and social capital (knowing others who know about/value science).

These 14 items comprise our science capital index and correspond to the dimensions of science capital; namely, scientific literacy, scientific-related dispositions/preferences (e.g. attitudes to science and scientists, perceptions of school science and teachers), knowledge about the transferability of science qualifications (in the labour market), consumption of science-related media, participation in out-of-school science learning activities, and science-related social capital (i.e. knowing individuals working in science-related jobs, talking with others about science).

Table 1 below presents a summary of these 14 items along with what dimension and theoretical aspect of science capital they relate to. Items were weighted (also included in Table 1) according to their theoretical centrality to the notion of science capital (for instance, having a parent who worked in science was weighted more heavily than having a neighbor who worked in science). We compared these with weightings derived from the logistic regressions described above and as the distribution of scores was virtually identical, we use the original, theoretically-derived weighting system.

[Insert Table 1 about here]

The scores were then summed across items, to generate a single science capital score for each young person. We do not claim that science capital is a single/unitary construct/factor, but rather has a number of different dimensions which, together, influence an individual's relationship with science and are connected to the extent to which people feel that science is 'for me'. Correspondingly, our measure, or index, of science capital is a composite measure that captures these different facets of the construct. Students' science capital scores were transformed along a scale from 0–100 for ease of interpretation, as ratio scales are commonly perceived as more intuitive than interval scales (e.g. -21 to 30.5 range).

On the survey, students were also asked subject-specific questions relating to their science, technology, engineering and maths attitudes in order to gain a sense of the extent to which science capital might also relate to broader attitudes towards the subject, not only aspirations (see Table 2 below for a summary of items). These questions were scored along a five-point Likert scale; 1=strongly disagree, 5=strongly agree. Items were summed to create four scores (science, technology, engineering and maths attitudes) which were used in the analyses.

[Insert Table 2 about here]

Analyses

This paper reports on students' responses to the following open-ended survey question as an indicator of post-18 aspirations, 'What best describes the main area of your desired degree/course/subject of study?' Responses were coded into the relevant disciplines by two of the authors. Dichotomous variables were then created (e.g. Physics vs non-Physics) and a series of independent-samples *t*-tests was conducted to compare levels of science capital among various STEM vs non-STEM university study aspirations, building on the analyses reported in Moote et al. (2019). The term 'computer science' is used here as this data relates to university study aspirations, with 'technology' being a broader discipline.

Correlational analyses were also conducted to explore the strengths of the associations between individual STEM subject attitudes described above and science capital. These analyses were chosen over a more complex MANOVA approach due to the continuous nature of the variables. The analyses reported here are intended to form an initial basis of our investigation into these issues (ie. Research Question 2). As discussed above, our wider project work (Moote et al., 2019) acknowledges and explores other factors related to science capital (ie. gender, ethnicity and cultural capital) in more detail.

Results

Addressing the first research question, independent sample *t*-tests (reported in Table 3 below) showed that students intending to pursue STEM subjects at university indicated significantly higher levels of science capital than students aspiring to non-STEM degrees. Comparing the effect sizes of these tests, our analyzes additionally showed that science capital is most strongly related to physics (with Cohen's d indicating a large effect size, *d*=1.38). Effect sizes were also large for chemistry (*d*=1.16), biology (*d*=1.02), and engineering (*d*=.93). In contrast, a medium effect size was reported when comparing science capital levels among students intending to study maths (*d*=.36) versus other subjects together and a small effect size was reported for computer science (*d*=.26).

[Insert Table 3 about here]

A series of correlations were run to explore relationships between the STEM subject-specific attitudes and science capital, addressing the second research question (see Table 4 below). As expected, correlational analyses showed that student science attitudes were strongly associated to their reported levels of science capital (r=.779). While the non-science, TEM attitudes included in the analyses were indeed related to science capital, the strength of these associations was moderate. Among the TEM attitudes, a stronger association was found between engineering and science capital (r=.423) followed by maths and science capital (r=.414). The association was weakest (but still of moderate strength) between the technology attitudes held by students and their reported levels of science capital (r=.327). In other words, engineering and maths attitudes seem to be more strongly related to science capital than technology – although it does still relate to technology attitudes. In other words, students with higher science capital had significantly higher maths, engineering, and technology attitudes.

[Insert Table 4 about here]

Discussion

Our previous work suggests that science capital provides a useful lens for understanding issues pertaining to science participation, with evidence showing that levels of science capital are clearly patterned by gender, ethnicity and cultural capital and relate significantly to the likelihood of a young person aspiring to and enrolling in post-compulsory science-related qualifications (Archer et al., 2015; Moote et al., 2019). This prior work has shown that science capital provides a greater level of discernment and focus than measures of cultural capital, distinguishing between those with high cultural capital but low science capital and those with low cultural capital but high science capital (see DeWitt et al., 2016). The concept has also been applied to policy and practice by those within the STEM engagement and enrichment sectors, but to date there has been no empirical evidence as to the extent to which science capital may, or may not, relate to attitudes and aspirations for technology, engineering and mathematics. The present paper addresses this gap and investigates the relationship between science capital and post-18 (specifically university) aspirations as well as other STEM attitudes.

We suggest that the reported associations between science capital and aspirations and attitudes to engineering, maths and technology indicate that the concept can, to a certain extent, be interpreted as representing not *just* science capital, but a wider, broader 'STEM capital'. In other words, based on the correlations reported in this paper (with significant and meaningful relationships found beyond science attitudes, i.e. also between science capital and TEM attitudes), science capital may share enough similarities to 'STEM capital' to be used as a reasonable proxy. However, the results highlight that there are important caveats, namely that the nature of this relationship is partial with regard to mathematics and technology (being associated mainly with attitudes and not aspirations) and weaker with regard to technology. As such, we see a value in further work exploring similarities and differences across the different STEM areas, not least given that existing literature tends to have been conducted within specified disciplinary areas, with relatively little work looking comparatively across and between the factors driving science, technology, engineering and mathematics participation.

Science Capital and STEM related attitudes

The present findings beg the question as to why attitudes to engineering seem more strongly aligned with science capital than those relating to mathematics and technology? We are not able to answer this question with our current evidence base. At most, we can offer a speculative suggestion that perhaps one explanation may be that science and engineering are popularly regarded as sharing a common focus on the *physical* world, while mathematics and technology might be associated more with the *digital* world. Another explanation may relate to subject prerequisites for degree level entry in the different discipline areas (e.g. in the UK, a science A level, particularly physics, is often a prerequisite for entry to engineering degree programmes, but not for computer science). Yet the four areas also seem to share sufficient commonalities that – as the analyses show – there are meaningful relationships between science capital and all three 'TEM' areas.

We are not particularly surprised that smaller effect sizes for post-18 maths aspirations were reported, given the popularity of mathematics A level and its reputation as a highly transferable and 'enabling' qualification (Blenkinsop, McCrone, Wade, & Morris, 2006; Sheldrake, Mujtaba, & Reiss, 2015), but suggest that the link between science capital and maths attitudes underlines the ongoing viability and relevance of the grouping of maths with technology, engineering and science under the banner of STEM.

Implications for Policy and Practice

We propose that our results can be interpreted to suggest that efforts aimed at building science capital among young people will likely improve not only aspirations and attitudes in science but would also likely extend to engineering. For instance, previous work that co-developed and implemented a science capital teaching approach with secondary science teachers and their classes in England resulted in significant increases in students' levels of science capital, their aspirations to study one or more sciences at A level and the extent to which they found science meaningful and relevant to their lives (Archer et al., 2015). This work did not ask students about their views to TEM, but the present findings suggest that it might not be unreasonable to expect that an approach that seeks to build science capital might also result in wider positive impacts on young people's engineering attitudes and aspirations, beyond just science attitudes and aspirations. We therefore suggest that there may be a benefit to extending the science capital teaching approach into a wider STEM capital teaching approach –

and to expanding the measurement of outcomes to include a focus on wider attitudes and aspirations to TEM, not just science, as a way of exploring these trends and possibilities further.

The close relationship between science capital and engineering attitudes and aspirations is also interesting given the absence, in England, of engineering from the school (and indeed mostly the pre-18) curriculum. It may be encouraging for those within the engineering education community that science capital seems strongly associated with positive views of and post-18 aspirations towards engineering – and may suggest that school science (and science capital building initiatives) could provide a pragmatic site for exploring further opportunities for engineering pathways. While technology and maths appear to be less strongly related, the fact that technology and maths attitudes are still significantly related to science capital suggests that there is a potential value to cross-STEM interventions.

We reflect that, given the relationships between science capital and the different STEM areas presented in this paper, there is a lack of coherence across policy and practice with regard to interventions aimed at supporting and improving participation in science, technology, engineering and/or mathematics. That is, our reading of the literature and field suggests that many of these efforts are undertaken with regard to a specific discipline, rather than seeking to maximize linkages. For example, we note that in the US the 'Mathematics and Science Partnership' was renamed in 2012 to omit mention of engineering or technology before awarding grants for improving teacher education. Likewise, in the UK, most interventions tend to be discipline-specific. For instance, schemes aimed at promoting engineering are conducted by engineering organizations, with little cross-fertilization *across* and *between* other STM areas or organizations.

Moreover some even raise the question of whether it is useful to speak of 'science' as a discipline given the distinct nature of each of the different sciences (Burns & Medvecky, 2018). As Wynne (2014) argues, 'a dense confusion of meanings' remains under-examined regarding science and discussions relating to public understanding of science. The results presented in this paper provide some clarification regarding the relationship of science capital to different science disciplines (namely biology, chemistry and physics), showing that there are sufficiently strong relationships to give us confidence in the utility of a concept of ‘science capital’. Our findings also indicate differences *within* the domain of ‘science’, such that a larger effect size was reported for aspirations to study physics, compared with biology and chemistry. We interpret this finding as potentially relating to the high status of physics (i.e. the highest levels of science capital – configured as representing particularly high symbolic value capital, relate most strongly to areas of science dominantly regarded as having particularly high status). However, we suggest that this represents an area for further future exploration, as discussed in Moote et al. (2019).

This paper also raises the question as to whether it is possible to ‘build’ and increase student science capital. Drawing on previous work, and in line with our conceptual approach, we suggest that the way forward lies in making changes to the *field*. As Khan (2014) argues, the value of capital is determined by the field, hence the value of a students’ capital (and what can, or cannot be translated or exchanged into symbolic high science capital, will vary across different contexts. We therefore suggest that attempts to ‘build’ science capital should usefully focus on shifting the relations of exchange within particular fields (what, and who, gets recognized as being ‘scientific’?) to better support the activation of more (and more diverse) students’ forms of capital. If the value of science capital lies in the processes that make it valuable, then perhaps the key task for science educators is to act on and seek to make changes to the field (rather than seeking to act on and change young people, as is the case in many existing STEM interventions) to create contexts within which different forms of (science) capital are valued, activated, and able to be converted into symbolic forms of capital (see discussions by Carter, 2003; Yosso, 2005).

This point - about changing the field, and not the young person - is particularly relevant and important with regard to the implications of our analyses for supporting not just increased, but also more equitable and inclusive STEM participation. We know from previous research that science capital is unevenly distributed in society, with more socially advantaged students being more likely to have high levels of science capital. The findings from the present paper suggest that these inequalities are particularly related to aspirations and attitudes in physics and engineering (helping to explain, for instance, the particularly stark and persistent gendered patterns of participation in the two fields). Consequently, we suggest that efforts to support increased and diversified participation in science and engineering need to focus on broadening the forms of (e.g. gendered, classed and racialized) habitus and capital that are valued in and by these fields, in order to better support the attitudes and aspirations of students from under-represented communities. That is, in order to support increased and widened participation, fields such as physics and engineering need to focus on changing their own normative values and practices, rather than seeking to change students, such as by giving them more information, inspiration or exposure to physics/ engineering.

Limitations and Future Research

Our findings provide insight into how we are measuring science capital and what relationships science capital may have with wider STEM attitudes and aspirations. One limitation to this is the restricted nature of our terminology and questioning around technology, engineering and mathematics. For instance, to what extent did students understand ‘technology’ in the sense that we were using it? As Burns & Medvecky (2018) highlight, surveys often assume that all respondents share the researchers’ understandings of terminology when respondents may have views that differ significantly. Our interview findings provide further support for this explanation but are not discussed here due to space limitations.

More generally, due to being based on self-report measures, the research presented here is limited by issues of both internal validity (e.g., response bias, control of the sample and/or spurious responses) and external validity. While the results presented can arguably be generalized to students in England, the fact that the year group were oversampled for minority ethnic groups needs to be remembered when interpreting the results and any wider cultural comparisons need to be made cautiously. Further research replicating these results in other countries would help to build confidence in the generalizability of the findings presented.

The alpha values for the engineering, technology and maths attitudes components approached the lower limit of what is considered acceptable (.70). This is not uncommon for components with relatively few items, however, it is possible the low alpha values were due to students’ lack of awareness of what an engineer or someone who works in technology does. We also appreciate that engineering and technology do not feature frequently in the English curriculum and therefore students may have differing understandings of what these disciplines include. Equally, maths may be viewed by students of this age range as such a broad discipline that answering these questions maybe have proved difficult for them.

While this paper aimed specifically to investigate contributions of STEM-related subject attitudes, we accept and acknowledge that other variables will be important to study and include in future modelling analyses to provide a more complete understanding of the multitude of factors relating to student's levels of science capital for this age group. Our ongoing work (Moote et al., 2019) has begun to shed light onto this, documenting that gender, ethnicity and cultural capital, and science self-concept are important factors that explain a significant proportion of the variance not captured in the current set of analyses. Additionally, further research could explore how these background factors influence the relationship between subject-specific attitudes and science capital. For example, do the effect sizes for the relationship between the specific STEM attitudes and science capital differ by gender? There may also be value in looking at the individual items and dimensions of science capital to investigate differences by gender, ethnicity and cultural capital, helping inform ongoing efforts to improve agency, social mobility and social justice science education work with underserved communities. We also acknowledge the possibility that a quantitative tool, such as this survey, may not be able to capture the complexity of science capital. However, through conducting repeated in-depth interviews alongside the surveys, our wider project work covers both the breadth and depth of participants' perspectives, therefore reducing threats to validity. Additionally, longitudinal case study analyses exploring the relationships studied in this paper through our qualitative work are on-going (Archer, MacLeod, & Moote, 2020).

The findings reported in this paper show that it is potentially useful and meaningful to employ the concept of science capital for understanding and addressing issues pertaining to young people's attitudes of engineering and mathematics as well as post-18 aspirations, but that its use may be limited with regard to understanding technology attitudes and aspirations. These findings might be considered surprising considering the similar participation profile of technology (Kemp, Berry, & Wong, 2018) and engineering students (Royal Academy of Engineering, 2016), being mostly white, male and middle class.

While we acknowledge that there could be various reasons for this, we suggest that the sector should be wary of seemingly 'cover-all/umbrella' terms and intervention efforts, as the present research shows that there are likely differences within and between each respective STEM discipline. However, given that our findings indicate that science capital is generally, albeit differentially, related to TEM, we suggest that the conceptual has a utility and viability which warrants further research to unpick and explore similarities and differences in attitudes and post-18 aspirations across all of the STEM disciplinary areas. Further, any efforts or interventions in schools and out-of-schools initiatives relating to increasing or diversifying participation in TEM subjects could helpfully use, and report, findings on any science capital teaching approaches implemented. Finally, as the results suggest that the relationship between science capital and TEM attitudes was strongest for engineering, this work supports the validity and necessity of more joint efforts in this area, particularly with regard to supporting more equitable and inclusive disciplinary cultures and systems to support more diverse participation.

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Table 1.
A summary of the items, response options and weightings included in the science capital index and details of the dimensions and theoretical aspect of science capital each item relates to.

Item	Science Capital Dimension	Theoretical Aspect	Response Options and Weighting
A science qualification can help you get many different types of job.	Knowledge about the transferability of science	Habitus (disposition)	-2 for strongly disagree, -1 for disagree, 0 for neither, 1 for agree, 2 for strongly agree
When you are NOT in school, how often do you talk about science with other people?	Talking about science in everyday life	Capital (social capital)	-2 for never, -1 at least once a year, 0 at least once a term, 1 at least once a month, 2 at least once a week
One or both of my parents think science is very interesting.	Family science skills, knowledge and qualifications	Habitus (disposition) Capital (social capital)	-1 for strongly disagree, -0.5 for disagree, 0 for neither, 0.5 for agree, 1 for strongly agree
One or both of my parents have explained to me that science is useful for my future.	Family science skills, knowledge and qualifications	Habitus (disposition) Capital (social capital)	-1 for strongly disagree, -0.5 for disagree, 0 for neither, 0.5 for agree, 1 for strongly agree
I know how to use scientific evidence to make an argument.	Scientific literacy	Capital (cultural capital)	-2 for strongly disagree, -1 for disagree, 0 for neither, 1 for agree, 2 for strongly agree
When not in school, how often do you read books or magazines about science?	Science media consumption	Capital (cultural capital)	-2 for never, -1 at least once a year, 0 at least once a term, 1 at least once a month, 2 at least once a week
When not in school, how often do you go to a science centre, science museum or planetarium?	Participation in out-of-school science learning contexts	Capital (cultural capital)	-2 for never, -1 at least once a year, 0 at least once a term, 1 at least once a month, 2 at least once a week
When not in school, how often do you visit a zoo or aquarium?	Participation in out-of-school science learning contexts	Capital (cultural capital)	-2 for never, -1 at least once a year, 0 at least once a term, 1 at least once a month, 2 at least once a week
How often do you go to after school science club?	Participation in out-of-school science learning contexts	Capital (cultural capital)	-2 for never, -1 at least once a year, 0 at least once a term, 1 at least once a month, 2 at least once a week
My teachers have specifically encouraged me to continue with science after GCSEs.	Science-related attitudes, values and dispositions	Habitus (disposition) Capital (social capital)	-2 for strongly disagree, -1 for disagree, 0 for neither, 1 for agree, 2 for strongly agree
My teachers have explained to me science is useful for my future.	Knowledge about the transferability of science	Habitus (disposition) Capital (cultural/social capital)	-2 for strongly disagree, -1 for disagree, 0 for neither, 1 for agree, 2 for strongly agree
It is useful to know about science in my daily life.	Science-related attitudes, values and dispositions	Habitus (disposition)	-1 for strongly disagree, -0.5 for disagree, 0 for neither, 0.5 for agree, 1 for strongly agree
Who do you talk to about science? Who are they?	Talking about science in everyday life	Habitus (disposition) Capital (social capital)	

Do you know anyone who works in science? Who are they?	Knowing people in science-related roles	Habitus (disposition) Capital (social capital)	0.5 for parents or carers, 0.5 for extended family, 0.5 for friends, 0.5 for siblings, 0.5 for directly with scientists, 0.5 for teachers, 0.5 for other, 0 for no one 2 for ‘parents or carers, 1 for siblings, 1 for extended family members, 1 for other

Table 2.
A summary of items and internal consistency (reliability) coefficients for the STEM perceptions subscales.

Subscale	Items	α	range
Science	I am good at science		
	A science qualification can help me get many different types of jobs	.740	3-15
	I would like to study more science in the future		
Maths	I am good at maths		
	A qualification in maths can help you get many different types of jobs		
	I am interested in learning more about maths	.732	3-15
Engineering	I am good at engineering		
	A qualification in engineering can help you get many different types of jobs		
	I am interested in learning more about engineering	.779	3-15
Technology	I am good at technology		
	A qualification in engineering can help you get many different types of jobs		
	I am interested in learning more about technology	.749	3-15

Table 3.
A summary of science capital means, standard deviations, and independent samples t-tests results for the STEM vs non-STEM university aspiration comparisons.

University Intentions	Science Capital Mean (SD)	*df*	*t*	*p*	*d*
Physics	60.99 (9.74)				
Non-Physics	42.94 (15.72)	124	18.801	<.001	1.38
Engineering	55.34 (10.73)				
Non-Engineering	42.81 (15.84)	250	15.853	<.001	.93
Math	48.44 (13.02)				
Non-Math	43.21 (15.93)	181	4.985	<.001	.36
Chemistry	58.30 (9.23)				
Non-Chemistry	43.16 (15.83)	74	13.303	<.001	1.16
Biology	56.24 (10.79)				
Non-Biology	42.43 (15.76)	403	20.552	<.001	1.02
Computer Science	47.12 (14.04)				
Non-Computer Science	43.27 (15.91)	163	3.280	<.001	.26

Note. *two-tailed significance values presented.

Table 4.
A correlation matrix for science capital and STEM perceptions.

	Science Capital	**Science**	**Technology**	**Engineering**	**Maths**
Science Capital	---	.779	.327	.423	.414
Science	---	---	.323	.413	.448
Technology	---	---	---	.631	.438
Engineering	---	---	---	---	.507
Mean	41.00	10.19	10.15	8.75	10.40
SD	15.53	2.64	2.49	2.63	2.69
range	0-100	3-15	3-15	3-15	3-15

Note. All correlations reported are statistically significant (p<.0001).

[i] The data analysed is generated by the Economic and Social Research Council-funded 'ASPIRES 2'project. The longitudinal study, and its predecessor ASPIRES study, have been tracking and exploring children's science and career aspirations from age 10-19. Methods include a quantitative online survey of the cohort and repeat interviews with a sub-sample of students and their parents. This paper draws on survey data from students age 17/18 years old (Year 13). The study subscribes to the ethical standards of the British Educational Research Association, and has been approved by the Institute of Education, University College London ethics committee.

[ii] We are aware that we are oversimplifying gender and agree that it is not a binary construction. However, going into the level of detail that reflects the complexity of gender was far beyond the scope our survey. In addition, an extremely small proportion declined to respond to the question. Thus, for the sake of parsimony, we have decided to use a simplified construction of gender in this paper – focusing on 'males' and 'females'.