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ABSTRACT

Gender Differences in Tertiary Education: What Explains STEM Participation?[1]

The share of women achieving tertiary education has increased rapidly over time and now exceeds that of men in most OECD countries. However, women are severely under-represented in maths- intensive science fields, which are generally referred to as STEM (science, technology, engineering, and maths). The under-representation of women in these subject areas has received a great deal of attention. This is because these fields are seen to be especially important for productivity and economic growth and are associated with occupations that have higher earnings. Subject of degree is an important part of the explanation for the gender wage gap. The aim of this paper is to review evidence on explanations for the STEM gap in tertiary education. This starts with statistics about background context and evidence on how well-prepared male and female students may be for studying STEM at a later stage. I then discuss what the literature has to say about the role of personal attributes: namely confidence, self-efficacy and competitiveness and the role of preferences and expectations. I go on to discuss features of the educational context thought to be important for influencing attributes and preferences (or mediating their effects): peers; teachers; role models; and curriculum. I then briefly discuss broader cultural influences. I use the literature reviewed to discuss policy implications.

JEL Classification: I20, J16

Keywords: STEM, gender gap, tertiary education

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Executive Summary

Although the share of women achieving tertiary education has increased rapidly over time and now exceeds that of men, women are severely under-represented in maths-intensive science fields (generally known as STEM or Science Technology Engineering and Maths). More detailed subject breakdowns suggest that female under-representation is more severe in some of these subject areas than in others and there are some science fields where women are over-represented (such as life sciences). There is considerable scope to improve European data by further disaggregation by field of study. On account of the high economic importance attached to maths-intensive science fields, much attention has been devoted to trying to understand the reasons for the gender gap. This report summarises recent literature, with a particular focus on papers within economics.

As students need prerequisites to enter STEM programmes, the gender gap in tertiary education results partly from factors that are evident before that time and which influence 'educational preparedness'. This encompasses general educational achievement, achievement in mathematical subjects (which are important for many STEM programmes), comparative advantage in subjects requiring mathematical versus literacy proficiency and course-taking in upper secondary education. Many studies suggest a rather limited role for educational preparedness in recent times (especially for the US), although course-taking within upper secondary education has been found to play a major role in some countries (such as Ireland and Canada).

Some studies point to interesting variation between countries with regard to test scores at age 15 (reflected in PISA) and the gender gap in STEM at tertiary level. For example, some Scandinavian countries (e.g. Finland) are noted for their high gender equality and relative performance of girls in science literacy in PISA, and yet have a relatively large gender gap (favouring males) in STEM college degrees. This is known as the 'gender equality paradox'. Recent studies caution against naïve interpretation of such patterns as hypotheses have been overturned by pooling data from countries over time, with the ability to control for institutional/cultural features that remain broadly constant.

'Educational preparedness' is itself an outcome of many other individual and societal factors, some of which also come into play among those who are highly 'STEM ready' by the end of upper secondary education. These include confidence in one's own ability and self-efficacy in particular subjects. A common finding in the literature is that even very high-achieving females are often held back by these factors. Also relevant (and related) is the 'female friendliness' of educational environments and the extent to which gender stereotypes are salient. This includes whether fields are perceived to lead to work that is 'people-orientated' or 'thing-orientated' as there is a marked gender difference in such preferences. There is a vast literature showing the importance of such factors for influencing field of study and/or ‘educational preparedness’ for subsequent choices. As these factors work cumulatively and in combination, there is no single factor that can be recommended to change these patterns in a substantial way. Furthermore, an apparently similar policy change can have different effects in different contexts. Policy design therefore needs to be sensitive to the country and specific educational system.

However, there are some common themes that emerge from the literature review with policy relevance. Firstly, as it is often the case that girls have a poorer perception of their own ability in maths-intensive subjects within the classroom, it is important that they have better awareness of how they stand among a broader cohort of students and that a ‘growth mindset’ pedagogy is encouraged. Secondly, females (and especially high achievers) respond well to female role models, whether amongst peers or teachers – in upper secondary as well as tertiary education. Policies that encourage the representation of women in these fields may have broad ramifications for how other females perceive such fields and their future choices.

There are numerous interventions to encourage more girls and women to enter and stay in STEM fields. Much more needs to be done to evaluate programmes in a scientific manner and to collate and disseminate results. A trusted source for the collation and dissemination of high-quality evaluations may do much to inform what is known and implemented to improve female engagement in STEM.

1. Introduction

The share of women achieving tertiary education has increased rapidly over time and now exceeds that of men in most OECD countries. However, women are severely under-represented in maths-intensive science fields, which are generally referred to as STEM (science, technology, engineering, and maths). The under-representation of women in these subject areas has received a great deal of attention. This is because these fields are seen to be especially important for productivity and economic growth (e.g. Griliches, 1992; Jones, 1995; Peri et al., 2015). The lack of women pursuing these fields is seen to be a constraint on economic growth within the European Union (EU).[2] Furthermore, maths-intensive STEM fields are associated with occupations that have higher earnings (i.e. reflecting the high labour market demand for people with proficiency in these areas).[3] Most economics papers that analyse the gender gap in STEM motivate this interest by the gender wage gap (favouring men) because subject of degree is an important part of the explanation for this (Blau and Kahn, 2017; Card and Payne, 2017; Francesconi and Parey, 2018; Machin and Puhani, 2003). One way to encourage more people into STEM-related occupations at the same time as addressing the gender wage gap is to encourage more women to engage in STEM at tertiary level. This would also have the benefit of increasing diversity in the workplace. Furthermore, if the lack of female representation has partly to do with forms of discrimination that come from stereotyping and an environment hostile to women, this is reason enough to explore what drives such discrimination and how it might be addressed. Challenging gender stereotypes and providing equal opportunities for men and women are goals of the European Commission Gender Equality Strategy.[4]

The aim of this paper is to review evidence on explanations for the STEM gap in tertiary education where good evidence exists. Most of the literature defines STEM as referring to science, technology, engineering and maths. I will follow this convention here, making it clear when I am referring only to particular fields. There is an extensive literature on this subject across several disciplines, which includes several reviews (such as Cheryan et al., 2017)[5] and Kahn and Ginther, 2018). I will draw on these reviews and other papers (including many very recent papers) and will primarily focus on the issue through the lens of an economist. As the range of issues covered is very broad, I make no claim

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[2] https://eige.europa.eu/gender-mainstreaming/policy-areas/economic-and-financial-affairs/economic-benefits-gender-equality/stem

[3] Deming and Norway (2019) find that although the returns to STEM subjects are high during the earlier part of an individual's working life, they do decline with time for some subjects due to technological change. Kinsler and Pavan (2015), show very high returns to science majors who work in related occupations.

[4] https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_357

[5] Cheryan et al. (2017) consider review papers since 1990 in psychology, sociology and education on the topic of women's under-representation in STEM fields. They search databases in psychology, sociology, education and economics. Their review is probably the most comprehensive available overall, though their focus is mainly on the US and does not cover such a wide range of papers in economics as in Kahn and Ginther (2018), or considered here. Many papers considered here have only been published since these reviews.

to be comprehensive on each individual topic. I cite the most relevant references I could find from a search that has primarily focused on the economics literature and drawn on the reviews cited above.

I start with an introduction to the background context using statistics on field of study from Eurostat and UNESCO and as reported in recent papers (Section 2). Then, I discuss evidence on how well prepared students may be for studying STEM at a later stage (i.e. 'preparedness'), making use of data from PISA and findings from the literature (Section 3). I go on to discuss whether cross-country preparedness and STEM participation can be explained by measures of gender inequality (Section 4). However, most of the gender gap is within country rather than between countries, and the remaining sections focus on studies that have sought to explain the gender gap within different countries. I discuss the role of personal attributes: namely confidence, self-efficacy and competitiveness (Section 5) and the role of preferences and expectations (Section 6). I go on to discuss features of the educational context thought to be important for influencing attributes and preferences (or mediating their effects): peers; teachers; role models; and curriculum (Section 7). I then briefly discuss broader cultural influences (Section 8). Subsequently, I use the literature reviewed to discuss policy implications, also drawing on insights made by some of the authors of relevant studies (Section 9) before concluding (Section 10).

2. Background Context

For tertiary-level education, gender segregation by field of study is very striking and has been well documented in previous literature. For example, in their review paper about women and STEM, Kahn and Ginther (2018) discuss this in relation to the US. They show that with regard to STEM, female under-representation is limited to maths-intensive science fields – geosciences, engineering, maths/computer science and physical science (which they call GEMP fields). They denote other STEM fields as LPS – life sciences, psychology and social sciences (excluding economics). In 2014 in the US, women received only 27 per cent of bachelors' degrees in mathematically intensive GEMP fields but 69 per cent of bachelors' degrees in LPS fields.

Figure 1 shows the percentage of women in tertiary education across a range of countries. In the majority of countries shown here, there are more women than men in tertiary education. However, Figure 2 shows a similar type of gender segregation in broad STEM groupings across these countries (using Eurostat data). There are vastly more men than women with degrees in science, technology, engineering and maths. Having said that, the ratio of men to women with degrees in natural sciences, maths and statistics is much more equal.

Statistics from UNESCO enable a slightly more detailed subject breakdown. They are presented here for EU countries (for 2017). Figure 3 shows the percentage of male (female) graduates by field as a percentage of male (female) graduates with tertiary education. This is shown for each of the following fields: (A) engineering, manufacturing, construction; (B) natural science, maths and statistics; (C) health and welfare; (D) information and communication technologies. This shows a remarkable degree of segregation across almost all countries, with (A) and (D) being more popular with men and (C) being more popular with women. Only in natural science, maths and statistics are the proportions relatively equal – at least in many of the countries of the EU. Although health and welfare may not always be included in some definitions of STEM, many programmes within this broad category require STEM skills.

Although a similar pattern can be found across countries, there is still some variation and gender gaps have evolved over time. Women's representation in each STEM field increased rapidly during the 1970s (Ginther and Kahn, 2016), and continued to grow in psychology and life sciences in the 1980s and 1990s before it stabilised (both ending above 70 per cent). In more recent decades trends have been much more stable across several STEM fields. This is shown for the US by the National Science Foundation reports (1997-2016)[6] with respect to physical sciences, biological sciences, maths and statistics, and physics. The statistics also show that the share of women with degrees awarded in computer science declined from 27 per cent in 1997 to 17 per cent in 2016. Reasons for the pattern of this evolution in specific STEM fields are not well understood.

Cheryan et al. (2017) document within-field gender gaps. For example, in engineering, women are more likely to be represented in chemical, biomedical and architectural engineering than in electrical, mechanical and nuclear engineering. In computer science, women are more highly represented in human-computer interaction than in robotics. Within surgical sub-specialties, women comprise 36 per cent of general surgery residents and fellows but only 13 per cent of orthopaedic surgery residents and fellows. There is little research about why particular sub-fields are more popular with women than others and this is clearly an important area for future research.[7]

3. Educational Preparedness: Prior Achievement, Comparative Advantage and Course-taking

As students need prerequisites to enter STEM programmes, the gender gap may result not only from choices made at the point of entry into tertiary education but also investment decisions made before – by young people, their families and educators. This is reflected in their 'educational preparedness', which we broadly define here to mean the following: (a) general educational achievement across a range of subjects – relevant because STEM programmes at tertiary level will be demanding

[6] https://ncses.nsf.gov/pubs/nsf19304/digest/field-of-degree-women

[7] Cheryan et al. (2017) hypothesise that factors which come out strongly in their literature review might have a role to play in explaining such disparities: namely, insufficient early experience, perceptions of a masculine culture and gender gaps in self-efficacy. These explanations are covered in later sections.

academically; (b) achievement in mathematical subjects - an important prerequisite for many STEM programmes; (c) comparative advantage in subjects requiring mathematical versus literacy proficiency. This is relevant because a person's choices may be induced by his/her relative strengths in proficiencies that are used to different intensities in tertiary-level studies; and (d) course-taking in upper secondary education which is itself influenced by (a), (b) and (c). These factors are themselves influenced by many other factors at the individual and societal level that are also relevant even among those who are STEM ready at the point at which they enter tertiary education. These will be discussed in subsequent sections.

Figure 4 shows the difference in PISA scores between 15-year-old girls and boys (i.e. the OECD's Programme for International Student Assessment). In all countries, there is a substantial gap (favouring girls) in reading. For science and maths, the gender gap is much smaller. Where there is a difference, it usually favours boys in maths – although not for all countries. For science, the picture is more mixed – sometimes favouring boys and sometimes favouring girls. Both Fryer and Levitt (2010) and Hyde and Mertz (2009) find that the gender gap in maths is not evident at the beginning of schooling but emerges over time. The substantial difference in reading favouring girls shows that, on average, girls' comparative advantage is in reading whereas for the average boy it is in maths or science (i.e. their performance in maths or science is better than their performance in reading). This is important because girls' and boys' choices might be influenced not only by their overall performance, but in how they perceive their own individual strengths in subjects requiring more literacy or numeracy skills.

According to the review by Kahn and Ginther (2017), many articles find that previous grades or test scores are correlated with subsequent choices concerning STEM course-taking and majors, but the correlation explains little of the overall gender differences in these outcomes. Speer (2017) challenges this common finding in a study that includes a much broader set of pre-college skills than found in most studies. While most studies in the US measure prior ability by SAT scores, he uses a broader set of pre-college skill measures that include maths, verbal, science and mechanical test scores. He finds that such measures account for 62 per cent of the gap in science content, 66 per cent of the gap in humanities content and 47 per cent of the gap in the probability of majoring in engineering. On the other hand, business and education fields have large gender gaps that are unexplained by test scores. Recent studies for Canada and Ireland by Card and Payne (2017) and Delaney and Devereux (2019a) respectively have found a much larger role for college preparedness in relation to the probability of STEM degree choices. In both cases, course-taking in upper secondary education is the most important driver of this.[8] In Canada, most of the gender gap in STEM enrolment is explained by differential readiness at the end of secondary school whereas it accounts for about 60 per cent of the gap in Ireland. Part of the explanation for the difference between Canada and Ireland is the fact that nursing is included in the STEM measure in Canada but not in Ireland. When nursing is included in the Irish STEM measure, gender gaps become much smaller. Indeed, within Ireland, there is considerable heterogeneity between STEM subjects with regard to the importance of educational preparedness for explaining the gender gap. The substantial gender gap in engineering is mostly explained by course-taking in upper secondary education and on grades, whereas the substantial gap in technology is mostly not explained by these measures. There is no gender gap to explain in science. Another interesting finding for Ireland is that there is a stronger role for comparative advantage at the top of the ability distribution. This has also been found for the US (Riegle-Crumb et al., 2012).

Boys and girls have also been found to react differently to past performance with regard to subsequent choices regarding STEM course-taking and majors (Kahn and Ginther, 2017). But this tends to depend on subject. For example, in a study about Israeli high school course choices, Friedman-Sokuler and Justman (2016) found that girls react more strongly to prior grades in biology and chemistry when making subject choices. On the other hand, boys reacted more strongly to grades in computer science and physics. Both in Ireland and in the UK, boys have been found to react more strongly to comparative advantage in English and maths with regard to their STEM choice than girls (Delaney and Devereux, 2019a; Aucejo and James, 2016).

It is relevant to consider gender difference in the variance of reading and maths scores as well as the average score. In an analysis of international test score data, Machin and Pekkarinen (2008) show higher variance in test scores for boys than for girls in most OECD countries. In maths, this comes about because boys are more likely to be found in the upper part of the distribution in maths (i.e. more of them are 'higher achievers' in maths). In reading this comes about because more boys are in the lower part of the distribution (i.e. more of them are 'lower achievers' in reading). To the extent that 'higher achievers' in maths are more likely to study STEM, this could help explain the gender difference we observe in who takes STEM subjects in tertiary education (Kahn and Ginther, 2017).

However, differences in prior achievement between girls and boys are not the whole story. For most STEM subjects, a significant share of the gender gap in tertiary-level educational choices cannot be explained by educational preparedness. For example, Delaney and Devereux (2019a) find that there is a nine percentage point gap in the propensity for males and females to choose STEM

[8] As noted by Buser et al. (2014), in the Netherlands, boys are significantly more likely to take maths classes in secondary school than are girls and similar patterns have been found in France, Denmark, Switzerland and Germany.

courses at tertiary level, even for persons who have identical preparation at the end of secondary school in terms of both subjects studied and grades achieved.

4. Explaining Cross-country Preparedness and STEM Participation

A number of studies relate measures of gender inequality at a country level to the gender gap in educational performance and more recently to the probability of entering STEM at tertiary level. One of the best-known such studies is by Guiso et al. (2008). They classify countries according to several measures of gender inequality – including the World Economic Forum's Gender Gap Index (GGI) which reflects economic and political opportunities, education and well-being for women. They use data on educational achievement from PISA 2003 and correlate the gender gap in performance with various measures of gender inequality. They find a positive correlation between gender equality and the gender gap in maths. These results suggest that the gender gap in maths, though it historically favours boys, disappears in more gender-equal societies. The same cannot be said for how boys score in maths compared with how boys score in reading. Boys' scores are always higher in maths than in reading and although the difference between boys' maths and reading scores varies across countries, it is not correlated with the GGI index or with any other measures of gender inequality. Thus, in more gender-equal countries, such as Norway and Sweden, the maths gender gap disappears, while at the same time, girls' comparative advantage in reading widens. Fryer and Levitt (2010) are able to replicate these findings using PISA data but not for TIMSS when using the full set of countries for which the GGI index is available).[9] In this case the relationship between the GGI and the gender gap in maths disappears. In fact, in countries like Bahrain and Iran, which are among the worst in terms of gender equality, girls are outperforming boys in maths and this is due to relatively strong performance by girls and not due to an unusually bad performance by boys. In further analysis, Fryer and Levitt (2010) find that the difference in results between PISA and TIMSS is driven by a small number of countries (in TIMSS) where all secondary schooling is sex segregated (including Bahrain, Iran, Jordan, Palestine and Saudi Arabia). As other factors might be driving differences between countries (which is acknowledged by the authors), one should not make too much of the correlation between single-sex schooling and maths performance. However, issues such as gender composition of classrooms do feature strongly in the broader literature, which will be discussed below.

The original paper by Guiso et al. (2008) has recently been challenged by Anghel et al. (2019). They explain that even though Guiso et al. (2008) control for countries' level of economic development in their analysis, cross-country estimates may well capture the effect of other country-specific confounding factors. To assess whether this is the case, they take advantage of five waves of PISA data

[9] TIMSS is the "Trends in International Mathematics and Science Study".

(2003 to 2015). By exploiting variation both across countries and within countries over time, they are able to assess whether the findings still hold once the influence of country-specific factors are controlled for more comprehensively. Their analysis suggests that the findings do not hold with these additional controls and therefore that the results reported by Guiso et al. (2008) likely reflect a spurious correlation between women's emancipation and other country-specific unobserved determinants of the maths gender gap. A broader point is that one should be a little sceptical of cross-country empirical analysis that does not control for country-specific effects (which also applies to the study by Fryer and Levitt, 2010).

Stoet and Geary (2018) conduct a cross-sectional study in a similar spirit to Guiso et al. (2008) – using PISA 2015 in this case. They found that women's representation in science, technology, engineering and mathematics education is higher in countries that rank lower on a gender equality index. They label this as the 'gender equality paradox' because gender-equal countries are those that give girls and women more educational and empowerment opportunities that generally promote girls' and women's engagement in STEM fields. For example, consider the case of Finland, which excels in gender equality, where adolescent girls outperform boys in science literacy, and which ranks second in European educational performance. Paradoxically, it has a relatively large gender gap in college degrees in STEM fields. A similar story is true of Norway and Sweden. The authors hypothesise that in contexts with fewer economic opportunities and higher economic risks, women may have a greater incentive to take up relatively high-paying STEM occupations compared to contexts with greater opportunities and lower risks. However, the authors acknowledge that the correlation between gender equality and the STEM graduation gap may be influenced by an omitted variable that drives both of these indicators. As this was indeed found to be the case by Anghel et al. (2019) in relation to a very similar analysis by Guiso et al. (2008), one should view these findings as tentative. It would be very interesting to use multiple waves of PISA data to test whether the 'gender equality paradox' is robust to controlling more fully for country-specific factors.

It should also be noted that there is substantial within-country heterogeneity in the extent of these gender gaps. Using multiple waves of PISA data Anghel et al., 2019 show that within-country variation accounts for about 61.5 per cent and 54.9 per cent of the total observed variation in the maths gender gap in the pooled sample of OECD and non-OECD countries respectively. Thus, it is likely that similar factors are at work within different countries that help to explain the gender gap in educational preparedness and in those other factors that give rise to the gender gap even among STEM-ready individuals.

5. Personal Attributes

There has long been a debate on the role of nature versus nurture with regard to gender differences in cognitive performance, which also partially influences field of study in tertiary education. As set out by Lavy and Sand (2018), this debate is based on limited credible scientific evidence because it is difficult to disentangle the impact of biological gender dissimilarities from environmental conditions. It is also difficult to measure stereotypes and prejudices and to test their causal implications. Whatever the underlying cause, gender differences in personal attributes have been found to account for gender differences in 'STEM readiness' (as defined above) and in the propensity to choose different fields of study within tertiary education.

Relevant attributes that appear in the literature include confidence, self-efficacy and competitiveness, which are related to each other. The results of laboratory experiments suggest that men are more likely to enter competitive arenas than women because of higher confidence (Gneezy et al., 2003; Niederle and Vesterlund, 2007). This also (negatively) influences female performance in high-level maths tests (Niederle and Vesterlund, 2007). As noted by Shi (2018), insofar as students perceive STEM majors to require technical mastery, gender gaps in beliefs about one's own ability can lead men and women to sort into different academic tracks. It might also influence why women drop out of STEM majors at much higher rates than men (as found by Astorne-Figari and Speer, 2018).[10] With regard to engineering specifically, Shi (2018) finds that female beliefs about lower academic ability (even for those who are academically prepared) are important in accounting for the gender gap in North Carolina. Murphy and Weinhardt (2018) find that gender differences in confidence are related to STEM fields' choices among college students in the US. Brainard and Carlin (1998) find that among females who switch out of STEM majors in the US, major reasons cited were 'lack of self-confidence' and 'feeling isolated'. Many studies find gender gaps in self-efficacy with regard to maths at all stages of education, even among those who are equally competent (Cheryan et al., 2017).

Buser et al. (2014) measure competitiveness in an experimental setting (using the same measure as Niederle and Vesterlund, 2007) and then relate this to actual track choices of students in the Netherlands one year later. The measure of competitiveness reflects the individual's preference for entering a competitive arena and not his/her performance within it. The institutional context is that secondary school students choose their track at age 15 and this strongly correlates with the choice of major in tertiary education. There is a clear ranking of tracks in terms of mathematical intensity and academic prestige, with the science track being ranked first. They find that even though the academic performance of girls is at least as good as that of boys, boys choose substantially more prestigious

[10] However, they also find that men are more likely to switch out of college than women in general, although the rate of women switching out of STEM majors is far higher than the male drop-out rate from college.

tracks than girls and are much more competitive than girls in the experiment (even though their performance on the task is the same). They find that the gender difference in competitiveness can account for 20 per cent of the gender gap in the academic prestige, and mathematical and science intensity of the chosen academic track, controlling for grades and perceived mathematical ability. This effect of competitiveness is not driven by measures of confidence or risk attitudes. The finding that girls react negatively to competitiveness is also found in France. Landaud et al. (2018) find that gaining admission to more selective high schools (with more highly achieving peers) makes no difference to the field of study chosen by boys one year later but induces a significant decrease in the probability that girls choose science and a symmetrical increase in the probability that they choose humanities. Buser et al. (2019) conduct an experiment among lower-secondary school students in Switzerland. They find that the gender gap in the willingness to compete is zero among those of lower ability and rises through the ability distribution, reaching 30 to 40 percentage points at the top of the ability distribution. At the top of the ability distribution, students who compete are more likely to choose a maths- or science-related specialisation. Fischer (2017) also finds that female undergraduate students react negatively to high-ability peers (via a competition effect) and are less likely to graduate with a STEM degree, whereas men's persistence is unaffected. The context is a large public university in the US where first year students are randomly assigned to different mandatory introductory chemistry lectures.

However, as discussed by Booth (2009), gender differences in competitiveness vary between cultures, with women being less competitive than men in a patriarchal society and more competitive than men in a matrilineal society (Gneezy et al., 2009). Booth (2009) shows that girls from single-sex schools were more likely to enter a tournament than those from co-educational schools, which is consistent with the finding of psychologists that the gendered aspect of individuals' behaviour is brought into play by the gender of others with whom they interact (Maccoby, 1998). As cited by Buser et al. (2014), a number of experimental studies have shown that for women both the performance in, and the willingness to enter, competitive environments is reduced when the competition group includes males (Gneezy et al., 2003; Balafoutas and Sutter, 2012; Niederdal et al., 2013).

Astorne-Figari and Speer (2019) show that women who leave STEM majors switch to majors that are much less male-dominated and competitive. However, they often seek out other science-related majors that are less competitive and more popular with women (such as nursing). Thus, they argue that switching out of STEM majors (characterised as having a high component of physical science/engineering/maths) has more to do with their culture and make-up than it is about fleeing science. In contrast Kugler et al. (2017) do not find a role for male-dominated majors in explaining the gender difference in changing choice of major in the US, nor do they find a differential response to poor grades. However, they do find that women are more likely to switch out of male-dominated STEM majors in response to poor performance and they interpret this as a response to multiple signals about lack of fit (including low grades, gender composition of the class and external stereotyping signals).

Overall, the literature does find evidence for relative lack of confidence and a lower willingness to compete among women as a reason for why they do not enter some STEM fields or are more likely to switch out of STEM majors (in the US) or are less likely to enter tracks that prepare them for STEM fields at the tertiary level (in Europe). However, these factors do not operate in isolation. They interact with the environment and culture in which individuals find themselves.

6. Preferences and Expectations

As with personal attributes, preferences and expectations are influenced by people's cultural environment. In their literature survey, Kahn and Ginther (2017) document that even at early ages boys and girls show different preferences and interests towards different subjects. In their earlier survey (Ceci et al. 2014) they summarise some of the psychology literature on gender preferences, which finds that on average women are more people-orientated and men more thing-orientated. This dichotomy is important in accounting for both vocational preferences and college majors. They go on to say that more recently, Eccles and Wang (2016) find that gender differences between entering occupations that are maths-intensive (geosciences, engineering, economics, maths/computer science and physical science) and other STEM fields (life sciences, psychology, and social science) are best predicted by women's greater preferences for work that is altruistic and people-orientated, compared with men's preferences for thing-orientated work. This might explain why women prefer biological and psychological science and are more likely (relative to men) to choose medicine instead of a doctorate in biology. This explanation also comes out strongly in the review by Cheryan et al. (2017). Among STEM majors, women report more interest in the people- and helping-orientated aspects of these majors than do men. Cheryan et al. (2017). note that stereotypes that pursuing the field will allow fulfilment of people-orientated goals such as affiliation, intimacy and altruism are lowest in maths and highest in biology, with computer science and engineering falling in between. They also note that the more women endorse goals to help and work with people, the lower their interest in computer science, engineering, maths and the physical sciences.

Zafar (2013) studies the choice of major using data from students in Northwestern University, collecting data about their subjective expectations. He finds that the most important factors in the choice of major are enjoying coursework, enjoying work at potential jobs and gaining the approval of parents. Non-pecuniary aspects of the workplace (enjoying work and reconciling work and family) matter a lot more to females than to males. He estimates that a policy intervention that were to raise the expectations of females about ability and future earnings in engineering to the same level as that of males would decrease the gender gap by 15 per cent, whereas replacing females' beliefs about enjoying coursework with those of males would decrease the gender gap by almost half. Wiswall and Zafar (2015) randomly provide students in a particular major with information about earnings and employment for people who choose that major. They find a greater role for preferences than expected earnings in the choice of major.

However, studies do show that students' subjective expectations of earnings are important determinants of educational choices (e.g. Stinebrickner and Stinebrickner, 2014; Arcidicono et al., 2012). In a recent study for Germany, Osikominu and Pfeifer (2018) investigate gender gaps using elicited expectations at the time of college major choice with a focus on STEM fields. Although they find that wage expectations do play a role for influencing the choice of major and that males have higher wage expectations than females, the gender differences in wage expectations do not appear to explain the gender difference in preferences for college majors. They interpret this as consistent with a situation in which women are more influenced by non-pecuniary aspects of their field of study than men.

In a study using administrative data for Norway, Kirkebøen et al. (2017) show that the payoff to a field of study depends critically on what the counterfactual is. For example, by choosing science instead of humanities, individuals almost triple their earnings early in their working career, whereas choosing science instead of engineering or business has little pay-off (in the Norwegian context). They also find that individuals tend to choose fields in which they have comparative advantage. Thus, both the chosen field and the next-best alternative could look different for men and women (i.e. they have different comparative advantages) and thus the relative return would also look different by gender. The complexity of identifying the true return to field of study by gender implies that it is also difficult to estimate how important pecuniary returns are for women relative to men.

Even though current studies suggest that men are more concerned about pecuniary aspects of qualifications than women, economic returns have been found to be important for explaining greater entry of women to higher education over time. Goldin et al. (2006) use data on high school graduates in the US in 1952, 1972 and 1992. They find that high school girls improve relative to boys in college preparation as measured by achievement test scores and by maths and science course-taking. They find that changes in these proximate determinants of college investments are driven by increases in girls' expected economic returns to college, which in turn arose from improvements in perceived labour market opportunities and an increase in the age of first marriage. These findings have similarities to Anghel et al. (2019) who use multiple waves of PISA data. Within non-OECD countries, they find a positive correlation between the female labour force participation rate and the relative improvement in girls' maths performance (as well as their relative over-performance in reading). This is consistent with a behavioural response to improved labour market opportunities for women, with the effect of increasing girls' overall cognitive performance. Thus, these studies suggest that there is a role for labour market opportunities (and increasing gender equality) to change behaviour and performance – even though it is not clear what effects this has on field of study.

7. Educational Context

Differences in preferences and educational preparedness do not develop in a vacuum but are developed within educational environments, which is in turn shaped by culture (discussed below). Relevant factors discussed in the literature for influencing STEM choices include peers, teachers and the school curriculum.

7.1. Peers

There are many papers that consider how the gender composition of peers at school and in college affects educational performance and the gender gap in field of study. There are several mechanisms through which gender composition might affect field of study. For example, this might include how males and females are ranked within the classroom, or by effects of gender composition on perceived competitiveness. There may also be important differences between schools which are single or mixed sex. Booth (2009) notes the psychological literature that shows there may be more pressure for girls to maintain their gender identity in schools where boys are present (Maccoby, 1990; Brutsaert, 1999). In their literature review, Cheryan et al. (2017) note that 'stereotype threat' may be induced simply by women being under-represented in a situation. This refers to the fear of confirming negative stereotypes about one's group (in this case, as having lower abilities in maths and science than men). They report that negative stereotypes about women's ability appear to be more problematic in computer science, engineering and physics than in biology, chemistry and maths. However, some researchers argue that publication bias in the literature may cause the significance of 'stereotype threat' to be overstated. (e.g. Pennington et al., 2019).

Recent studies in China and Denmark have considered how gender peer ability composition in the first year of high school affects track choices in the subsequent year. Monuganie and Wang (2019) find that in Chinese high schools, an increase in the share of high-performing female peers increases the probability that women will choose a science track relative to men, whereas men are unaffected by the gender composition of high-ability peers. They interpret this finding as consistent with a role model or affirmation effect for female students, mitigating the adverse effects of negative gender stereotypes and altering females' beliefs. At first this seems somewhat at odds with the finding that girls are less likely to choose the science track in highly competitive environments (as discussed in Section 5). Monuganie and Wang (2019) argue that this is because women can benefit from high-performing peers, conditional on them being of the same gender.

Brenoe and Zolitz (2019) conduct a very similar study in Denmark focusing on the gender composition of peers in high school (within the maths track). In contrast to the study in China, they find that a higher share of females makes women less likely to enrol in STEM fields and more likely to enrol in health-related studies in college. Men are less affected but also behave more gender-stereotypically when more female peers are present: they become more likely to enrol in STEM studies and less likely to enter health-related studies. In this case, they argue that the mechanism is through the effects of having more males in the classroom on the perception of comparative advantage in STEM for women. Specifically, having more female peers alters the GPA (grade point average) in favour of men, which may give women reason to believe they are less prepared for college studies in STEM. However, one point in common with the Chinese study is that female role models can play an important role. In the Chinese case, this was the mechanism through which higher-achieving girls benefited from the presence of other higher-achieving girls. In the Danish study, having a mother who is STEM-educated completely mitigates (negative) peer effects.

As in the case of the Danish study, Delaney and Devereux (2019b) consider how relative class rank in school matters in Ireland (although the consideration of rank is more explicit in this case). In Ireland, there are many mixed-sex and single-sex schools and the STEM gender gap is bigger for those who attend mixed-sex schools. In mixed-sex schools, girls tend to be lower ranked in maths and higher ranked in English than boys. Delaney and Devereux (2019b) find rank to be important for explaining the gender gap in the choice of STEM as a field of study in tertiary education. They also find that this can partially explain why those who go to same-sex schools are less influenced by gender in whether they enrol in STEM at tertiary level.

However, single-sex schooling is not always found to increase the probability for females to enter into STEM fields. Park et al. (2018) analyse this issue in Seoul, where students attending academic high schools cannot choose their schools - academic high schools must receive students who were assigned by lottery. Their investigation of students' maths test scores, their choice of the science/maths test and the actual STEM university major consistently show that all-girls schools do not make significant differences to these STEM outcomes. On the other hand, all-boys' schools increase boys' performance in maths, the probability of choosing the science/maths test (which is required to apply for a STEM college major) and the probability of attending university with a STEM major. Thus, in this case, single-sex schooling exacerbates gender differences in STEM within tertiary education.

Bostwick and Weinberg (2018) examine the effects of gender peer composition within STEM doctoral programmes on persistence and degree completion. Gender peer composition is seen as a proxy for the female friendliness of the environment. They show that women entering cohorts with no female peers are 12 percentage points less likely to graduate within six years than their male counterparts. This primarily works through changes in the probability of dropping out in the first year of a PhD programme and are largest in programmes that are typically male dominated.

7.2. *Teachers*

Teacher grading bias has been found to have differential effects on boys and girls. One aspect considered in recent papers by Lavy and Sand (2018) and Lavy and Megalokonomou (2019) is how this affects field of study in upper secondary education and high school. Lavy and Sand (2018) consider grading bias in primary school in Israel. This is measured by students' average test scores in a 'non-blind' exam that the teacher marks, versus a 'blind' exam marked externally. They find that favouritism of boys among maths and science teachers has an especially large and positive effect on boys' maths test scores and on the probability of successful completion of advanced maths and science studies in high school, whereas the effect on girls is in the opposite direction. The bias is interpreted as reflecting teachers' stereotypical biases in the relative proficiency of boys and girls in these subjects.

Lavy and Megalokonomou (2019) explore the extent to which teachers' gender bias in high school influences students' academic performance in high-stakes exams that determine admission to universities and on students' choice of university field of study.[11] The analysis is of high school in Greece, where the performance in high school exams is the sole determinant of university admission. Teacher bias (favouring boys) is found to have a large role in explaining both performance and students' choice of field of study in university. The bias strongly and significantly affects the probability that girls will enrol in different fields of study but has no significant effects for boys. They find that teachers have a persistent pattern of discriminatory behaviour and is related to their quality as measured by their value added. They conclude that improving teacher quality would largely eliminate gender stereotype bias among teachers.[12]

Gong et al. (2018) analyse the effect of having a male or female teacher at middle school in China. The focus of this study is simply on whether having a teacher of a particular gender matters (and not about whether the teacher is biased). They focus on schools in which the assignment of students to classrooms is random. While there is a broad literature showing that having a female

[11] Teacher bias is measured as the difference between a student's school exam score in 11th and 12th grade (scored by the student's teacher) and his or her external exam score (taken at the end of 11th and 12th grade and scored nationally).

[12] Policy reports such as this recent one for France emphasise continuing professional development on gender equality for all those involved in education. http://www.haut-conseil-egalite.gouv.fr/stereotypes-et-roles-sociaux/travaux-du-hcefh/article/rapport-formation-a-l-egalite

teacher is beneficial to girls' educational performance, this study is unusual in being able to look at the effect of teacher gender on non-cognitive outcomes. Among their findings is that the presence of a female teacher counters the perception that girls are not as strong at maths and better motivates girls to study the subject. They interpret their findings as supporting the stereotype threat hypothesis (referred to above) and role model theories.

7.3. Role Models

Although role models may come in the form of peers and parents (referred to above), some studies have considered the role of professor gender at the post-secondary level. One of the most convincing of these studies is by Carrell et al. (2010) as in their context, students are randomly placed into classrooms (i.e. in the US Air Force Academy, students are randomly assigned to professors for a variety of mandatory standardised courses). Their results show that although professor gender has only a limited impact on male students, it has a powerful effect on female students' performance in maths and science classes, their likelihood of taking future maths and science courses and their likelihood of graduating with a STEM degree. Furthermore, the effects are much larger for students with high maths scores. The finding of strong effects for high-ability females is reminiscent of the finding discussed above by Monuganie and Wang (2019) that gender peer composition also has a stronger (and positive) effect on these students – which is also interpreted as an effect of role models. Carrell et al. (2010) show that some male professors are very effective at teaching female students but that having female introductory maths and science professors continues to exercise a positive influence on female students' long-run outcomes even after controlling for professors' value added.

Canaan and Mouganie (2019) find very similar results to Carrell et al. (2010) in the context of a four-year private college in the US. In this case, students are randomly assigned to academic advisors (who are also faculty members) in their first year of college. Being matched to a female rather than a male science advisor substantially narrows the gender gaps in STEM enrolment and graduation, with the strongest effects occurring among students who are highly skilled in maths. In contrast, the gender of an advisor from a non-science department has no impact on students' major choice.

Bottia et al. (2015) evaluate whether the composition of high school faculty influences college students' decision to major in STEM fields. Specifically, they measure composition as the proportion of female high school maths and science teachers. The context is students who were educated in North Carolina both in high school and in university. The results show that faculty composition has no effect on males but a powerful effect on female students' likelihood of declaring and graduating with a STEM degree. In common with Carrell et al. (2010), effects are largest for female students with the highest maths skills.

The review by Cheryan et al. (2017) also emphasises the potential importance of role models. They note that the patterns of existing under-representation mean that there is a greater scarcity of potential female role models in computing, engineering and physics than in biology, chemistry and maths. However, they emphasise relatability rather than gender exclusively as a relevant trait of a good role model. These are people with whom students feel a sense of connection, similarity and identification. They note research that shows that role models who do not fit current masculine stereotypes of computer science and are relatable to women are able to increase women's interest, even if these role models are male.

7.4. Curriculum

The importance of the curriculum on offer varies over time and across countries.[13] For example, Hyde and Mertz (2009) note that a prominent explanation for the gender gap in maths in the past (in the US) was the differential patterns of course-taking, with girls less likely than boys to take advanced maths courses in high school and also less likely to take chemistry and physics where complex problem solving is involved. This is something that has changed over time with girls now more likely to take advanced maths courses than they were in the past. Carrell et al. (2010) note that in the US, the nearly non-existent differences in college preparatory maths and science courses are not predictive of gender differences in college major. Hyde and Mertz (2009) attribute the dramatic improvement in maths performance by US females to two recent cultural trends: (i) girls taking more maths and science courses during high school, due in part to changes in requirements for graduation and admission to colleges, and (ii) the opening up to girls in the early 1970s of intensive speciality high schools, colleges and graduate schools along with career opportunities in STEM fields.

In other countries, the courses or track chosen by girls and boys has been found to play a more important role in explaining STEM field choice in tertiary education. We see this in many European countries where students make choices in upper secondary education that strongly influence what choices are available to them subsequently. This is discussed above in Section 3.

There have been recent studies that consider the effect of a curriculum reform in high school using a convincing empirical strategy in Denmark, the UK and Germany respectively. The studies for Denmark and the UK examine reforms that affect high-ability students only, whereas the studies for Germany affect the whole student body. In Denmark, Joensen and Nielsen (2016) find that a reform which makes the high school curriculum less restrictive (specifically enabling individuals to combine advanced maths with chemistry rather than just physics) had a large effect on girls and strongly

[13] Although this review is about STEM fields, 'arts and design' is part of a broader 'STEAM' definition which is being incorporated into the renewed EU agenda for higher education. .https://ec.europa.eu/education/policies/higher-education/about-higher-education-policy_en

increased their relative probability of choosing health sciences and technical sciences in tertiary education. In the UK, De Philippis (2016) evaluates a reform which enabled individuals to take advanced (or 'triple') science from age 14 (i.e. one full qualification in physics, chemistry and biology) as opposed to taking less advanced options. She finds that this had an equal effect on boys and girls in secondary school but only induced boys to enrol in STEM at the tertiary level. However, she does find an effect on girls' propensity to study medicine. In Germany, several studies have examined a reform in the state of Baden-Wurttemberg that made advanced maths compulsory in the last two years of high school. These include Gorlitz and Gravert (2018) and Biewen and Schwerter (2019). About 20 per cent of students voluntarily took this option prior to the reform (and hence effects are identified for the other 80 per cent). The reform is found to increase the university enrolment rate for both boys and girls but only affected STEM among boys (Gorlitz and Gravert, 2018). Biewen and Schwerter (2019) finds that the reform affected boys through a positive effect on the probability of completing tertiary education in engineering and computer science, which was to some extent counteracted by a negative effect on maths and physics. For girls, there was no such positive effect and a slightly negative effect on the probability of completing maths and physics degrees. These studies suggest that the specifics of the curriculum reform and who it affects (e.g. high-ability or average student) are important for how such changes affect the gender gap in STEM tertiary education, although all the curriculum reforms considered here do increase overall enrolment in STEM at tertiary level (i.e. if we do not break this down by gender). Therefore, although curriculum reforms that facilitate more students to become STEM ready have achieved this objective, they have not always narrowed the gender gap in STEM at the tertiary level.

One of the explanations for the gender gap in the review by Cheryan et al. (2017) is insufficient early (i.e pre-college) experience in computer science, engineering and physics, compared to biology, chemistry and maths. While the latter are widely offered in US high schools, most do not provide opportunities for students to learn computer programming, and physics is only taught in 63 per cent of US high schools.[14] They argue that efforts to offer students STEM experience can increase interest for both groups but do little to diminish gender gaps in participation if broader cultural factors, such as the masculine cultures of these fields, are not addressed. A large international project "The Relevance of Science Education" (the ROSE project) suggests that females might be prepared for STEM education if comprehensive education programs wisely exploited knowledge about differences in the interests of girls and boys when designing school curricula (Sjøberg and Schreiner, 2010).[15]

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[14] Statistics cited in Cheryan et al., (2017) from the US Department of Education (2014).

[15] For example, boys were found to be interested in explosives and engines, whereas girls were more interested in the environment and healthy living: https://www.seproject.no/publications/english-pub.html

8. Broader Cultural Influences

Cheryan et al. (2017) define a masculine culture in STEM fields as being "a social and structural environment that signals a greater sense of belonging to men than women" (Cheryan et al., 2017). They explain that aspects of this masculine culture include stereotypes of the field that are incompatible with the way that many women see themselves; negative stereotypes and perceived bias; and few role models for women. In Cheryan et al.'s (2017) review of the literature, the 'masculine culture' of computer science, engineering and maths is one of three overarching factors that explain gender balance between STEM fields. The other factors are insufficient early experience and larger gaps in self-efficacy in these sub-fields. However, these other factors are not independent of this 'masculine culture'. For example, lack of early experience does not lead to female under-representation in fields such as psychology and nursing. According to Cheryan et al. (2017), it is only when a lack of early experience is present alongside a perceived masculine culture that gender differences are observed.

Cheryan et al. (2017) draw on a very large range of references in psychology and education and find that stereotypes of people in various STEM fields correspond to current patterns of gender disparities, with the most male-dominated fields being associated with the most masculine traits. Correlational evidence suggests that implicit or automatic associations between STEM and males have negative consequences for women's science and maths interests and aspirations.

In brief, the stereotype is 'male, socially awkward and focused on technology'. Such stereotypes are more prominent in computer science, engineering and physics than in biology, chemistry and mathematics and have been shown to correlate with gender disparities in interests. In another paper, Cheryan et al. (2015) describe computer science and engineering as stereotyped in modern American culture as male-orientated fields that involve social isolation, an intense focus on machinery and inborn brilliance – all of which are qualities typically more valued by men than women.[16] The literature reviewed by Cheryan et al. (2017) suggests that women are less likely than men to believe they fit these stereotypes and more likely to be deterred when the stereotypes are salient.

It is very difficult to estimate the independent effect of 'masculine culture' because it is a broadly defined concept and difficult to change in an experimental (or quasi-experimental) context

[16] As the focus of this review is on STEM fields, the emphasis here is on stereotyping within these fields. However, as discussed by Cheryan et al. (2017) stereotypes that are incompatible with traditional male gender roles may also help to explain gender disparities in fields and careers in which men are underrepresented.

other than specific aspects of this within field experiments.[17] But it is plausible that this culture underlies why the educational context described in Section 7 matters so much.

9. Policy Implications

What are the policy implications arising from what we currently know about the causes of the STEM gap? In this Section, I will reflect on implications from the literature reviewed above, including ideas put forward in some of the papers reviewed. To facilitate this, Table 1 summarises findings from some of the studies referred to in Sections 5-7.

As discussed in Sections 3 and 4, the gender difference in STEM engagement at tertiary level reflects both differential preparedness prior to this stage and differential choice among those who are STEM ready in terms of grades and courses taken. Some of the same factors influence both 'readiness' and choice conditional on being STEM ready. These include confidence in one's own ability (or self-efficacy) and preferences. Some of the relevant findings are summarised in the first two panels of Table 1. Personal attributes more likely to be found in females, such as lack of confidence in maths and a dislike of competitive environments (at least if also predominantly male), lead to a lower probability of choosing STEM tracks both in upper secondary and tertiary education. Furthermore, the preferences of females towards more 'people-orientated' work, together with the perception that some STEM subjects do not facilitate such jobs, may lessen interest in subjects such as computer science, engineering, maths and the physical sciences.

The literature points to aspects of educational context that can change attributes such as self-efficacy and confidence as well as preferences. Some of these are referred to in the lower part of Table 1 and are also related to broader cultural influences (discussed in Section 8). For example, the 'female friendliness' of the educational environment matters, and the extent to which stereotypes are salient (whether in terms of the perception that boys are better than girls in maths/science or that the perception that masculine/feminine traits and interests are differentially matched according to subject). As these factors work cumulatively and in combination, there is no single factor that can be recommended to change these patterns in a substantial way.

The literature on educational context (lower part of Table 1) suggests that various proxies for female friendliness do matter in general. Yet one must be careful about extrapolating findings from one institutional context to another. For example, increasing the share of female peers in high school was found to have a positive effect on girls' propensity to enrol in STEM subjects at tertiary level in

[17] For example, psychological studies include small-scale experiments that measure the effect of encountering a stereotypical computer science student on women's interest in computer science (discussed in Cheryan et al., 2015).

China but not in Denmark (Monuganie and Wang, 2019; Brenoe and Zolitz, 2019); single-sex schooling appears to be relevant for influencing STEM choices in tertiary level for girls in Ireland but not in Seoul (Delaney and Devereux, 2019b; Park et al., 2018). Therefore, policy design needs to be sensitive to the country and specific educational system. There are no universal prescriptions.

However, there are some common themes that emerge from the literature review. Firstly, it is often found that girls have a lower perception of their own ability in maths-intensive subjects. With regard to Ireland, Delaney and Devereux (2019b) suggest that high school students should be made more aware of their own ability in maths and English because they may be comparing their own performance only to people within their class as opposed to having a true sense of how they stand among the broader cohort of students. Such a policy also has the benefit of being relatively easy to implement relative to broader educational reforms. Another policy option is to address the perceptions of ability by inculcating a 'growth mindset' in pedagogical practice throughout schooling. In maths, this is the extent to which individuals believe that their maths abilities can be improved over time with effort, as opposed to being unchangeable. It has been shown to be particularly efficacious for girls (Boalar, 2013).

Secondly, girls do respond well to female role models and this appears to be especially the case for girls of higher ability. While it may not be practical (or desirable) to change educational systems to be segregated along gender-specific lines, it would be very interesting to study whether setting of high-ability students along the lines of gender in particular subjects might influence performance and future course-taking.[18] Given the strong effects of role models across most of the literature, it would seem to be important to address this both in schools and in tertiary education. This is also a conclusion of Zafar (2013) who finds that most of the difference in STEM at the tertiary level is driven by gender differences in tastes and preferences. He concludes "a possible policy implication…is to encourage policies that increase the representation of females in academic science and engineering, since these female professors may change female students' beliefs and preferences toward STEM coursework and careers". Cheryan et al. (2015) emphasise the importance of diversifying the image of computer science and engineering. They argue that girls are currently exposed to an unrealistic image of these fields that depicts all computer science and engineering cultures as fitting a narrow profile. They argue that as more women and girls are welcomed into these fields, the process of culture change will likely build on itself.

There are numerous interventions to encourage more girls and women to enter and stay in STEM fields. As argued by Cheryan et al. (2017) and also the Skills Commission in the UK (2019), much

[18] 'Setting' along the lines of ability is common within secondary schools in the UK. This is where students of different abilities are taught in separate classes for particular subjects (e.g. maths) but not for others.

more needs to be done to evaluate programmes in a scientific manner and to collate and disseminate results. Cheryan et al. (2017) and Cheryan et al. (2015) report very heartening case studies of a number of university departments in the US that made changes to their computer science departments with very impressive subsequent increases in the percentage of female computer science graduates within a decade (i.e. Harvey Mudd, Carnegie Mellon and University of Washington).[19] As described succinctly by Cheryan et al. (2015), in addition to structural changes (e.g. recruitment procedures), these programmes changed stereotypes of computer science by using diverse role models, exposing students to a wide range of applications for computer science and revamping their introductory course so that it was no longer seen as a field for 'geeky know-it-alls'. These examples show that it is possible to put a combination of policies in place and have big effects on enrolment. Thus, the gender gap in STEM in tertiary education may be prominent in many different countries, and often for similar reasons. But it is not inevitable. Culture can change.

10. Conclusion

The STEM gender gap in tertiary education results from factors that influence educational preparedness as well as factors that influence those who are 'STEM ready' at the point of making choices within tertiary education. These factors are often similar, such as lack of confidence among females (particularly with regard to maths ability) and lack of 'female friendliness' of educational environments even within upper secondary education (see Table 1). The common stereotyping of male and female abilities as well as the stereotyping of particular fields of study seem to have a lot to do with this.

The policy responses to these issues need to vary according to the educational system in place. For example, in Denmark, curriculum reform in upper secondary education has been shown to make a difference (Joensen and Nielsen, 2016). In Greece, it has been shown that improving the quality of teachers would remove grading along the lines of gender stereotype (Lavy and Megalokonomou, 2019). Some policy ideas could be tested without making any major changes to curriculum or personnel. These include providing students with more information on their own performance relative to a broader student cohort (Delaney and Devereux, 2019b) and perhaps experimenting with teaching high-ability students maths and science within gender-specific groupings (which would be possible within educational systems such as that in the UK). There is a huge range of initiatives actually implemented to encourage females into STEM fields but very often these are not evaluated in a scientific way. In a recent UK Skills Commission overview about women in engineering, one of the

[19] The percentage of female computer science graduates increased from under 10 per cent to 40 per cent at Harvey Mudd and Carnegie Mellon; and from 15 per cent to 30 per cent at the University of Washington).

recommendations was to set up a body to provide clear oversight of 'women in engineering initiatives' which would disseminate findings and help practitioners to understand the evidence base. Perhaps such an initiative is needed with regard to 'women in STEM' more broadly and across more countries.

The barriers that prevent more women from considering tertiary education in maths-intensive science fields often have common origins. As least some of the solutions seem to be broadly applicable. The need to have more female role models in such fields is one such solution that stands out in this review.

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Figure 1: Tertiary education: gender divide

2016. Eurostat figures for OECD countries (ISCED levels 5 to 8)

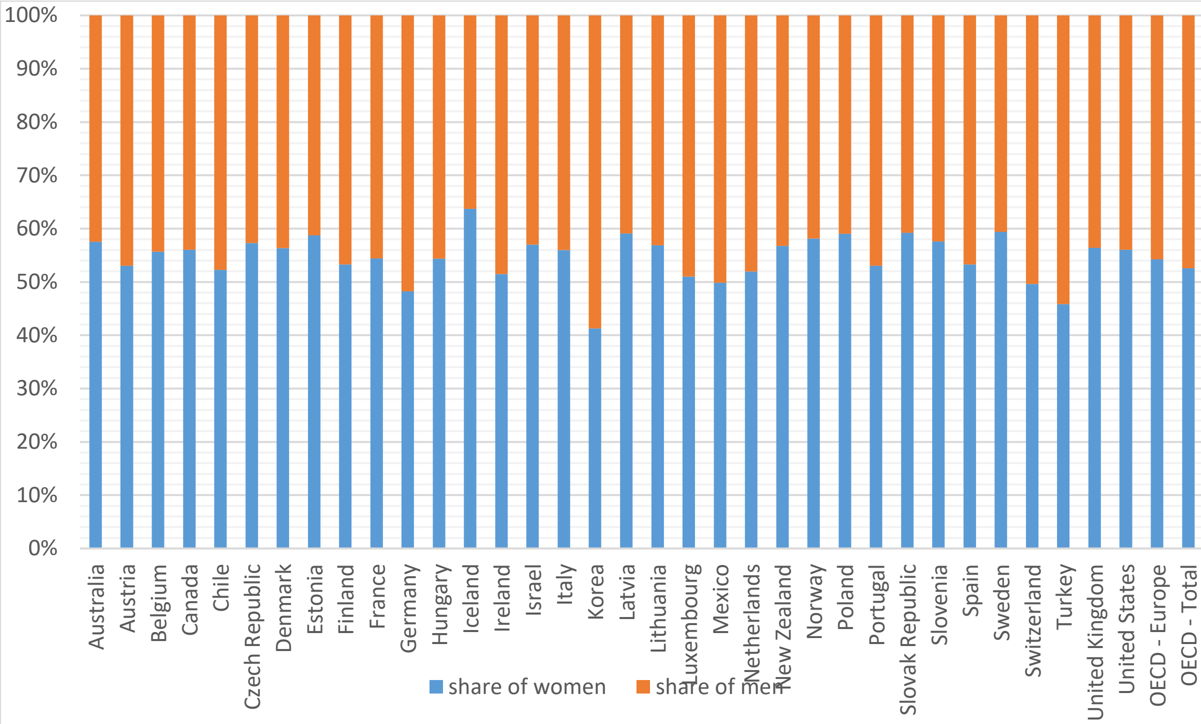
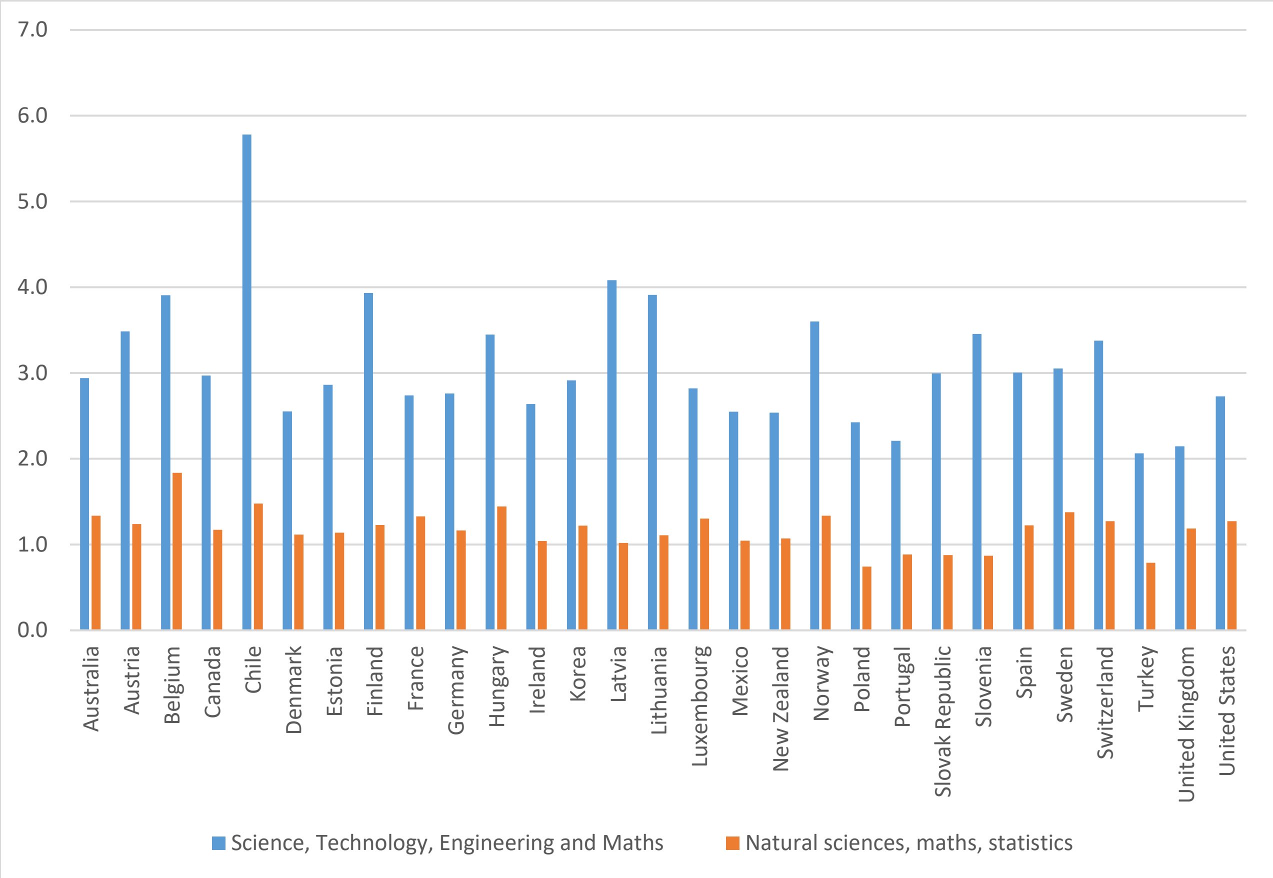


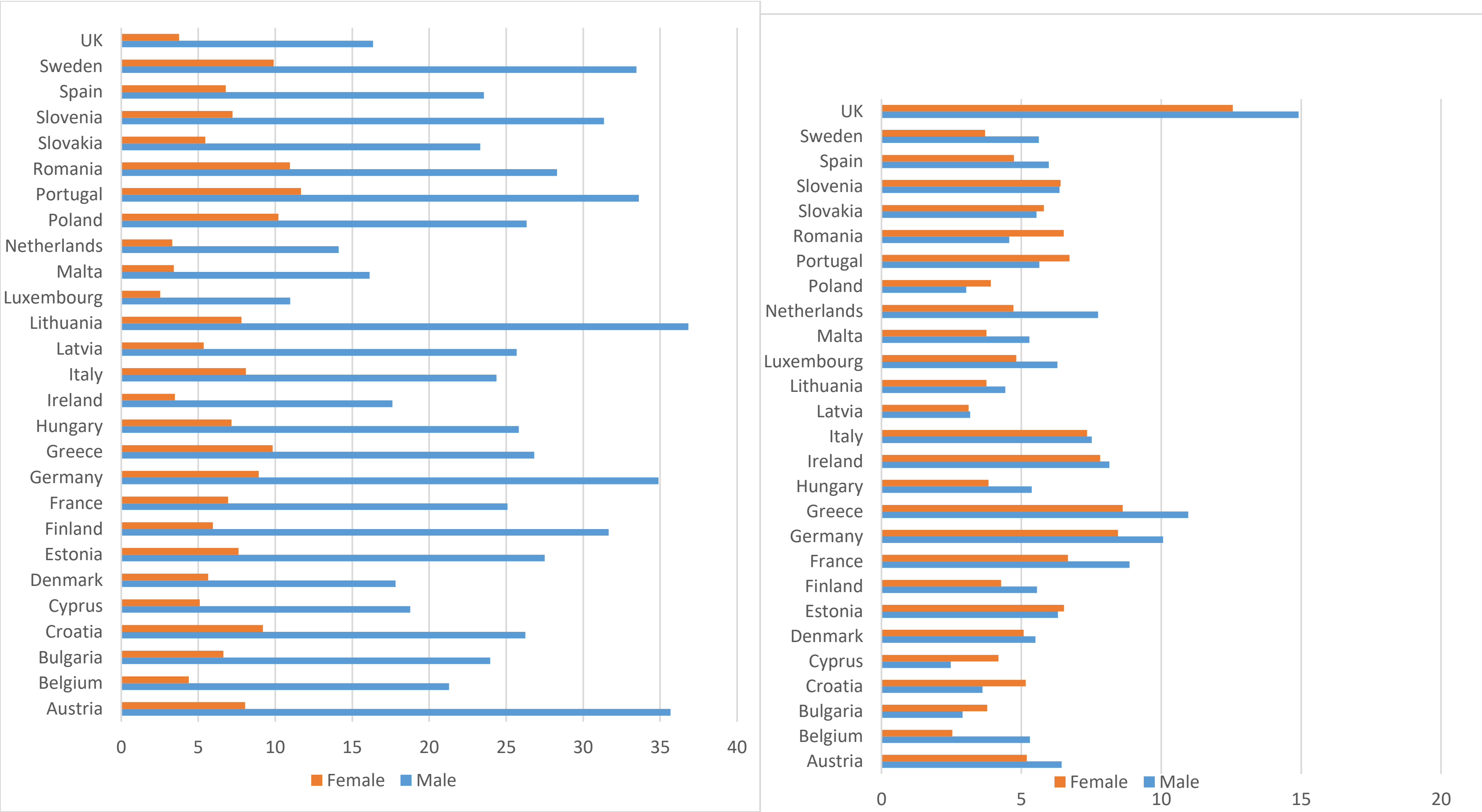
Figure 2: Share of tertiary graduates: Ratio of men to women in different fields of study
2016. Eurostat figures for OECD countries. Tertiary education = ISCED levels 5-8.



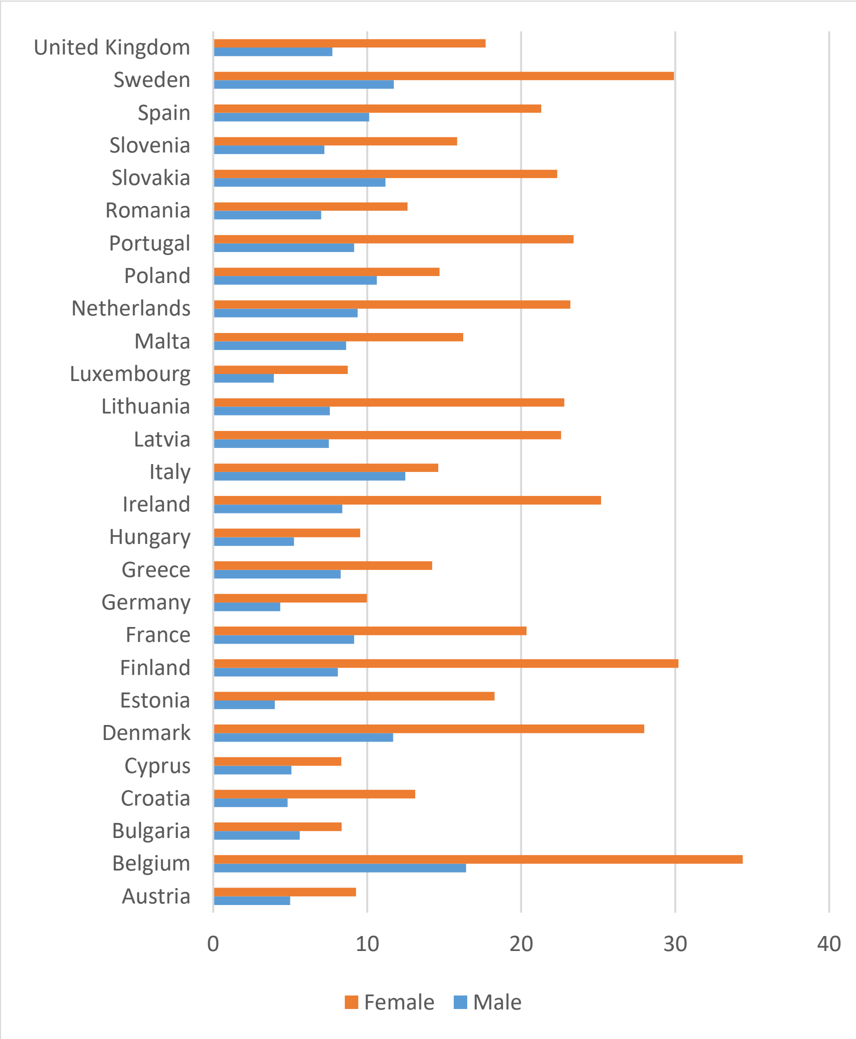
Note: Both these categories of subject areas would typically be included within a broadly defined definition of STEM.

Figure 3: Male (female) graduates by field as a percentage of male (female) graduates with tertiary education
Source: Unesco data, 2017. https://apiportal.uis.unesco.org/

A) Engineering, manufacturing, construction **B) Natural science, maths, statistics**



C) Health and welfare



D) Information and communication technologies

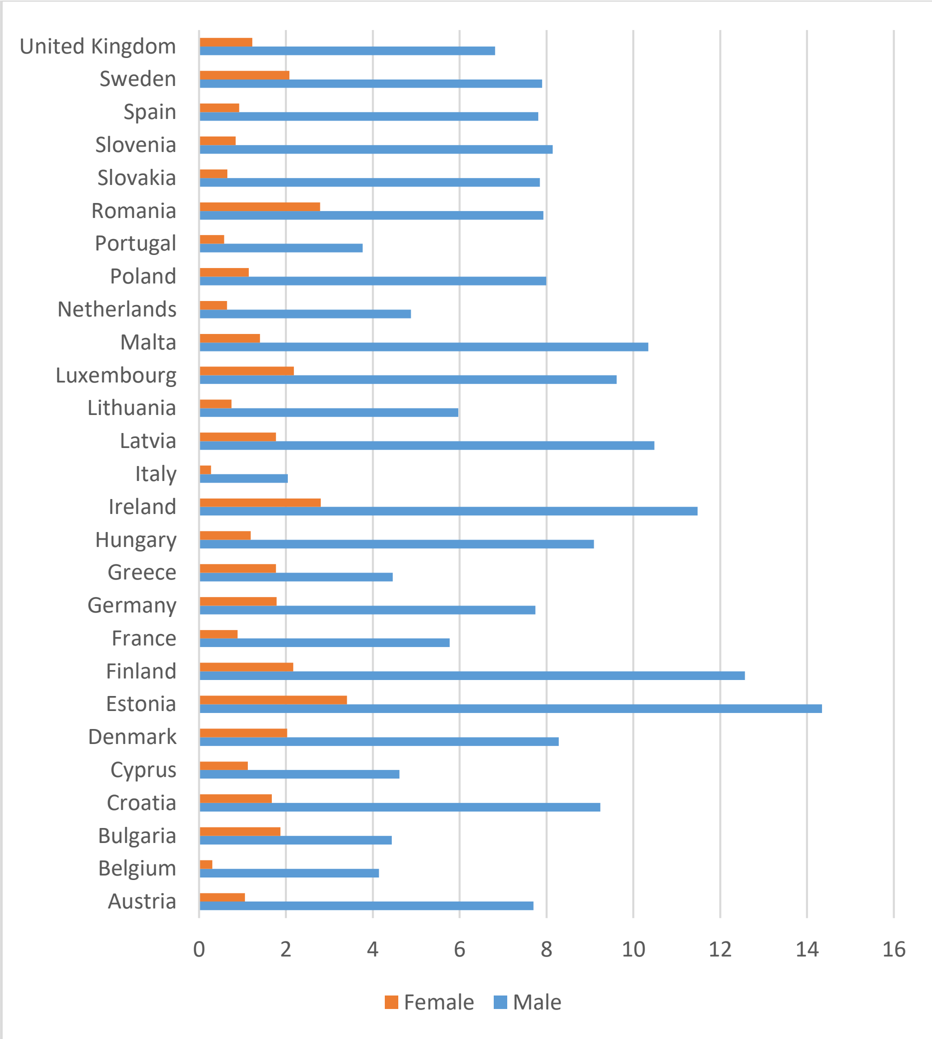


Figure 4: Difference in PISA scores (within country) between boys and girls
OECD figures. 2018.

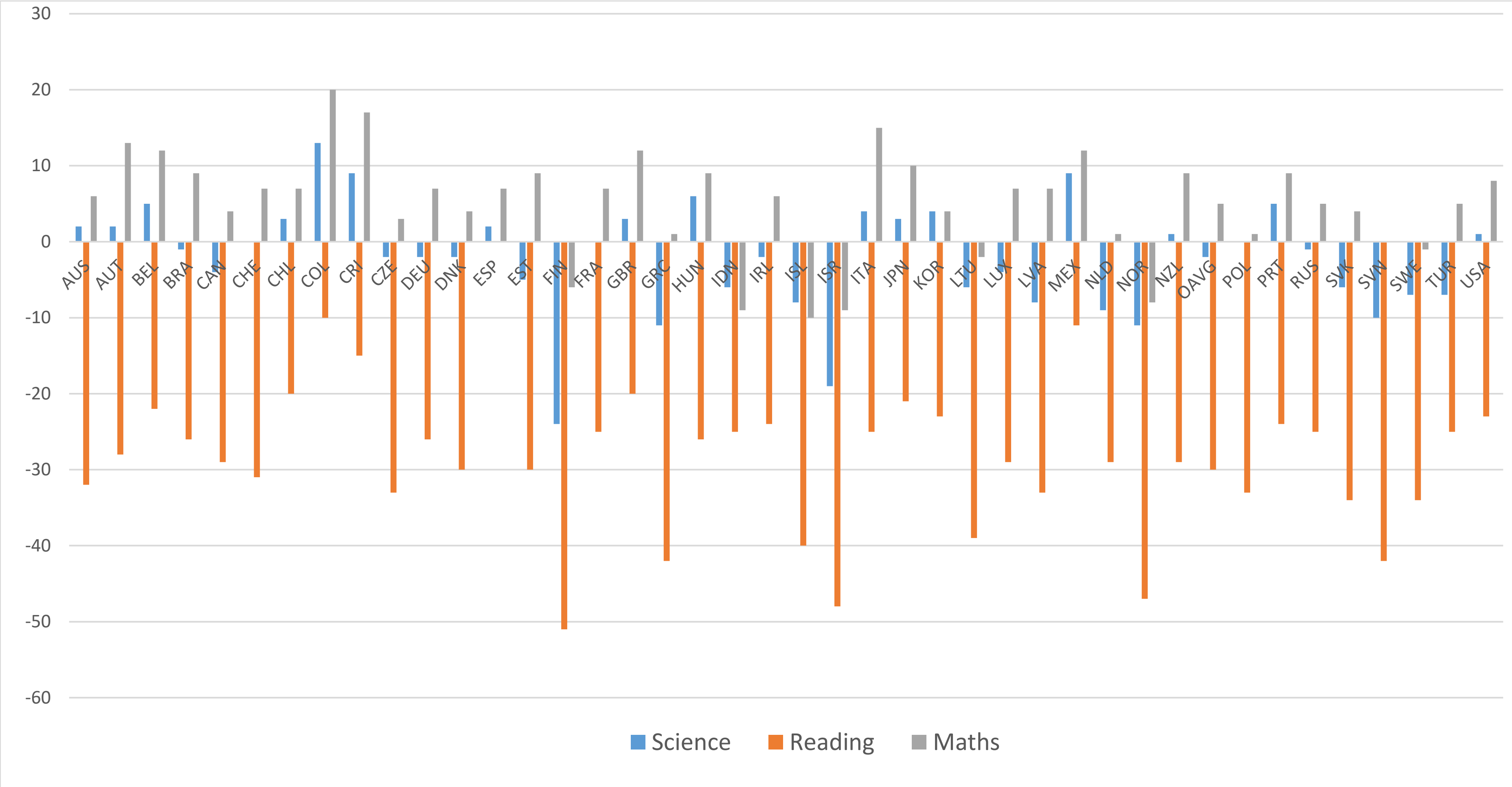


Table 1: Summary of selected papers referred to in Sections 5-7

Personal attributes: confidence, self-efficacy and/or attitude to competitiveness (lower among females)	
Behaviour of females relative to males	**Setting/context**
Less likely to enter competitive arena	Laboratory experiment (Gneezy et al. , 2003; Niederle and Vesterlund, 2007).
Less likely to perform well in high-level maths test	Laboratory experiment (Niederle and Vesterlund, 2007).
Less likely to choose STEM track in upper secondary education	Buser et al. (2014): competitiveness is negatively related to choosing more prestigious tracks in the Netherlands. Laudaud et al. (2018): admission to selective high schools in France decreases probability that girls choose science.
Less likely to choose STEM in tertiary education	Shi (2018). Engineering in North Carolina. Murphy and Weinhardt (2018). College choices in US.
Switch out of STEM major once in university	Astorne-Figari and Speer (2018, 2019) and Brainard and Carlin (1998) for US.
Preferences/expectations	
Female preference for work that is altruistic and people-orientated v male preference for thing-orientated work	Review by Cheryan et al. (2017). They note that the more women endorse goals to help and work with people, the lower their interest in computer science, engineering, maths and the physical sciences.
Female preferences for enjoying work and non-pecuniary aspects	Zafar (2013): subjective expectations of students in North Carolina.
Wage expectations	Oskominu and Pfeifer (2018) for Germany. Wage expectations relevant for men and women for college degrees but do not explain gender gap.
Educational context	
Higher proportion of female peers in school year	Mounganie and Wang (2019): a larger share of high-performing girls in first year of high school in China increases probability of STEM track in subsequent year. Interpret as role model/affirmation effect. Brenoe and Zolitz (2019): similar study for Denmark but find opposite result except for girls with a STEM-educated mother (mitigates negative effect).
Single-sex schools	Delaney and Devereux (2019b): Ireland. STEM gender gap in tertiary education is smaller among those who attended single-sex schools. Park et al. (2018): Seoul. Girls' schools make no difference to STEM choice in tertiary education. Boys' schools increase probability of STEM choices.

Higher proportion of female peers in tertiary education	Review by Cheryan et al. (2017): Negative stereotypes about women's ability appear to be more problematic in computer science, engineering and physics than in biology, chemistry and maths. Bostwick and Weinberg (2018): more females reduce probability of dropping out of first year PhD programme in the US.
Gender of professor/advisor/teacher	Carrell et al. (2010): US Air Force Academy. Powerful effect on female performance in maths and science, course-taking and STEM graduation. Canaan and Mouganie (2019). Four-year private college, US. Female science advisor narrows gender gap in STEM enrolment and graduation. Bottia et al. (2015): composition of high school faculty in North Carolina. Powerful effect on female probability of graduating with a STEM degree Gong et al. (2018). China. Female teacher improves girls' academic performance and better motivates girls to study maths