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Gender and parental education as indicators of students' engagement with STEM subjects

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ABSTRACT

A workforce trained in STEM skills is a fundamental requisite for socioeconomic wellbeing and innovation, however one of the factors limiting its availability is the progressive attrition of women along the academic and professional pipeline. In this study, a survey was carried out with 504 students aged 14 to 18 in two British high schools to investigate any association between students' gender or parental education status and their engagement with STEM disciplines.

This study highlighted a worrying trend in terms of students' choice of scientific role models: only 12% of the participants picked a woman when asked to name an influential scientist, suggesting that the limited availability of female role models might be a factor contributing to the gender gap from an early stage of the STEM educational pipeline. Our data also confirm previous observations that, while girls are overall less likely to express preference for the majority of STEM subjects, they are significantly more likely than boys to express a preference for biology.

Moreover, we found a previously unreported association between parental education and students' choice of science news sources, whereby participants whose parents/guardians have a university degree are more likely to mention their parents as a source.

KEYWORDS

STEM subject choice; gender; secondary school; parental education; role models

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Background

STEM (science, technology, engineering and mathematics) skills are widely recognised as a crucial motive force contributing to social, technological, economic progress and wellbeing. The availability of a STEM-trained workforce has a clear positive correlation with a society's capability for innovation and global competitiveness (Beede et al., 2011). Within the last decade, there has been a considerable shortage of STEM workers to meet the demands of a constantly evolving labour market, especially with regards to research and development in the private/industrial sector (Xue & Larson, 2015). It is widely recognised that the loss of female workforce along the academic and professional pipeline is a key contributor to the present STEM skills shortage, a phenomenon which is particularly pronounced in mathematics-intensive fields (Wang & Degol, 2017). Already at the undergraduate level, the STEM field presents a heavy internal gender imbalance: while women in the UK are well-represented overall (51.1% of total STEM undergraduates) and often overrepresented in medical (79.4%) and biological (61.1%) disciplines, their proportion plummets significantly in more mathematics-intensive fields such as physics (39.9%), computer sciences (17.4%) and engineering/technology (15.8%) (Higher Education Statistics Agency, 2019; The Institution of Engineering and Technology, 2015). The same trend emerges from the breakdown of UK postgraduate student numbers by gender and subject, with women being overrepresented in subjects allied to medicine (75%), biological sciences (67%), medicine and dentistry (61%) and underrepresented in physical sciences (42%), mathematical sciences (37%), computer sciences (25%) and engineering/technology (24%) (The Wise Campaign, 2015). STEM-educated women are reportedly more likely than men to discontinue their pursuit of a career in their subject field after higher education. As a result, the gender gap increases with seniority along the STEM pipeline, with women holding 25% of total STEM jobs and only 13% of the management roles in the field (The Wise Campaign, 2019).

While the extent of the gender gap is less pronounced at the early stages of the STEM pipeline, several of its causative factors and their underpinning mindset can be traced back to the years of school (and, arguably, pre-school) education (Campbell, 2015). Although most scholars agree that "there are no single or simple answers to the complex questions about sex differences in science and mathematics" (Halpern et al., 2007), an increasing body of evidence indicates that said differences are more likely to depend on social/environmental factors (e.g. socially ingrained gender roles, parental influence, students' aspirations, availability of role models) rather than innate cognitive differences (Ceci, Williams, Ginther, & Kahn, 2014; Johnston, 2005; Lloyd, Gore, Holmes, Smith, & Fray, 2018). Unsurprisingly, several studies have identified parental support and education as key determinants of students' engagement with (and ultimately success in) STEM disciplines (Archer, Moote, Macleod, Francis, & DeWitt, 2020; Milner-Bolotin & Marotto, 2018). Indeed, socioeconomic conditions also have a major impact on students' intentions to pursue a STEM career: coming from a wealthier familial

background attenuates the effect of negative predictors of STEM engagement such as gender and ethnicity (Niu, 2017).

Recent achievement data in UK primary and secondary schools corroborate the observation that disengagement with STEM subjects is likely to be based on acquired rather than innate factors. In national Standard Assessment Tests (SATs) carried out at the end of primary school, 68% of girls and 60% of boys attained the expected standard in reading, writing and mathematics, with girls outperforming boys both overall and in each individual subject (Department for Education, 2019). A similar trend can also be observed with regards to students achieving the higher standard in all subjects with the exception of mathematics, where girls underperform boys by 4%. This observation might hint at an early disengagement of high-achieving female students from mathematics-intensive tasks.

The General Certificate of Secondary Education (GCSE) is the first qualification awarded to English secondary school students at the end of Key Stage 4 (KS4, Years 10 and 11, ages 14 to 16). In secondary school, students can pursue single award science (a single GCSE combining biology, chemistry, and physics), double award science, or triple award science (delivering a separate GCSE in each of the three disciplines). In the last assessment round, girls outperformed boys in the single science (+1.9% achieving grade A and A*), additional science (+3.2%), biology (+7.3%), chemistry (+7%), and ICT (+5.2%), and performed within less than 1% of boys in mathematics (+0.1%) and physics (-0.5%) (Office of Qualifications and Examinations Regulation, 2019). It is worth emphasising that (with the exception of ICT where girls only represented 36.3% of total candidates), the scores shown above refer to an approximately equal number of male and female candidates, indicating that the higher female achievement is most probably not caused by selection bias.

After completing KS4, students can either undergo vocational training via an apprenticeship/traineeship or progress to Key Stage 5 (KS5, Years 12 and 13, ages 16 to 18) and further their studies towards the achievement of, in most cases, General Certificate of Education Advanced Level (A-level) or Business and Technology Education Council (BTEC) qualifications. In the last assessment round, girls represented 54.4% of A-level students and 41.1% of technical certificate students (Department for Education, 2018). In terms of uptake of STEM subjects, girls were overrepresented in biology (63.4%) and, albeit to a lesser extent, chemistry (52.7%) and underrepresented in mathematics (38.1%), physics (22.1%) and computer science (11.7%). Despite their significant underrepresentation, girls performed (by percentage achieving A and above) very similarly to boys in all STEM A-levels: biology (+0.1%), chemistry (-2.3%), mathematics (-0.7%), physics (+0.1%), computer science (+0.3%) (Joint Council for Qualifications, 2019).

The comparison between recent SATs, GCSE and A-levels data indicates that, despite girls performing similarly or better than boys in mathematics and science across all year groups, STEM gender participation appears already polarised at the end of secondary education, with mathematics-intensive subjects as male-

dominated fields. These observations strongly support previous findings suggesting that the transition between compulsory and voluntary schooling (KS4 to KS5 in the English system) is a critical "leaky point" in the STEM educational pipeline (Boaler, Altendorff, & Kent, 2011; Siani & Dacin, 2018).

Aims of the study

The main aims of this study are to explore the outlook of KS4 and KS5 students towards STEM subjects, investigate any gender-specific trends that might help in the interpretation of the causes of students' disengagement with STEM and suggest potential intervention strategies. As parental education has been proven to have an impact on students' academic formation and early decision-making, the secondary aim of this study is to assess how this parameter intersects with gender by investigating whether students whose parents/guardians are in possession of a university degree show differential engagement with STEM subjects compared to their peers (Lloyd et al., 2018; Svoboda, Rozek, Hyde, Harackiewicz, & Destin, 2016). For the purposes of this analysis, the term "engagement" refers to, and is measured by, students' self-reported expression of interest in STEM disciplines via subject preference, willingness/ability to name an influential scientist, and perusal of scientific news. Students' responses to questions probing these three aspects can be interpreted as proxies of their intrinsic motivation towards STEM learning (Gasiewski, Eagan, Garcia, Hurtado, & Chang, 2012).

Study design and methods

Data collection took place in two non-selective secondary schools in Southern England (Dorset and West Sussex, respectively). Both institutions consisted of high school (Year 7 to Year 11 – ages 11 to 16) and sixth form (Year 12 and Year 13 – ages 16 to 18). Convenience sampling was carried out in these two specific institutions due to their geographical proximity and academic ties with the authors of the study. Hard-copy questionnaires were distributed in December 2018 by form tutors to Key Stage 4 and Key Stage 5 students and completed during form time (regular timetabled sessions where students can discuss pastoral and academic matters with their tutor) to avoid selection bias due to students' differential attendance at specific subjects' lessons. The questionnaires comprised a mix of multiple-choice questions (MCQ) and open-ended questions (see Table 1). Some of the questions were similar across the KS4 and KS5 questionnaires, while others were designed to specifically reflect the different structure and curriculum of the two key stages.

Data were analysed in IBM SPSS 24 using multiple chi-square tests for association. Chi-square tests are non-parametric tools appropriate for analysing frequency data, and thus do not require a specific distribution or homogeneity in the data (McHugh, 2012). They assess whether the proportions for one nominal variable are different among values of another nominal variable, with the null hypothesis assuming that there is no association between the two variables (McDonald, 2014). A significance level of 0.05 was used for all analyses.

This study was carried out in accordance with the University of Portsmouth ethical guidelines. Ethical approval from the Science Faculty Ethics Committee was

obtained prior to the start of the investigation. All participants were informed of the voluntary and anonymous nature of the survey, and of their right to withdraw from it.

Table 1: questions used in the survey

Questions for Key Stage 4	Questions for Key Stage 5
• What gender were you assigned at Birth? (MCQ)	• What gender were you assigned at Birth? (MCQ)
• Does one or more of your parents/guardians have a university degree? (MCQ)	• Does one or more of your parents/guardians have a university degree? (MCQ)
• Which subjects do you enjoy most from the list? (MCQ)	• Which subjects do you enjoy most from the list? (MCQ)
• What is your favourite science subject? (MCQ)	• Are you currently studying at least one STEM based A-Level? (MCQ) • If so, which one/s? (Open-End)
• Can you provide the name of an influential person within science? (Open-End)	• Can you provide the name of an influential person within science? (Open-End)
• Where do you usually hear about science related news? (Open-End)	• Where do you usually hear about science related news? (Open-End)
• How could science lessons be made more interesting and appealing to you? (Open-End)	• How could science lessons be made more interesting and appealing to you? (Open-End)

RESULTS

Summary of study participants

This study involved a total of 504 student participants in two comprehensive secondary schools, which were split approximately equally between genders (49.2% males; 50.8% females) and institutions (41.1% West Sussex, 58.9% Dorset). The relative majority (49.6%) of participants reported that their parents or guardians did not hold a university degree, 23.2% that they did hold a degree, and 27.2% were unsure. No further demographic data such as ethnicity was collected from participants. In this paper, to facilitate visual appreciation of data, graphs referring to gender differences are shown in greyscale, whereas those referring to the effect of parental education status utilise black/white bars.

Summary of findings

Overall, students' gender was significantly associated with their general subject preference, science-subject preference, and the gender of the STEM influential person they named. In comparison, parent/guardian education status was only significantly associated with student's favourite sources of science news. The uptake of STEM A-Levels by KS5 students was not significantly associated with either gender or parent/guardian education status.

Table 2: breakdown of the study population by students' gender and parent/guardian graduate status

Gender	Parent/Guardian Education	Count
Male		**248**
	No Degree	120
	Degree	56
	Unknown	72
Female		**256**
	No Degree	130
	Degree	61
	Unknown	65

Table 3: Summary of the presence of a significant association between students' attitudes towards STEM and students' gender or parental education status. Ticks indicate statistically significant ($p<0.05$) association, crosses a lack thereof.

	Gender	Parent/guardian education status
Whole-cohort subject preference	✓	X
Science-subject preference in KS4	✓	X
STEM A-Levels uptake in KS5	X	X
Student's favourite sources of science news	X	✓
STEM influential person	✓	X

Whole-cohort subject preference

A total of 503 KS4 and KS5 students provided a list of their favourite subjects. Overall, the majority (62.8%) of students included at least a STEM subject (Biology, Chemistry, Physics, Mathematics, ICT) in their list. There was a significant association between gender and preference for STEM subjects ($\chi^2 = 16.227$, df = 1, $p < 0.001$; Figure 1), with 71.7% of males and 54.3% of females including at least a STEM subject on their list of favourite subjects. Of the 503 students, 367 also indicated whether their parent/guardian held a university degree. Parent/guardian education status was not significantly associated with whether students preferred STEM subjects ($\chi^2 = 0.249$, df = 1, $p = 0.618$; Figure 1).

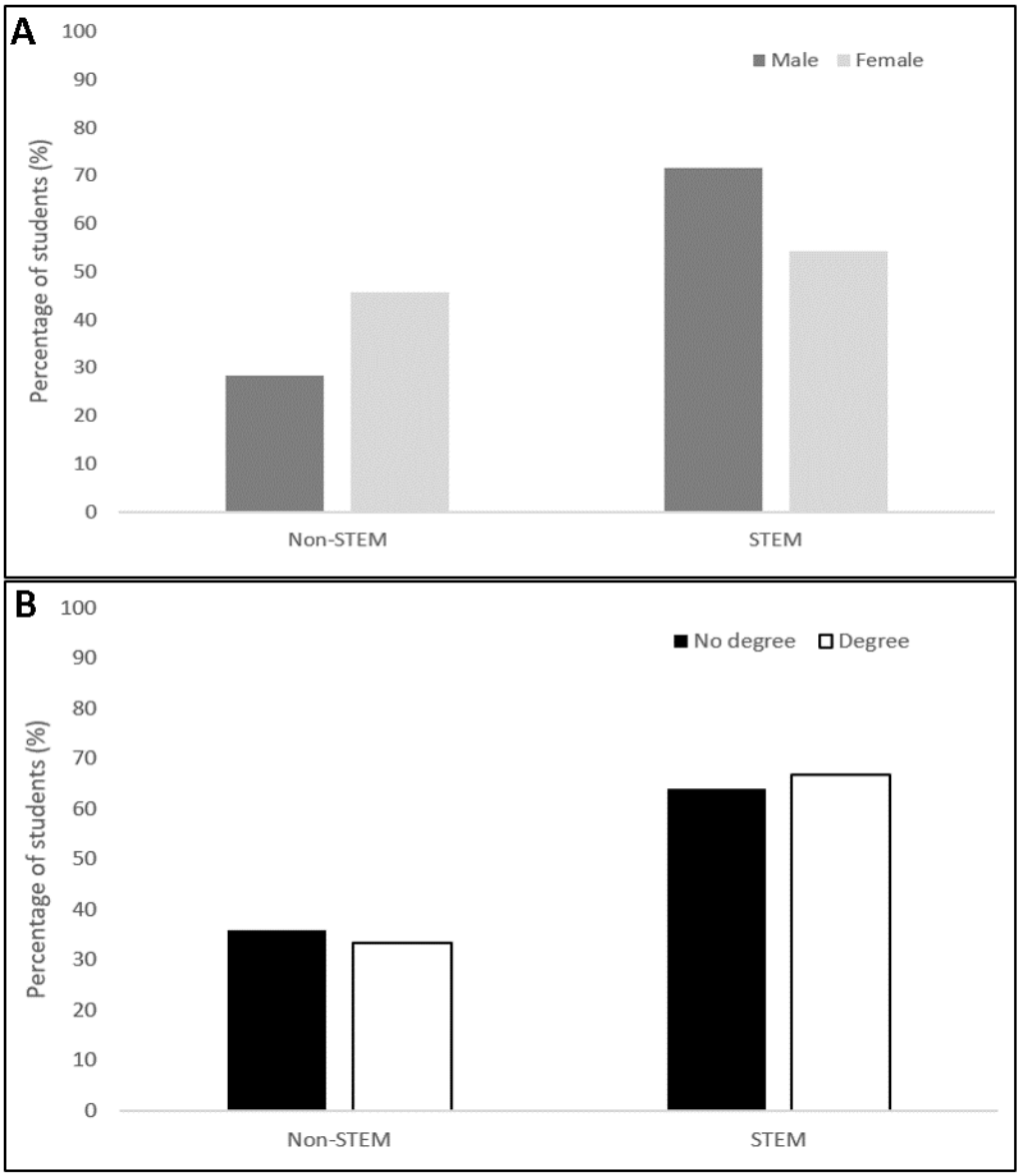

Figure 1: association between students' subject preferences and their gender (A) or parental education (B). Males were significantly more likely than females to express preference for at least one STEM subject. No statistically significant association was observed between students' parental education status and their subject preference.

Science subject preference in Key Stage 4

A total of 325 KS4 students indicated their favourite science subject (Biology, Chemistry or Physics). Of these, six listed multiple sciences as their favourite and were excluded from further analysis. Overall, of the remaining 319 students, Biology was the favourite science subject (36.7%), followed by Chemistry (35.4%) and Physics (27.9%). There was a significant association between gender and science-subject preference ($\chi^2 = 25.849$, df = 2, $p < 0.001$; Figure 2). Within females, the favourite science subject was Biology (51.0%), followed by Chemistry (29.1%) and Physics (19.9%). Within males, the favourite science subject was

Chemistry (41.1%), followed by Physics (35.1%) and Biology (23.8%). Of the 319 students, 213 also indicated whether their parent/guardian held a university degree. Parent/guardian education status was not significantly associated with science-subject preference among students ($\chi^2 = 0.011$, df = 2, p = 0.995; Figure 2).

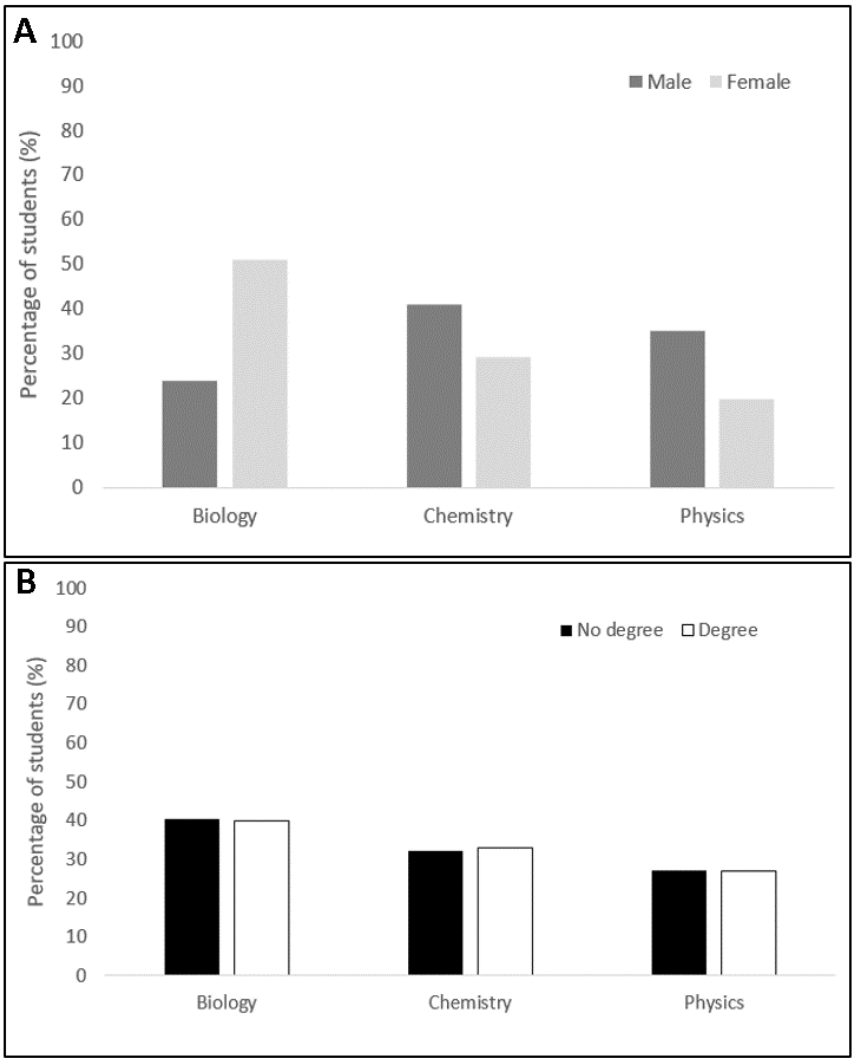

Figure 2: association between KS4 students' science subject preference and their gender (A) or parental education (B). Girls were significantly more likely than boys to express a preference for biology, and less likely to prefer chemistry or physics. No statistically significant association was observed between KS4 students' parental education and their preference in terms of science subjects.

STEM A-Levels uptake in Key Stage 5

A total of 164 KS5 students indicated whether they were currently studying at least one STEM-based A-Level. Of the 48.2% who were, 78.5% (40.3% male, 59.7% female) were studying one STEM-based A-Level, 16.5% (38.5% male, 61.5% female) were studying two, and 5.1% (100% male, 0% female) were studying three. To account for small sample sizes, students were grouped according to

whether they were studying none, a single, or multiple (i.e. two or three) STEM-based A-Levels. There was no significant association between gender and the number of STEM-based A-Levels studied (χ^2 = 1.378, df = 2, p = 0.502; Figure 3). Of the 164 students, 144 also indicated whether their parents/guardian held a university degree. To account for small sample sizes, students were grouped according to whether they were studying none, a single, or multiple (i.e. two or three) STEM-based A-Levels. There was no significant association between parent/guardian education status and the number of STEM-based A-Levels studied (χ^2 = 2.509, df = 2, p = 0.285; Figure 3).

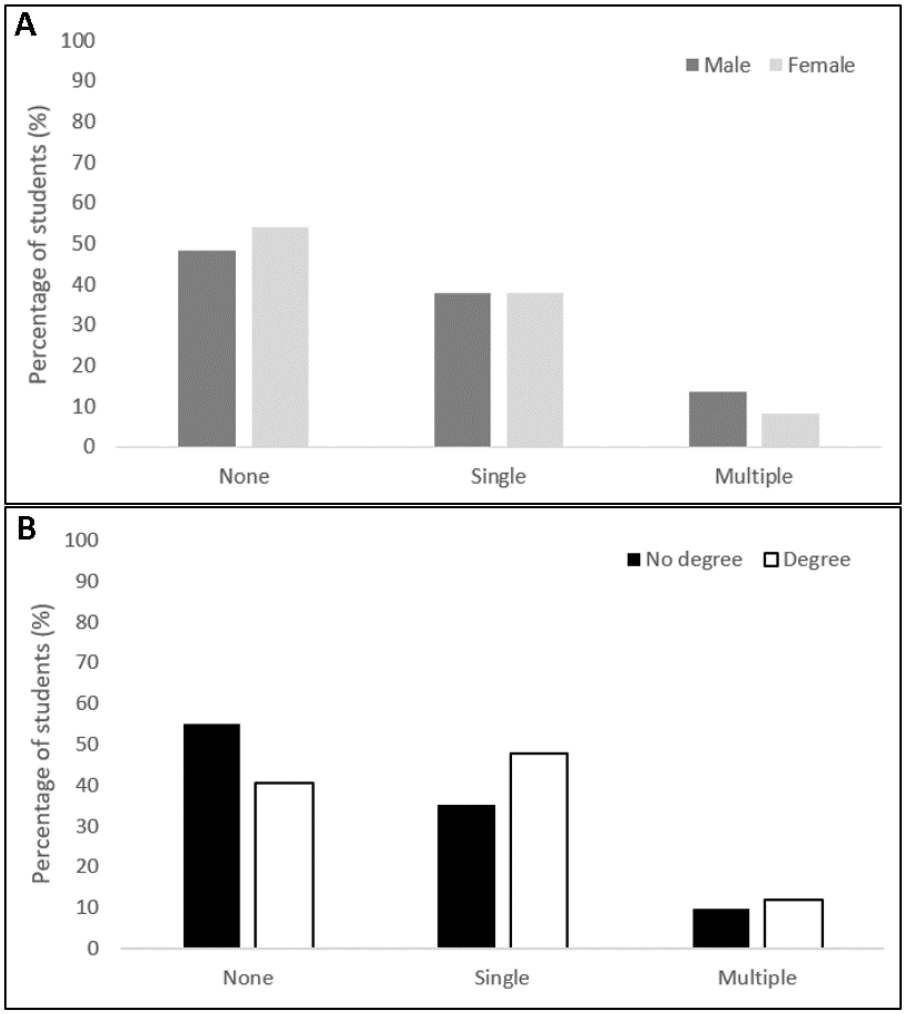

Figure 3: association between number of STEM A-levels undertaken and KS5 students' gender (A) or parental education (B). None of the observed differences were statistically significant.

Students' favourite sources of science news

A total of 483 KS4 and KS5 students listed their sources of science news; note that many students listed multiple sources (n = 695). The most frequently mentioned source was social media (32.4%), followed by news (16.7%), TV (14.1%), teachers (9.6%), parents (6.6%), friends (5.8%), and newspapers/magazines (3.9%).

Additionally, 'other sources' accounted for 10.9%. There was no significant association between gender and sources of science news (χ^2 = 10.532, df = 7, p = 0.160; Figure 4). Of the 483 students, 367 also indicated whether their parent/guardian held a university degree (n = 526 sources). There was a significant association between parent/guardian education status and sources of science news (χ^2 = 15.773, df = 7, p = 0.027; Figure 4). Within students whose parent/guardian did not hold a university degree, social media was the most frequently listed source (35.1%), followed by news (14.6%), TV (13.2%), teachers (12.6%), other sources (11.1%), friends (5.0%), parents (4.4%), and newspapers/magazines (4.3%). Within students whose parent/guardian did hold a university degree, social media was the most frequently listed source (30.4%), followed by news (17.4%), TV (15.2%), parents (10.3%), teachers and friends (both 8.2%), other source (6.0%), and newspapers/magazines (4.3%).

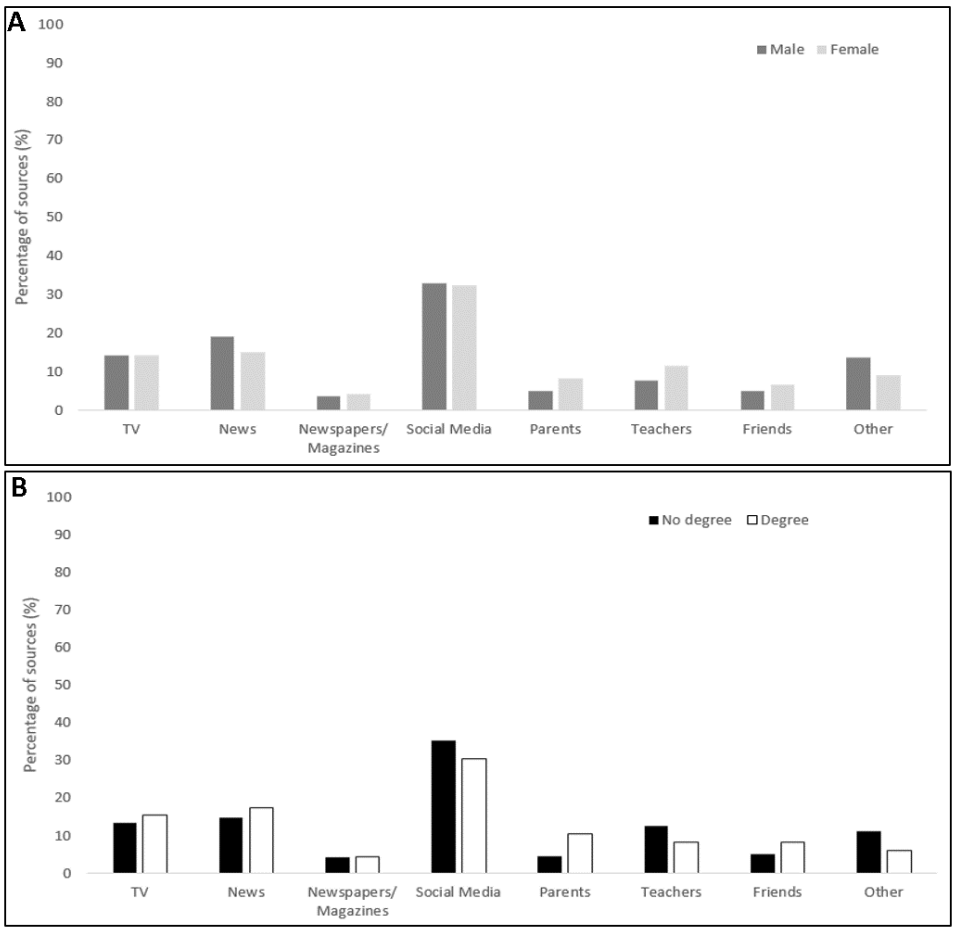

Figure 4: association between students' favourite sources of science news and their gender (A) or parental education (B). No significant association was observed with regards to gender, however a statistically significant association was observed between students' parental education status and their favourite sources of science news. Students whose parents/guardians hold a university degree were over twice as likely to cite them as a source.

STEM Influential Person

Of the 504 KS4 and KS5 students surveyed, 142 did not provide an answer to the question requesting them to provide the name of an influential person within science. Of the 362 who did provide an answer, 359 students named a person who was identifiable as male (88.5%) or female (12.4%). The most popular male role models amongst participants were Albert Einstein, Stephen Hawking, and Isaac Newton; the most popular female role models were Rosalind Franklin, Marie Curie, and a science teacher (name intentionally omitted) in one of the two institutions. There was a significant association between the gender of students and the gender of scientists they named ($\chi^2 = 22.714$, df = 1, $p < 0.001$; Figure 5).

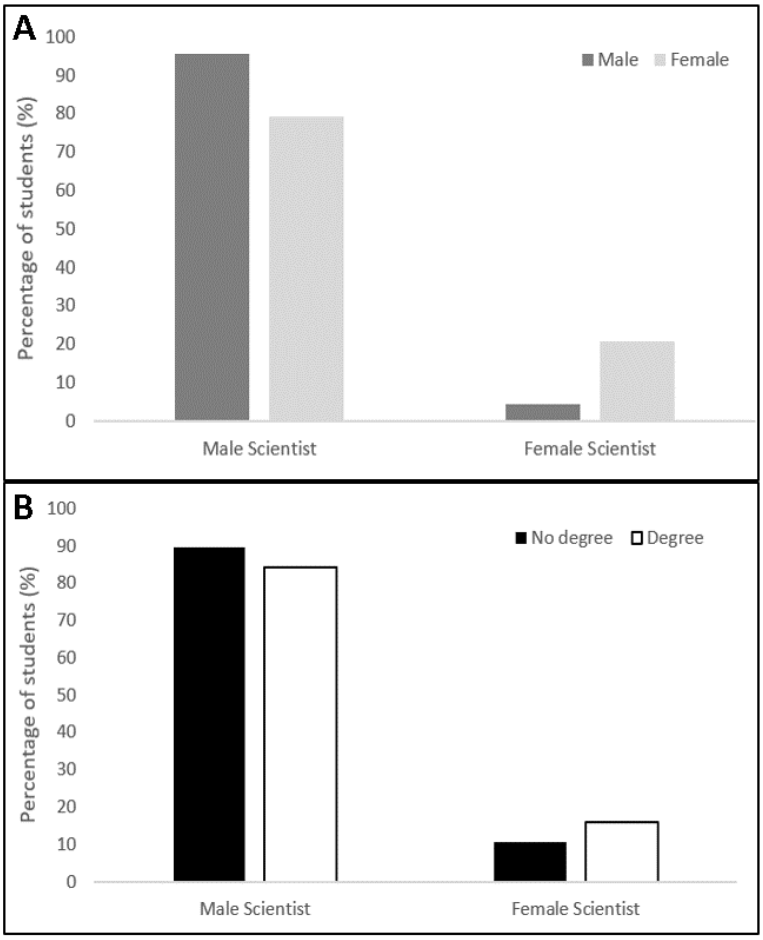

Figure 5: association between students' gender (A) or parental education (B) and the gender of the STEM influential personality they named. All students were considerably more likely to name a male scientist than a female one, however girls were significantly (approximately 5 times) more likely than boys to name a female scientist. No statistically significant association was observed between parental education status and students' choice of a male/female STEM influential figure.

Overall, students of both genders were more likely to name male scientists (79.2% female students, 95.7% male students), however female scientists were more frequently named by female students (20.8% females, 4.3% males). Of the 359

students, 277 also indicated whether their parents/guardian held a university degree. Parent/guardian education status was not significantly associated with whether students named a female or male role model ($\chi^2 = 1.582$, df = 1, p = 0.208; Figure 5).

DISCUSSION AND CONCLUSIONS

Among the 504 students surveyed in this study, gender showed a much greater association than parental education with students' engagement with STEM subjects. While it has previously been reported that parental pressure does indeed have an impact on students' self-reported achievement in STEM, our data seems to indicate that this effect may not be ascribable to parental education status (Hoferichter & Raufelder, 2019). With regards to all of the analysed variables, having parents/guardians in possession of a Higher Education degree only showed a statistically significant association with students' choice of science news sources. Students whose parents/guardians did not hold a University degree only listed them as the seventh out of eight preferred source of science news, whereas the position moved up to the fourth place in the case of University-educated parents.

Conversely, students' gender did not show a statistically significant association with their choice of science news source. Regardless of gender and parental education status, the vast majority of participants indicated social media as their go-to source of science news, with over twice as many preferences compared to parents or teachers. While this should not be seen *per se* as an inherently negative phenomenon, it does indeed pose reasonable concerns with regards to the quality and reliability of science news obtained via a largely unverified medium in an era characterised by the uncontrolled production and diffusion of fake news (Vosoughi, Roy, & Aral, 2018). It is critical that educators avoid the temptation to demonise the use of social media as a source of information, and instead try to harness its pedagogical potential by integrating primary literature in school science teaching and fostering digital literacy towards a critical approach to accessing and evaluating online sources (Bates, McKeever, Reilly, & Roulston, 2017; Phillips & Norris, 2009).

Amongst the participants in this study, girls were significantly less likely than boys to include at least one STEM discipline in the list of their favourite subjects, confirming previous observations that secondary school is a critical period with regards to girls' engagement (or lack thereof) with STEM subjects (Siani & Dacin, 2018). A clear gender difference in STEM preference is already noticeable amongst KS4 students, with girls expressing over twice as many preferences than boys for biology while being considerably less likely to prefer chemistry or (to an even greater extent) physics. Intriguingly, despite girls expressing overall fewer preferences for STEM subjects in KS4, our results show no significant association between gender and the number of STEM A-levels undertaken at KS5. This observation, consistent with national data, might reflect the high female uptake of biology A-levels; indeed, 48% of all the science A-levels undertaken by female participants were in biology. Another plausible interpretation might be that, in the current climate of economic uncertainty, students might be led to take up a subject they see as "useful" (e.g. science or mathematics) rather than, or in addition to, one they are more passionate about but is perceived to open up fewer career

opportunities (e.g. arts or humanities) (Blom, Cadena, & Keys, 2015). Future surveys could expand upon this aspect by specifically asking students to explain why they have chosen particular subjects.

The analysis of influential science figures named by the study participants draws a profoundly unsettling figure, with only 20.8% of girls and 4.3% of boys naming a female scientist. This observation could be partially ascribed to the fact that several of the role models cited by the students (e.g. Isaac Newton, Albert Einstein, Charles Darwin) refer to historical periods where science was by and large a male-dominated field. However, it is reason for further concern that (with the sole exception of a female science teacher) no contemporary women were named by the students, whereas most of the mentions to contemporary scientists referred to male role models (e.g. Stephen Hawking, Brian Cox, David Attenborough, Bill Nye). This discrepancy can indeed be explained, or at least corroborated, by the strong gender imbalance associated with STEM characters in popular culture, whereby women only represent a minority of the real or fictional scientists popularised by movies, TV shows and documentaries (Steinke & Paniagua Tavarez, 2017). However, as our study highlighted a strong affinity of students with social media as a source of science news, this could be harnessed by educators to provide an opportunity for students to broaden their awareness of diverse science figures by directing them towards online platforms operated by female scientists.

The current study explored students' engagement with STEM subjects in association with gender and parental education. However, as with any study, there are some limitations and potential improvements for this work. The sample size was relatively high, with 504 students surveyed across two schools located in southern England. Broader geographical coverage would lend strength to this work, by exploring patterns at a local, regional, and national level. Additionally, whilst the current study broadly covered all STEM topics, it had a particular focus on science subjects. Future studies may also benefit from expanding on this work to consider technology, engineering and mathematics in more depth with regard to gender and parental education. Whilst the current study did not find a strong association between parental education and students' engagement with STEM subjects, future studies may benefit from exploring this factor in more depth. For example, the question "*Does one or more of your parents/guardians have a university degree?*" could be expanded upon to provide additional context. This could include details such as whether both, one or neither parent held a university degree; if their degrees are in a STEM subject; if the student was from a heterogeneous family unit; if the student had regular contact with each/both parents; and/or if the student had older siblings who were attending university or in possession of a university degree. While such context was beyond the scope of the current study, future studies may find it beneficial to pursue this further.

In conclusion, this study shows that both gender and parent/guardian educational level play a role in the attitudes of KS4 and KS5 students towards STEM disciplines. It reveals opportunities for improvement of the curriculum with regards to helping students utilise different science news sources, verify 'fake news' stories, and broaden their awareness of diversity amongst scientists. The results of our study

support previous observations of an early disengagement of girls from STEM subjects (with particular regards to mathematics-intensive disciplines) and indicate that the shortage of accessible female role models might play a key role in this process. Curriculum design and academic outreach are two key factors contributing to the endeavour of providing school-age students with a wide range of authoritative and diverse scientific role models. It is critical that policymakers and educators are mindful of gender balance when designing school curricula and planning didactic activities to ensure that they reflect the diversity of the contemporary scientific landscape. Finally, it would be advisable for higher education institutions to strengthen their outreach programs within local communities to provide school students with a diverse range of relatable research-active role models such as postgraduate students and junior researchers.

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