Self-Confidence and STEM Career Propensity: Lessons from an All-Girls Secondary School

Abstract: Gendered barriers in education and attrition along the academic and professional pipeline are key determinants of the current STEM skills shortage. While enrolment in STEM undergraduate courses has been increasing in the recent decades, STEM degree choices still suffer from considerable gender imbalance, whereby women are underrepresented in maths-heavy subjects and overrepresented in biological and healthcare subjects. This study sought to investigate the relationship between maths/science self-confidence and propensity towards STEM careers during secondary education, a critical period in the university course decision-making process. Non-parametric analysis of cross-sectional survey data collected in an English all-girls secondary school revealed an overall decline in self-confidence over the 5 years of secondary education, which was statistically significant for science, but not maths. Self-confidence in maths showed a strong positive correlation with students’ propensity towards careers in maths and science, but not in technology/engineering. Likewise, self-confidence in science was positively correlated with maths and science propensity, but had no effect on technology/engineering propensity. These findings indicate that the teaching of maths and science is by itself not sufficient to promote engagement with STEM career pathways in engineering and technology. Secondary curricula should explicitly emphasise the links between the learning of mathematical and scientific concepts, their practical applications, and the career opportunities they enable.

Keywords: STEM, gender bias, motivation, career aspirations, self-confidence

1 Introduction

Female underrepresentation along the Science, Technology, Engineering, and Mathematics (STEM) educational and professional pipeline has been identified as a key determinant of the STEM skills shortage in the global labour market (Kramer, Tallant, Goldberg, & Lund, 2015). A recent analysis of multiple large-scale datasets identified that STEM professional trajectories are tightly linked with the choice of undergraduate subject (White & Smith, 2021). Crucially, the same study (p. 705) highlighted that while enrolments in STEM courses have been generally rising over time, “increases in participation in science at undergraduate level in recent decades have largely been along traditionally gendered lines.” Female participation in STEM education and employment tends to be lower in maths-intensive fields (Wang & Degol, 2017) and “largely restricted to the biological sciences, subjects allied to medicine, and other subjects such as psychology” (White & Smith, 2021). The decision-making process leading to gender imbalance in undergraduate courses is rooted in experiences and mindsets acquired by students throughout their primary and secondary studies (Blazev, Karabegovic, Burusic, & Selimbegovic, 2017; Penner & Paret, 2008). Secondary school years are a critical time period with regards to the consolidation of adolescents’ personalities, motivation, self-efficacy and career aspirations (Siani & Dacin, 2018). Secondary students’ perception of their own competence plays a key role in their career decision-making; however, a gender bias exists in their self-assessment process: female students tend to significantly underestimate their own task competence compared to ability-matched male peers (Correll, 2001). The maladaptive underestimation of their own competence results in the progressive loss of self-efficacy, motivation and ultimately engagement with STEM subjects, leading girls to confirm and internalise societal gender stereotypes in a process that can be modelled through different conceptual frameworks (Murphy, MacDonald, Wang, & Danaia, 2019; Siani, Marley, Smith, & Donnelly, 2020).

According to goal-orientation theory, developed by Dweck and colleagues, achievement goals can be distinguished in
two broad categories: performance goals and learning goals (Dweck & Leggett, 1988; Elliott & Dweck, 1988). Performance goals are the ones “in which individuals seek to maintain positive judgments of their ability and avoid negative judgments by seeking to prove, validate, or document their ability and not discredit it” (Elliott & Dweck, 1988, p. 5); their pursuit is thought to expose learners to feelings of helplessness and maladaptive cognitive patterns. On the other hand, learning goals are those “in which individuals seek to increase their ability or master new tasks” (Elliott & Dweck, 1988, p. 5), leading them to embrace challenges and engage in positive learning behaviours. Building upon these theoretical foundations, Dweck proposed that learners can be placed on a continuum with regards to their self-theories on intelligence and ability (Dweck, 2006). On one end of the spectrum, learners with performance goals hold subconscious beliefs that intelligence is an unchangeable or inherent trait, e.g. being “smart” or “good at something.” In opposition to this so-called “fixed mindset,” individuals with a learning goal orientation have a more dynamic or incremental view (described as a “growth mindset”) of intelligence, whereby individuals are not inherently good or bad at certain subjects/tasks, and their ability can be improved by studying or practicing them. Interventions designed to foster a growth mindset in secondary students have been shown to improve task value, self-efficacy, and self-regulation in science classes (Bedford, 2017). Likewise, a longitudinal analysis highlighted that secondary students who embraced a growth mindset showed higher task values in maths and increased STEM career aspirations, and that this process was mediated by expectancy beliefs (Degol, Wang, Zhang, & Allerton, 2018). Crucially, the same study (p. 976) also revealed that “this mediated pathway was stronger for females than for males, such that females had higher math achievement than males when they endorsed a growth mindset.”

The maladaptive motivational patterns and early disengagement of female students from STEM subjects and career aspirations can also be interpreted through the lens of Eccles’ Expectancy Value Theory (EVT). EVT has proven to be a valuable tool to investigate the factors affecting secondary students’ choice of tertiary education pathway (Lykkegaard & Ulriksen, 2016). Indeed, the outcomes of interventions based on EVT indicate that “by instilling utility values, intrinsic values, and expectancies for success into young students, we may be able to further ‘pressurise’ the STEM pipeline, thereby increasing the flow of minority students into STEM careers” (Ball, Huang, Cotten, & Rikard, 2017, p. 380). Exposure of school girls to gender-matched role models has been shown to directly increase the EVT task-value factors (attainment value and intrinsic value) as well as their success expectations and propensity towards a STEM career (González-Pérez, Mateos de Cabo, & Sáinz, 2020; Siani, McArthur, Hicks, & Dacin, 2022). Latent profile analysis of US High School Longitudinal Study data revealed that students’ motivational profiles in maths and science (i.e. their expectancy and value beliefs) could predict their achievement and STEM major intentions, and that “women were disproportionately underrepresented in profiles in the High Math/High Science profile” (Fong, Kremer, Hill-Troglin Cox, & Lawson, 2021, p. 13).

The present study sought to address two key aims. The first aim was to elucidate how girls’ self-confidence in maths/science and their STEM career propensity vary across the 5 years of secondary education. The second aim was to evaluate whether students’ self-confidence in maths and science is differentially correlated to their propensity towards pursuing a career in maths, science, or technology/engineering. It is important to note that while career propensity was measured with regards to all broad subjects covered by the STEM acronym (science, technology/engineering, maths), students’ self-confidence was only assessed with regards to maths and science. This was an intentional decision reflecting the fact that maths and science are presented in UK secondary curricula as clearly defined individual subjects, therefore making it easy for students to unambiguously assess their confidence in them. On the other hand, while elements of technology and engineering are indeed taught in UK secondary schools, their teaching is spread across different subjects (science, maths, design, technology, and computing), which might confound students’ interpretation of their self-confidence in those topics.

2 Methods

2.1 Survey Design and Distribution

The questionnaire used in this study (Table 1) was adapted from the Student Attitudes Towards STEM Survey – Middle and High School Students, a validated research instrument “intended to measure changes in students’ confidence and efficacy in STEM subjects, twenty-first century learning skills, and interest in STEM careers” (Friday Institute for Educational Innovation, 2012, p. 1).

The survey was designed using Google Forms and was composed of four sections, designed to gather information on the participants (Section 1) and on their perspectives on maths (Section 2), science (Section 3),
Section 1: Personal information

1. What school year are you currently in?
2. What is your ethnicity?
3. Can you think of a person (can be living, historical or even fictional) that inspired you to study maths or science? If yes, write here who he or she is.

Section 2: Maths

4a. Maths is hard for me
5c. I would consider choosing a career that uses maths
6a. I can get good grades in maths
7c. I will need maths for my future work
8a. I can handle most subjects well, but I cannot do a good job with maths

Section 3: Science

9b. Science is hard for me
10f. I would consider a career in science
11b. I can get good grades in science
12f. I will need science for my future work
13b. I can handle most subject well, but I cannot do a good job with science

Section 4: Engineering & technology

14. I like to imagine creating new products
15. I am good at building and fixing things
16a. Designing products or structures will be important for my future work
17a. Knowing how to use maths and science together will allow me to invent useful things
18. I believe I can be successful in a career in engineering
19. Can you think of any reasons preventing you from pursuing a career in science, technology, engineering, or maths?

Table 1: Questionnaire used in the survey

<table>
<thead>
<tr>
<th>Question</th>
<th>Maths Self-Confidence Score</th>
<th>Science Propensity Score</th>
<th>Maths Propensity Score</th>
<th>Technology/engineering propensity score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td>2</td>
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</tbody>
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Section 4: Engineering & technology (Section 4). The 5-points Likert-type questions in Sections 2–4 were used to calculate the self-confidence and propensity scores used as dependent variables in the study.

The survey link was distributed between February and March 2022 as part of science lessons by science teachers in an all-girls secondary school in Hampshire, UK (institution name intentionally omitted).

2.2 Scores

Participants were scored based on their survey answers to quantify their self-confidence and propensity towards different subjects. Scores were calculated by assigning a numerical value to their answers to selected Likert-type questions as indicated in Table 1. For most questions, increasing numerical values were assigned in direct relation to the level of agreement (e.g. Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly Agree = 5). However, for questions 4, 8, 9, and 13 the assignment was reversed to account for the fact that agreement with those statements signifies a lower confidence.

2.3 Statistical Analysis

Statistical analysis was carried out using IBM SPSS 28 with a significance threshold of \( p \leq 0.05 \) for all tests. Due to the ordinal nature of the data collected in the survey, non-parametric tests were used in their analysis. Kruskal–Wallis tests were used to compare median scores between different groups of students. In cases where a significant difference was highlighted, post-hoc pairwise comparisons were carried out using Dunn’s tests, and the significance levels were adjusted for multiple simultaneous comparisons using the Bonferroni correction to minimise type I errors. Correlation between variables was analysed using Kendall \( \tau_b \) coefficients.

Ethical approval: This study was carried out in accordance with the University of Portsmouth research ethics policy. Ethical approval (code BIOL-ETHICS #023-2022) was gained prior to the start of the investigation. Informed consent was assured by prefacing the survey with a disclaimer explaining the purpose and modalities of the study. The disclaimer also informed participants of the voluntary and anonymous nature of the survey, and of their right to leave any questions unanswered or withdraw at any point prior to submission of the answers. All data collected were handled and stored in accordance with the General Data Protection Regulation.

3 Results

Eighty-two female students participated in the survey across educational Key Stage 3 (year 7 to year 9) and Key Stage 4 (year 10 and year 11). The participants’ breakdown by year group is shown in Table 2.

Figure 1a shows that median self-confidence score in maths declined from 12 in year 7 to 9 in year 11; however,
a Kruskal–Wallis test revealed that none of the observed differences were statistically significant ($\chi^2 = 7.863; \text{df} = 4; p = 0.097$). A significant difference ($\chi^2 = 13.201; \text{df} = 4; p = 0.01$) was observed in science self-confidence with respect to students’ year group (Figure 1b). Dunn’s post-hoc pairwise tests highlighted that the only statistically significant ($p = 0.033$) difference was between year 8 (median science self-confidence score = 12) and year 11 (median science self-confidence score = 9).

Figure 2 shows the association between students’ year group and their propensity towards a career in maths (Figure 2a), science (2b), and technology/engineering (2c). A decline in median propensity was observed between year 7 and year 11 for both maths and science careers; however the difference in both cases was not statistically significant ($\chi^2 = 4.837; \text{df} = 4; p = 0.304$ for science; $\chi^2 = 8.313; \text{df} = 4; p = 0.081$ for maths). A significant association ($\chi^2 = 12.381; \text{df} = 4; p = 0.015$) was observed between students’ school year and their propensity towards technology/engineering careers. Post-hoc pairwise tests revealed that year 7 students had significantly lower median propensity than students in year 8 ($p = 0.04$), year 9 ($p = 0.000011$), and year 11 ($p = 0.016$).

Kendall’s $\tau_b$ tests revealed strong positive correlations between self-confidence and career propensity in

<table>
<thead>
<tr>
<th>Year group</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key Stage 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 7</td>
<td>14</td>
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</tr>
<tr>
<td>Year 8</td>
<td>11</td>
<td>13.5</td>
</tr>
<tr>
<td>Year 9</td>
<td>20</td>
<td>24.4</td>
</tr>
<tr>
<td>Key Stage 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 10</td>
<td>8</td>
<td>9.8</td>
</tr>
<tr>
<td>Year 11</td>
<td>20</td>
<td>24.4</td>
</tr>
<tr>
<td>Prefer not to say</td>
<td>9</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Table 2: Breakdown of the study population by school year group and educational Key Stage

Figure 1: Association between students’ year group and their self-confidence in maths (a) and science (b).
Figure 2: Association between students' year group and their career propensity for maths (a), science (b), and technology/engineering (c).
both maths ($\tau_b = 0.568$, $p = 1.43 \times 10^{-10}$, Figure 3a) and science ($\tau_b = 0.352$, $p = 0.000078$, Figure 3b).

Figure 4 shows how self-confidence in maths and science correlates with career propensity in the other STEM subjects. Students’ propensity to pursue a career in technology/engineering was not significantly correlated with their self-confidence in maths ($\tau_b = 0.049$, $p = 0.580$, Figure 4a) nor science ($\tau_b = 0.003$, $p = 0.977$, Figure 4b). On the other hand, a strong positive correlation was found between students’ propensity towards a career in science and their maths self-confidence ($\tau_b = 0.301$, $p = 0.00063$, Figure 4c) and vice versa ($\tau_b = 0.355$, $p = 0.000071$, Figure 4d).

4 Discussion and Conclusions

The analysis of the survey responses provides considerable insight into the relationship between self-confidence and STEM career propensity in secondary school girls, and elucidates how both variables change across the 5 years of secondary education.

A decline in median self-confidence between year 7 and year 11 was observed for both maths and science. The difference was statistically significant with regards to science but not maths, conceivably owing to the small sample size for some of the year groups as suggested by the Kruskal–Wallis $p$-value being close to the 0.05.
significance cut-off for both subjects. While suitable to the nature of this study, non-parametric tests are known to have lower statistical power than their parametric counterparts, and therefore to be prone to underestimating the significance of results due to type II statistical errors (Hoskin, 2012). The observation of a decline in science self-confidence in secondary school complements the trajectory highlighted by previous reports of the progressive loss in pupils’ self-efficacy and interest in science over the course of primary education (Lei, Green, Leslie, & Rhodes, 2019). Similarly, a recent analysis of a large datasets of responses provided by 7,302 primary and secondary UK students revealed a decline in maths self-confidence and facility (proportion of correct answers), particularly around the transition from primary to secondary education (Foster, Woodhead, Barton, & Clark-Wilson, 2022).

No significant associations were observed between students’ year group and their propensity towards a career in maths or science. This observation could be interpreted in light of a recent longitudinal study of maths and science motivation and career intentions among 24,000 high schoolers in the US (Middleton, Mangu, & Lee, 2019). The findings reported by Middleton and colleagues revealed that approximately a third of the sample (the so-called “stayers”) expressed intentions to pursue a STEM career in the ninth grade and confirmed their interest in the eleventh grade, while equal proportions of students lost their intention (the “leavers”) or expressed ex-novo STEM propensity (the “newcomers”). The averaging out of the opinions of stayers, leavers, and newcomers might explain the absence of significant differences in science and maths career propensity observed in the present study. This effect might be ascribable to the cross-sectional sampling strategy employed in the study, which as discussed later constitutes one of its main limitations.

While no significant differences were observed between year 8 and year 11, year 7 students expressed considerably lower propensity towards technology/engineering careers than their older peers. The sudden change in perspective might be explained by the limited emphasis placed on the practical and cross-curricular applications of scientific and mathematical concepts in primary school curricula. This interpretation is supported by previous reports that while primary school pupils enjoy hands-on interventions designed to foster their engagement with technology and engineering, they generally express limited interest in pursuing a career in the field (Silver & Rushton, 2008). Conversely, a recent literature review revealed that secondary education has an “influential and relevant” impact on students’ STEM career orientation, further reinforcing that the
primary/secondary transition is a critical period in the development of students’ career aspirations (Reinhold, Holzberger, & Seidel, 2018).

Strong positive correlations were observed between self-confidence in maths and science and propensity towards a career in the same subject (i.e. maths self-confidence vs maths career propensity, science self-confidence vs science career propensity). This (perhaps unsurprising) finding corroborates the abundant literature affirming the crucial role of self-confidence and self-efficacy as early determinants of STEM career intentions (Blotnicky, Franz-Odendaal, French, & Joy, 2018; Brown, Concannon, Marx, Donaldson, & Black, 2016; Lent, Brown, & Hackett, 2000; Multon, Brown, & Lent, 1991).

Self-confidence in maths and science showed significant positive correlations not only with career propensity in the subject itself as described in the previous paragraph, but also between the two subjects (i.e. maths self-confidence vs science career propensity, science self-confidence vs maths career propensity). While a significant association between science self-efficacy and maths career intentions had been previously reported, the study by Kwon and colleagues revealed no significant impact of maths self-efficacy on science career intentions (Kwon, Vela, Williams, & Barroso, 2019). On the other hand, our findings provide evidence that self-confidence in maths and science can reciprocally predict career propensity in both subjects.

Remarkably, neither self-confidence in maths nor in science showed any significant correlation with students’ propensity towards a career in technology/engineering. This apparently counterintuitive observation can be interpreted in light of previous findings obtained by modelling secondary students’ STEM career intentions using an expectancy-value model (Smit, Robin, & De Toffol, 2020). The suggestion that “school science lessons might not offer sufficient experiences in applied science to secondary school students” and therefore, particularly in the case of girls, “students have trouble seeing the connections between science-based technology topics in school and in real life” (Smit et al., 2020, p. 1) would explain the lack of a statistical correlation between science self-confidence and technology/engineering career propensity.

5 Conclusions

The generalisability of the findings of this study is subject to a few limitations inherent to the cross-sectional sampling strategy employed in the survey. The cross-sectional approach provides an effective snapshot of the perspectives of different groups of learners studying within the same school environment at the same moment in time. However, compared to a longitudinal study, it does not allow the evaluation of how the opinions of individual students or groups develop over the course of their secondary education. Moreover, the use of cross-sectional data may result in the averaging out of opposing trends (e.g. the “leavers vs newcomers” effect discussed earlier on), potentially resulting in the loss of crucial information on individual behaviours within the study group.

Despite these limitations, this study provides novel insight on the interplay between maths/science self-confidence and STEM career propensity in secondary school girls. The decline in science self-confidence over the 5 years of secondary education and the lack of a correlation between maths/science self-confidence and technology/engineering career propensity have significant implications for the professional practice of educators and policy makers. With regards to the former, student engagement and self-confidence could be bolstered by further strengthening the links between schools and universities in the form of (among other possibilities) collaborative science projects or outreach activities. Exposure to relatable role models (e.g. research-active postgraduate students or early career researchers) and hands-on involvement in level-appropriate research activities are invaluable tools to enthuse students with the subject and bolster their self-confidence. With regards to the latter observation, the findings of this study reinforce the urgency for secondary curricula and schemes of work to integrate clearer links between theoretical concepts in science and maths, their applications in technology and engineering, and the career pathways they enable.

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Informed consent: Informed consent has been obtained from all individuals included in this study.

Authorisation for the use of human subjects: The research related to human use complies with all the relevant national regulations, institutional policies and in
accordance the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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