Mathematics and Science Inequalities in the United Kingdom:

When Elitism, Sexism and Culture Collide.

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Abstract

An examination of gender, social class and ethnicity performance and participation patterns in different UK countries shows that inequities occur in relation to gender, class and ethnicity but that the patterns of inequity look quite different in the three domains. Achievement is equal for different genders but many more males take mathematics forward to advanced levels; social class differences persist in both achievement and participation, and ethnicity shows a varied pattern with some groups performing and participating at particularly high levels and some particularly low. This paper identifies some critical issues that we face in making mathematics and science equitable and begins to analyse some of the barriers that stand in the way of students who are female, and from some ethnic and social groups.

Introduction.

Mathematics and science are both subject areas in which considerable inequities prevail, both in terms of achievement and participation. An examination of UK performance and participation patterns in mathematics and science, by gender, social class, and ethnicity, reveals that inequities occur for all of these groups, but that the patterns of inequity look quite different for the three groups. This paper will review patterns of performance and participation by gender, ethnicity and social class in mathematics and science using the most current forms of data available. Whilst it is helpful to survey and present inequitable patterns for these three different groups, it is not possible to explore all of the reasons for the different inequalities in the same paper. In the second part of the paper we offer starting places for analyses of the causes of inequality but hope that more detailed and comprehensive analyses may be prompted by the overview provided here.

Gutierrez (2002) offers a definition of equity as: 'erasure of the ability to predict students' mathematics achievement and participation based solely on characteristics such as race, class, ethnicity, sex, beliefs and creeds, and proficiency in the dominant language' (2002, p9). This definition is helpful for whilst some would argue that students are treated equally in mathematics and science classrooms in the UK, it is unfortunately true that achievement and participation are far too predictable when characteristics such as gender, social class and ethnicity are known. The provision of equitable opportunities for students from different groups to achieve and go forward in mathematics and science has been identified as critical for the future of our society (Boaler, 2009; Smith, 2004), as well as the students concerned. Indeed mathematics has been defined by some as the new "civil right" that students need in order to function well in society (Moses, 2001). But a review of the data that exists for science and mathematics reveals that significant barriers stand in the way of students who are female, and from some ethnic and social groups, that are important to recognize and understand. This paper offers such an opportunity.

Part 1. Examining Patterns of Performance and Participation

High Achievement but Low Participation – Do Barriers Still Impede The Progress of Girls and Women?

Gender inequities in mathematics and the sciences have a long history in the UK, and until 1997 girls routinely achieved less than boys in scientific subjects at GCSE level (Burton, 1986, 1990, 1995; Boaler, 1997, 2002a; DfES, 2007). These differences prompted considerable attention from researchers and practitioners and it is partly due to their work in combating gender inequities that achievement at GCSE is now equal. In England, Wales and Northern Ireland girls and boys achieve at the same or similar levels in mathematics and science GCSE. However it should be noted that mathematics and science are the only subjects in which girls have not pulled far ahead of boys. Furthermore, the results for 2009 show that, for the first time since 1997, boys slightly outperformed girls in mathematics, a shift which is widely agreed to be due to the removal of coursework from the assessment process (Harrison, 2009; Curtis, 2009). Table 1 shows performance patterns at GCSE for mathematics, the different sciences and for English language, with the latter showing significantly lower levels of achievement for boys, relative to girls.

Table 1. Achievement of A*-C Grades in GCSE by Gender, in England, Wales & Northern Ireland.

	2009 GCSE Attainment of A*-C Grades by Gender								
	England			Wales			Northern Ireland		
	Female (%)	Male (%)	n	Female (%)	Male (%)	n	Female (%)	Male (%)	n
Mathematics	57.0	57.6	689666	53.2	54.7	38322	59.0	61.3	26750
Science (New Specification)	61.4	59.2	459099	59.5	59.4	28842	49.8	49.8	5564
Science Double Award	n/a	n/a		n/a	n/a	n/a	87.9	85.7	15188
Science Single Award	n/a	n/a		n/a	n/a	n/a	69.6	67.3	3954
Physics	93.1	93.2	84197	92.5	93.4	4121	93.1	90.3	2861
Chemistry	94.3	93.7	85114	92.6	92.2	4178	91.6	93.7	2954
Biology	90.9	92.8	92399	92.2	92.8	4356	90.2	90.8	4150
English	69.2	56.2	638899	68.4	52.4	37561	73.5	62.5	24646

Source: Joint Council for Qualifications (JCQ)_2009_National Provisional GCSE (Full Course) Results.

The equal achievement of girls and boys in the mathematical sciences, which was achieved in the last decade and has continued with some consistency, is extremely positive, particularly given the widespread public perception, fuelled by media reports, that males achieve at higher levels in mathematics and science (Boaler, 2002a; Cohen, 1999). But the equal achievement of girls and boys at GCSE hides some important inequities in the opportunities that are provided to students, and these become apparent when considering students' participation at A-level and in the Scottish Highers, shown in table 2.

Table 2. Advanced level Participation in Mathematics, Physics, Chemistry and Biology in the UK, 2009.

	A-Level Participation									Higher Participation		
	England			Wales			Northern Ireland			Scotland		
	Female (%	Male (%)	n	Female (%	Male (%)	n	Female (%	Male (%)	n	Female (%	Male (%)	n
Mathematics	40.4	59.6	66552	41.3	58.7	3165	43.9	56.1	2758	48.3	51.7	10140
Physics	22.1	77.9	26610	19.5	80.5	1474	28.1	71.9	1352	28.4	71.6	6445
Chemistry	48.3	51.7	38465	46.1	53.9	2188	53.4	46.6	1838	49.8	50.2	4812
Biology	57.2	42.8	49526	56.4	43.6	2641	60.7	39.3	3318	64.4	35.6	3237
Total Population	53.8	46.2	777170	55.2	44.8	384333	55.9	44.1	31374	55.6	44.4	

Source: Joint Council for Qualifications (JCQ) National Provisional GCE A Level Results – 2009
http://www.jcq.org.uk/attachments/published/984/JCQ-A-Level.pdf

Also SQA 2009 Pre Appeals National Qualification Result Males and Females
http://www.sqa.org.uk/sqa/36315.html

Table 2 reveals a number of interesting patterns, one being the low participation of young women in all of the UK countries, in mathematics and physics, with chemistry offering more equal participation, and biology greater participation from young women. The low participation of young women occurs even though there are slightly higher numbers of females than males in the UK population as a whole (Office for National Statistics, 2001). The second interesting result concerns the differences between the different countries in gender participation patterns. In mathematics, in England and Wales, for example, only 40% and 41% respectively of advanced level students were female in 2009, compared to 44% and 48% of students in Northern Ireland and Scotland respectively. These different patterns with Northern Ireland and Scotland appearing to offer more equal opportunities are repeated in relation to physics, the subject with the most serious inequities in participation (Murphy & Whitlegg, 2006). In England and Wales 22% and 20% of advanced level physics students were female respectively, compared to 28% in both Northern Ireland and Scotland. The distribution of chemistry participants is more balanced, with the proportion of female participants ranging from 48% in England to 53% in Northern Ireland. Biology is the subject that shows a different pattern with relatively low proportions of male participants, ranging from 36% in Scotland to 44% in Wales. These gender patterns, particularly showing the low participation of girls in mathematics and physics, in all of the UK countries, are persistent and serious, and although boys' participation in biology is relatively low, the numbers studying biology are much closer to societal needs than those taking physics and mathematics. The numbers taking physics are particularly low and although the numbers taking mathematics are more healthy, the need for students who are qualified in mathematics is at a record high (Boaler, 2009), and mathematics is fundamental to many other areas of study and work (Smith, 2004; Glenn, 2002; Hoyles et al, 2002). Looking across the UK we see that approximately 83,000 students take mathematics, 36,000 take physics, 47,000 take chemistry and 59,000 take biology. Serious gender inequities in advanced level participation in mathematics and physics continue as students progress through school and university – usually becoming more severe in the university and employment years. In 2008 women made up 39% of those taking mathematics degrees and 20% of those taking physics degrees. In the same year only 19% of people employed in science, engineering and technology occupations were women (UK Resource Centre for Women, 2009).

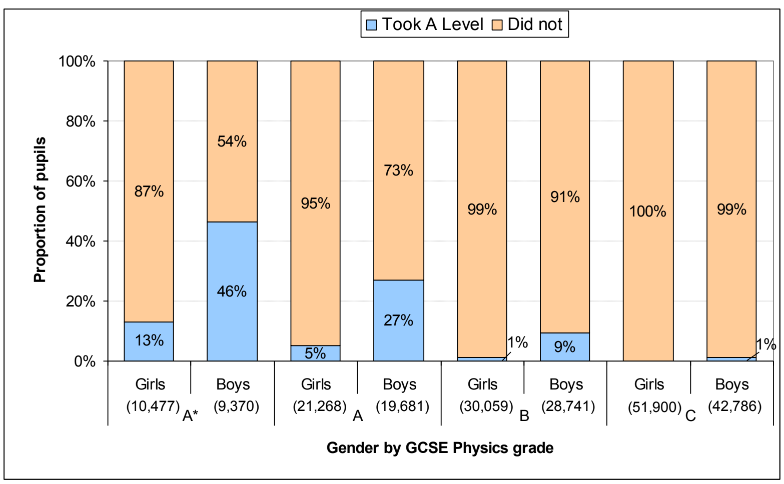
Tables 3, 4, and 5 were produced by the Department for Education and Skills (DFES)[1] because of government concern regarding inequities in the participation of girls in mathematics and physics. The tables show the proportion of students who choose these A-level subjects by prior achievement. The data for chemistry participation are also given, as a contrast case. The results shown in these tables are made more interesting by the fact that prior achievement is the single most important factor in subject choice (The Royal Society, 2008).

[1] The DFES is now the Department for Children, Schools and Families, or DCSF.

Table 3. The proportion of pupils who take A-Level mathematics by gender and GCSE grade, in England.

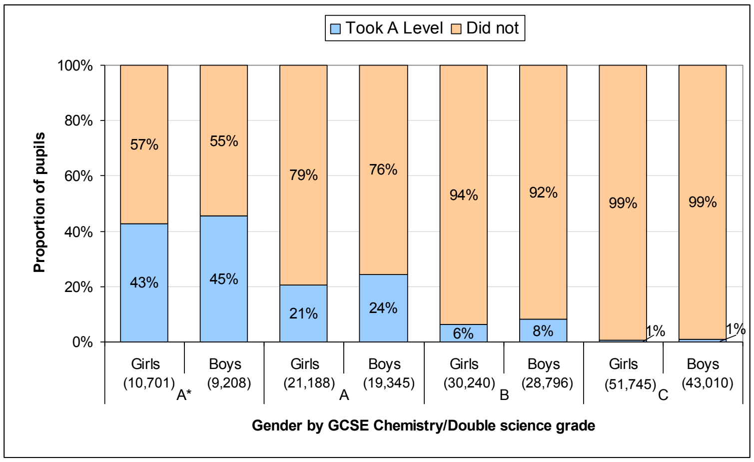
Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

Table 4: The proportion of pupils who take A-Level physics by gender and GCSE physics/double science grade, England.



Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

Table 5: The proportion of pupils who take A-Level chemistry by gender and GCSE chemistry/double science grade, England.



Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

Tables 3-5 show a number of interesting results. First, they show a large disparity in the numbers of high achieving females and males who choose to go forward with mathematics and physics. In mathematics 80% of males with an A* grade at GCSE choose to take A-level mathematics, compared to only 64% of girls with an A* grade. In physics the disparities are more extreme, with 64% of boys with an A* choosing to go forward with physics, compared to only 13% of girls with an A*[2]. Such differences do not exist in the domain of chemistry where 43% and 45% of females and males respectively, who gain an A* at GCSE, continue with the subject at A-level.

The other interesting finding that is revealed by Tables 3-5 concerns the extremely low numbers of students, female and male, who continue with A-level mathematics, physics or chemistry, after gaining a B grade at GCSE. This is an issue that relates to the sciences in particular (The Royal Society, 2008), and will be addressed in the final section of this paper.

[2] These figures show an aggregation of students taking discreet science subjects at GCSE and Double Science. In 2007 16.5% of GCSE students took Double Science, while Chemistry, Physics, and Biology received 1.2% of students each. In Physics, the attainment of girls and boys was skewed slightly towards boys, with 48.5% of boys and 45.8% of girls earning A*/A. Double science, which represents a far larger population of students, skews towards girls with 15.8 % of girls and 13.5% of boys earning A*/A. The population of table 4 (in the noteworthy A*/A columns) is made up of approximately 140,500 students who took Double Science and 27,700 students who took Physics GCSE.

Table 6 shows the proportions of students achieving A-C grades in the different A-level subjects in England, Wales and Northern Ireland and the Highers in Scotland. This shows the strong performance of females, who achieve a slightly higher proportion of the A-C grades in almost all cases. Thus the girls who take mathematics and science at advanced levels continue the capable performance demonstrated at GCSE level.

Table 6 'Good' (A-C) performance at A-level / Highers.

2008 A-Level Attainment A-C.							2008 Highers, A-C	
	England		Wales		Northern Ireland		Scotland	
Mathematics	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
A-C Grade (proportion of all A-C grades,%)	40.6	59.4	42.0	58.0	47.8	52.2	48.3	51.7
A-C Grade (proportion of all girls / boys taking the subject, %)	82.9	79.5	83.5	79.8	78.1	77.3	72.1	72.2
Physics	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
A-C Grade (proportion of all A-C grades, %)	23.1	76.9	25.5	74.5	33.6	66.4	28.4	71.6
A-C Grade (proportion of all girls / boys taking the subject, %)	75.9	69.1	76.5	65.8	82.4	72.5	77.8	73.1
Chemistry	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
A-C Grade (proportion of all A-C grades, %)	49.6	50.4	51.5	48.5	57.0	43.0	48.6	51.4
A-C Grade (proportion of all girls / boys taking A-level, %)	77.7	74.5	74.5	71.6	85.4	78.3	77.9	78.8
Biology	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**
A-C Grade (proportion of all A-C grades, %)	59.2	40.8	38.7	61.3	62.0	38.0	65.7	34.3
A-C Grade (proportion of all girls boys taking the subject, %)	69.8	66.6	65.2	61.5	78.1	77.3	70.6	71.4

Source: Joint Council for Qualifications (JCQ)_2008_National Provisional A Level (Curriculum 2000) GCE Results, http://www.jcq.org.uk/attachments/published/984/JCQ%20A-Level%20Results%202008.pdf

SQA 2008 Annual report Tables NH5a, b, http://www.sqa.org.uk/sqa/33682.html

When considering the issue of gender equality in relation to mathematics and science a very clear picture emerges showing the strong performance of young women, with low levels of participation at advanced levels. The equal performance of girls and boys in mathematics and science has prompted some complacency around the issue of gender in recent years with some people believing that low participation rates merely reflect the 'natural' inclinations of the different sexes. Such a position becomes increasingly untenable when considering the participation of young women in different countries. In the United States for example, women have participated in mathematics undergraduate degrees in equal proportions for some years; in 2008, for example, 48% of mathematics majors were women (Science Daily, 2008). Indeed the participation rates of females and males at advanced levels in Scotland and Northern Ireland are also more positive than those in England and Wales. Such data throw into sharper perspective the low participation rates of young women in mathematics and science in England and Wales. Such inequities have serious consequences – for women, as they are denied access to scientific and technological careers from which they may benefit in many ways, for the disciplines of mathematics and science which are not being advanced by women's perspectives (Burton, 1995, 1999), and for society which is in need of many more people qualified in mathematics and science. The important question raised by the data is why girls, whose achievement is so strong in mathematics and physics at GCSE, do not choose to continue with these subjects post-16 in equal numbers. This question will be considered in the final part of this paper.

Low Achievement Leading to Low Participation – The Endurance of Social Class Inequalities.

Inequalities relating to social class, in particular the low performance of students from homes with few financial resources, remain a challenging and pervasive problem for the UK (Noyes, 2009; DfES, 2007; Gillborn & Mirza, 2000). The categorization of 'social class' is complex and cannot be reduced to levels of income alone. Bourdieu (1982, 1986) and others (Noyes, 2003; Ball et al, 1996) have demonstrated the importance of different forms of capital, in particular cultural capital, that are valued within the education system. However, any review of examination data, at this point in time, necessarily equates social class with income. We are further restricted by the fact that the data is only provided for schools in England.

Despite these limitations, considerations of income in the analysis of children's achievements and participation continue to be important.

Social class is much more difficult to measure than gender and some of the variables used to measure social class have prompted controversy. In this paper we will use two measures – eligibility for free school meals (FSM) and the Income Deprivation Affecting Children Index (IDACI), both of which have advantages and disadvantages, as set out in Gorard, See, & Smith, (2008). To summarize these, FSM is an indicator of a student living in a family with an income that is below the poverty line, which applies to between 12 and 20% of students in England (Gorard, See, & Smith, 2008). FSM has the advantage of being a legal definition that is not open to interpretation, but it has the disadvantage of only dividing students into two groups – receiving or not receiving free school meals and so only measures the extremes of poverty. The IDACI variable is based upon several factors including household income and postal address. It places all students on a scale and so is more comprehensive, although it has been criticized for compounding measurement difficulties, and for basing judgments on characteristics such as postal address, which can be misleading (Gorard, See, & Smith, 2008). Both measures do however reveal the same consistent pattern of the lower performance of students from more challenging home circumstances, (Noyes, 2009).

Table 7 illustrates the phenomenon, which begins early in school, showing the relationship between the IDACI variable and achievement at age 11, the end of Key Stage 2. This shows a clear inverse relationship between achievement and 'income deprivation' with higher levels of deprivation showing lower levels of achievement.

Table 7. Key Stage 2 results 2007, percentage reaching level 4 or above, England, by IDACI (Gorard, See, & Smith, 2008)

IDACI decile	Eligible pupils	English	Mathematics	Science
0 - 10 % most deprived	71,895	68	66	79
10 - 20 %	64,390	71	68	81
20 - 30 %	59,211	74	71	83
30 - 40 %	56,084	77	73	86
40 - 50 %	53,676	80	77	88
50 - 60 %	52,506	83	79	90
60 - 70 %	52,587	85	81	91
70 - 80 %	52,514	87	83	92
80 - 90 %	51,926	89	85	94
90 - 100 % least deprived	52,312	91	88	95

Table 8 shows a similar pattern, this time using the FSM variable, with GCSE achievement in science and in all subjects, and the percentage of A* grades in science subjects, all showing significant differences between FSM and non-FSM students.

Table 8 GCSE Achievement, England, 2005/6 (Gorard, See, & Smith, 2008).

	Students eligible for FSM	Students not eligible for FSM
Mean capped points score all subjects.	266	373
Mean capped points score science subjects.	25	35
A* grade science double award.	0.6	3.5
A* grade physics	0.1	1.1
A* grade chemistry	0.1	1.0
A* grade biology	0.1	1.0
A* grade mathematics	0.6	3.9

When considering social class it is clear from all measures that there is a strong and worrying relationship between social class and achievement in the UK, which has not diminished over time. The UK has one of the highest associations of social class with educational performance in the OECD countries (OECD, 2002). It is important to note however, that social class underachievement is not limited to mathematics and science and the phenomenon that is shown by the data in this paper extends across the curriculum.

The underachievement of students from lower social class groups also significantly influences their participation in mathematics and science as prior achievement is the biggest factor in determining whether a student moves forward post-16 (Royal Society, 2008). But it is unclear whether social class impacts participation other than through prior achievement. Some analyses have shown that when prior achievement and gender are taken into account, social class has very little impact on subject choice (Gorard, See, & Smith, 2008). When participation is analysed by FSM and grade, for example, there are virtually no differences in participation among the high achievers, as table 9, showing mathematics participation, illustrates. The students eligible for FSM are choosing mathematics in slightly higher proportions, although it is noticeable that the FSM dataset of students with A*-C GCSE grades is very small.

Table 9: The proportion of pupils who go onto take A Level mathematics by FSM eligibility and GCSE mathematics grade, England.

Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

The reasons that students from less wealthy backgrounds achieve at lower levels pre and post 16 – and in science and non science subjects (Gorard, See & Smith, 2008) – are complex and have been the subject of many analyses. In the final section literature will be reviewed that give some indications of the reasons for the prevailing links between wealth and achievement.

Uneven Achievement and Participation - The Highs and Lows of Ethnicity Data.

Whereas analyses of gender inequities show unequal participation rates and analyses of social class show underachievement at all levels, the picture changes again when considering ethnicity. Data on the performance and participation of different ethnic groups show significant differences between them. Table 12, for example, shows the achievement of A*-C grades at GCSE for mathematics and English, by the largest ethnic groups in England. This shows that Chinese and Indian students achieve at higher levels in English and in mathematics, with the achievement of Chinese students in mathematics being particularly strong (Archer & Francis, 2007). The data also show that the lowest achieving groups, for both subjects, are the Caribbean and Pakistani students. The achievement of Caribbean students in mathematics is particularly low, an issue to which we will return in the next section of the paper.

Table 12 Achievement by ethnicity: Good (A*-C) Performance in Mathematics and English GCSE.

	English A*-C (%)	n	Mathematics A*-C (%)	n
African	49.7	10873	45.9	10873
Bangladeshi	51.5	5871	47.8	5871
Caribbean	47.5	8647	36.2	8647
Chinese	66.5	2332	80.5	2332
Indian	68.8	13652	68.0	13652
Pakistani	46.4	14024	43.5	14024
White British	57.1	486470	51.6	486470

Source: National pupil database, DCSF & Gorard & See, 2008.

Achievement differences occur between different ethnic groups in subjects that are very different, such as mathematics and English, but there are also some issues that relate particularly to mathematics and science. These issues are highlighted in Tables 13, 14 and 15 which show the proportion of students who have gained an A or A* at GCSE and go forward to A-level mathematics, physics, and chemistry from each ethnic group.

Table 13: The proportion of pupils with grade A*/A at GCSE mathematics who go on to take A Level mathematics by ethnicity, England.

Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

Table 14: The proportion of pupils with grade A*/A at GCSE physics/double science who go on to take A Level physics by ethnicity, England.

Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

Table 15: The proportion of pupils with grade A*/A at GCSE chemistry/double science who go on to take A-Level chemistry by ethnicity, England.

Source: DFES, 2007. Participation in Science and Mathematics. Unpublished Report.

In mathematics the highest participating group was the Chinese students, with 78% of those with an A or A* grade choosing A-Level mathematics; other high groups include Indian, Pakistani and African students whereas the lowest participating group, proportionally is white British students (45%). In physics the proportions of students going forward were much smaller but the students who went on at the highest rate were the Chinese students, with white British students choosing physics at the relatively high rate of 20%. Caribbean and Pakistani pupils with the same GCSE grades had the lowest uptakes (11% and 14% respectively). In A-level chemistry it is the Pakistani students who were most well represented (61%) with Indian (56%), African (51%), Bangladeshi (48%), and Chinese (47%) students all choosing chemistry in high numbers, compared with only 26% of White British students, and 21% of Caribbean students.

Tables 13-15 show some important differences in participation between different ethnic groups, even when achievement is held constant, with the most prominent trend being the low participation of Caribbean students who consistently rank low in all subject areas. Other interesting patterns include the strong participation of Chinese students in all subjects, particularly mathematics and physics, the high rate of participation of Pakistani students in Chemistry, and the fact that fewer white British students pursue mathematics A-levels than any other ethnic group. These trends will be considered in the next section of this paper.

Table 16 shows that A-level achievement differences compound the inequitable patterns in participation.

Table 16: A-level Performance by Ethnicity, England, 2006.

	Mathematics		Physics		Chemistry		Biology	
	% Took	% A-C Grades	% Took	% A-C Grades	% Took	% A-C Grades	% Took	% A-C Grades
Any Other Asian Background	19.7	82.9	7.1	60.5	17.4	79.2	17	72.3
Bangladeshi	8.9	81.0	3.1	62.6	9.1	65.5	9.50	60.8
Caribbean	5.0	67.0	1.6	64.4	3.7	55.7	5.5	44.5
Chinese	28.7	85.4	11.1	76.8	15.6	82.6	13.8	76.8
Indian	16.6	81.1	5.0	68.0	14.1	77.2	15.0	68.9
Pakistani	8.4	76.4	2.7	65.8	11.9	68.0	13.0	62.0
White British	8.6	76.4	4.8	64.6	5.7	70.2	8.6	62.7
All Students	8.5	79.8	4.1	69.3	6%	74.3	7.6	67.6

Source: The National Pupil Database, 2007.

The Caribbean students were the lowest performing group in mathematics, chemistry and, in particular biology, where their grades were 23% below the average for all students. In physics, Bangladeshi students were the lowest performing group at 7% below the average. Pakistani students were also low performing in physics at 3.5% below the mean and Caribbean students were 5% below the average. The highest performing ethnic groups include Chinese, and ‘other Asian’ students. Chinese students consistently scored the highest overall with the proportion of A-C grades between 5.6% and 9.2% above the average. Indian students achieved just above the average in all subjects except Physics, where they dipped just below the mean rate of achievement. White British students consistently performed just below the average. Table 16 also highlights the issue raised by the data in tables 12-15, of unequal participation at advanced levels. In mathematics, for example, 28.7% of Chinese students take A-level compared with only 8.6% of White British students and 5% of Caribbean students. These differences reveal some very serious inequities in participation, in addition to performance (see also Archer & Francis, 2007; Gilbourn & Youdell, 2000).

Part 2: Exploring the Reasons for Inequities in Participation and Achievement.

When considering the underachievement and low participation of students from certain groups in mathematics and science, research has consistently found that some factors impede the progress of girls and students from lower SES groups as well as some ethnic groups. Some of these factors are considered below.

Gender.

Although some scholars have questioned whether gender is a high priority, given the large achievement differences that persist for students of different ethnicities and social classes (Archer & Francis, 2007), Noyes (2009) has demonstrated that, beyond prior attainment at GCSE, being female has a greater effect on the likelihood of a student participating in A-level mathematics than any other factor. Research on gender and mathematics and science highlights a number of reasons for the low participation of girls and women at advanced levels, with one of the leading barriers appearing to be the teaching approaches used in classrooms and the corresponding forms of participation offered to students, with which girls, in particular, choose not to identify (Boaler, 2002 a,b,c; Mendick, 2005; Solomon, 2007). Boaler (2002 a,b), for example, followed approximately 300 students through two schools in the UK, from when they were 13 to when they were 16. One of the schools used a traditional approach to the teaching of mathematics, whereby students watched teachers demonstrate methods and then practised them, whereas the other engaged students in a broader form of mathematics that centred upon problem solving, discussions and investigative work. The research compared the students' experiences, beliefs, understanding and GCSE achievement in the two approaches. One of the outcomes of the study was the low achievement of girls, relative to boys, in the traditional approach and the equal achievement of girls and boys in the problem solving approach. The low achievement of girls in the traditional approach was due, in part, to the procedural nature of their mathematics teaching and the lack of opportunities students received to explore mathematics in depth, to ask questions and to push for a deeper, more conceptual understanding. The boys also suffered from the lack of opportunities to develop conceptual understanding, but this did not concern them as much and they continued to follow the teacher's instructions in order to achieve results. The girls wanted more and their desire to question, probe and understand concepts was more intense and resulted in disaffection when opportunities for depth of understanding were not given. Boaler described the preferences that affected girls in both schools as a 'quest for understanding' (2002b, p139). Zohar and Sela (2003) took the notion of 'quest for understanding' and considered whether it was also prevalent among girls in physics classes. They found that it was. The researchers drew from a database of approximately 400 high schools in Israel that offered advanced placement physics classes. They sampled 50 students from the schools and interviewed 25 girls and 25 boys. They found that the girls in physics classes were exhibiting the same preferences that Boaler had found in mathematics classes, resisting the requirement to memorize without understanding, saying that "it drives you nuts", (Zohar and Sela, 2003, p261). The girls talked about wanting to know why methods worked and how they were linked. The authors concluded that 'although both girls and boys in the advanced placement physics classes share a quest for understanding, girls strive for it much more urgently than boys, and seem to suffer academically more than boys do in a classroom culture that does not value it' (Zohar & Sela, 2003, p260). In both studies the girls did not want easier versions of physics or mathematics – the versions of mathematics and science they wanted required considerable depth of thought – but they wanted opportunities to inquire deeply, and they were averse to versions of the subjects that emphasized rote learning. This was true of boys and girls but when girls were denied access to a deep, connected understanding, they turned away from the subjects. In subsequent studies Boaler has shown that the identities offered to students in traditional mathematics classes, particularly ones in which students are required to passively watch a teacher demonstrate methods and reproduce them, turn both girls and boys away from mathematics, with girls being particularly negatively affected (Boaler, 2002c, 2009; Boaler & Greeno, 2000). Other work on gender, identity and mathematics, has shown that the participatory structures offered to girls in mathematics classes often lead them to perceive mathematics work as masculine. Mendick (2006) found that for young women, the decision to choose mathematics creates tensions, as identification with mathematics poses a challenge to their feminine identity.

The greater desire exhibited by girls to understand mathematics and science, in depth, may be due to a number of factors, ranging from differences in confidence – a finding that has consistently emerged from attitudinal research (Hart, 1989, Leder, 1982, Seegers, & Boekaerts, M, 1996) to the emerging research on brain differences (Boaler, 2009, Brizendine, 2007, Sax, 2004), but the reasons for such preferences are not as important as the fact that girls consistently show preferences for teaching approaches that are not generally offered in mathematics and science classrooms (Jacobs & Bleeker, 2004; Mendick, 2006; Solomon, 2007; Boaler, 2009). In many mathematics and science classrooms teachers have responded to the overly full National Curriculum and the need to prepare for standardised tests by denying students the opportunity to explore in depth, to ask probing questions and to conduct exploratory and practical work (OFSTED, 2008a; BBC News, 2010). In a recent study of schools that had been particularly successful at encouraging high numbers into mathematics and science A-levels (Boaler, Altendorff & Kent, *in preparation*), it was found that the successful departments used a more exploratory and active approach in mathematics and science than is typical, engaging students in regular discussions and in group work, allowing more time for depth of understanding. When such opportunities are given, girls and boys achieve at equal levels *and* pursue mathematics and science to higher levels. Examination statistics show us that girls can achieve at equal levels to boys, even when they experience mathematics environments where the focus is on the memorization of methods, rather than the discussion of ideas and the opportunity to develop conceptual and connected understandings (OFSTED, 2008a), but that such environments lead to low participation at advanced levels.

Another reason that has been given for girls not identifying with certain subjects concerns the images shown in books. The nineteen-eighties prompted widespread awareness of the gender bias that existed in mathematics and science textbooks with illustrations predominantly featuring men and boys and problems set in contexts perceived as male, such as sport and engineering (Spender, 1982, Kelly, 1987). A quarter of a century has passed since such observations were made and we should now be at a stage when all textbooks used in schools are sensitive to the issue of equity, with regards to ethnicity, social class and disability, as well as gender. But Kawabe (2007) recently applied the 'ABC of Gender Analysis: A Framework of Analysis for the Education Sector' to three science textbooks commonly used in English schools and found stark differences both in the number of portrayals of males and females in the textbooks (approximately 215 males to 126 females) and the roles they were enacting. As she reports, women and girls were 'cooking in kitchens, listening to a radio or drying their hair' and were depicted as a singer, gymnast, scuba diver and optician, whereas the men and boys were depicted as a policeman, scientist, doctor, astronaut and fire-fighter and they were shown using complex technology and experimenting in laboratories (2007, p26). Frost, Reiss and Frost (2005) report similar problems with the representation of culture and ethnicity – 'black scientists feature very little in UK textbooks or materials' (2005, p3). Inequitable portrayals of the work of women and men, as well as people from different ethnic groups, send powerful messages to young people about their role in science in society and should be a cause of much concern. It could be argued that these are not important, as they do not seem to affect ethnic participation, but when society continues to perpetuate the idea that maths and science is for men and boys, then we have a duty to pay attention to the extent to which that message is given, and reinforced in school textbooks.

Many researchers have noted the increased engagement of girls in curricula in which they can find connections between the presented materials and issues in their lives and in society more generally (Osborne & Collins, 2000, Krogh & Thomsen, 2005). It is particularly important that girls perceive science, including physics, as 'something that people do, influenced by historical, political, cultural and personal factors, not just a body of knowledge' (Murphy and Whitelegg, 2006, p iv). In addition there are areas of the physics curriculum and contexts through which concepts are illuminated that are more and less interesting to girls. Osborne and Collins (2000) found that girls were more interested in the areas of light and electricity, whereas boys were more interested in forces in relation to cars and flight. Both girls and boys were enthused by Space, the Earth and the solar system. A systematic review of the issues and contexts highlighted in the physics curriculum could serve as the basis for a re-organisation, with a greater use of issues and contexts that are appealing to girls and to both sexes, rather than mainly to boys. This would help tackle the widespread perception among girls that physics is not useful to their lives or their future role in society.

When the Institute of Physics conducted a review of research on ways to promote girls in physics in 2004, one of their concluding recommendations was that the QCA should consider the extent to which the National Curriculum portrays an accurate and contemporary picture of physics in the modern world. (2004, p vi). Feminist critics of science have long argued that a masculine discourse associated with an objectified version of science, rather than a science that considers social issues and concerns, leads to the under representation of women in science (see for example, Harding, 1991). Hughes (2004) studied the use of a curriculum which represented chemistry as an applied subject taught through social contexts and concluded that it would be 'tempting' to draw conclusions about female inclusivity, but her evidence of female engagement was not extensive enough to overcome concerns about essentialist thinking, which are important for any equity researchers when considering the suitability of different approaches for students. Fortunately, the research evidence on good teaching in both mathematics and science shows that approaches that are promising for the achievement, engagement and participation of girls, are also approaches that are better for boys. Teaching for equality, it seems, could be thought of more simply as good teaching for all. A new emphasis on 'How Science Works' has recently been introduced into the science curriculum; this encourages discussions of the nature of evidence and the ethical considerations arising from scientific work. Such an approach has the potential to increase gender equity and The Institute of Physics has urged QCA and OFSTED to monitor the impact on gender participation and achievement in the forthcoming years.

In mathematics there have recently been some parallel curriculum changes to encourage more problem solving and extended investigative work at Key Stage 3, as well as a proliferation of pathways and courses offered to 14-19 students and these, too, will require careful study of performance and achievement patterns. Indeed changes in curricula and in courses available, in mathematics and sciences, should be carefully monitored for any corresponding changes in participation or performance for students of different social groups, ethnic groups and genders. The fact that data from the first cohort of students for whom coursework was not available as a contribution to mathematics GCSE show that boys have gone ahead in mathematics, slightly, for the first time in twelve years, should be cause for concern, although the response from some media outlets seemed to be celebratory. The recent underachievement of girls at primary levels in mathematics, with 27% of girls achieving level 5 grades in 2008 compared to 34% of boys should also be prompting serious investigations of causes, especially as the new gender differences at primary levels coincide with the government's National Numeracy Strategy with its emphasis on speed and recall, as well as a move towards ability grouping for young children. Such investigations are particularly important as research tells us that negative attitudes towards the study of mathematics start at an early age (Mendick, 2005, Solomon, 2007).

Ethnicity and Social class

Research on teaching approaches has been less conclusive when it comes to underachievement by social class or ethnicity, with some research showing that mentors and role models are more important for encouraging children of ethnic groups that match with their mentor (Pomeroy, 1994). But there is some evidence that students from under-represented ethnic groups are also more likely to enjoy and participate in mathematics and science when they are actively involved (Ladson-Billings, 1997; Ortiz-Franco, Hernandez, & De La Cruz, 1999, Behm, 2001). Ladson-Billings (1997) for example, provides examples of approaches that offer African-American students opportunities to perform at higher levels that are characterized by problem solving and exploratory lessons, rather than the performance of routine tasks. Ortiz-Franco, Hernandez & De La Cruz (1999) propose that Latino students perform at higher levels when connections are emphasized and students work collaboratively rather than competitively. But perhaps more critically at this time, recent research has highlighted the role played by the recent and widespread move to rigid ability grouping in English schools in the construction of failure and the denial of opportunity for particular groups of students.

Ability grouping, or setting, is more commonplace in mathematics and science classrooms than any other curriculum areas (Kutnick et al, 2005) and it is more rigidly applied in England than in most countries in the world (Beaton & O'Dwyer, 2002). This practice, whereby teachers decide what students can do, and place them into a group that determines their level of work and future performance, has been found, repeatedly, to increase inequities, particularly for students from lower SES backgrounds (Ball, 1981; Boaler, Wiliam & Brown, 2000; Boaler, 1997c, 2005, 2009). Gillborn & Youdell argue that ability grouping plays a central role in the educational 'triage' that systematically disadvantages working class and minority students, characterised by reforms emphasizing league tables and GCSE pass rates, based upon elitist and racist notions of intelligence (Gillborn & Youdell, 2000 p 198). Three recent and alarming findings on the impact of ability grouping include:

- In a study conducted for the DCSF, Dunne *et al* (2007) analyzed grouping practices in 168 schools. They found that working class pupils were more likely to be placed into lower sets than their middle class counterparts *with the same prior attainment*, even though teachers had said that prior attainment was the determining factor. The researchers found that social class was *the most important factor* in set placement, gender did not have an impact and ethnicity had a weak impact – Bangladeshi pupils, for example, were less likely to be put into higher sets, after controlling for achievement.

- In 2004 researchers investigated a nationally representative sample of 15,000 young people to consider the source of inequalities for ethnic minority students in England, commissioned by the DCSF (Strand, 2007). They found large gaps in achievement by social class and ethnicity. They also found that Black Caribbean students were under represented in the higher tiers of Key Stage 3 tests for mathematics and science, after controlling for prior attainment and pupil, family, school and neighbourhood factors. 'All other things being equal, for every three white British pupils entered to the higher tiers only two Black Caribbean students were entered both for mathematics and science' (Strand, 2007, p8). As the researchers controlled for prior attainment as well as family circumstances such as poverty, this indicates a worrying state of affairs for Caribbean students in schools in England.

- Ability grouping in mathematics is now used extensively in primary schools, with half or more students regularly being told that they are not good at mathematics, at a very early age (Boaler, 2010). In a recent study, published by the DCSF, (Nunes et al, 2009), researchers followed 14000 children and found that 'in schools that used sets in primary school children in middle and bottom groups were not given the opportunities to learn mathematics that were given to children in schools that did not use setting.' (2009, p x) Researchers also found that

> the mathematics achievement levels of schools employing setting were significantly lower than schools that did not.

The low placement of Caribbean students, after controlling for attainment, is probably part of the reason that they are the lowest participating ethnic group in the sciences and the second lowest in mathematics. Table 15, for example, shows the strikingly low proportions of Caribbean students choosing chemistry A-level even when they have achieved an A or A* in the subject. If students feel that they are being undervalued and underestimated they are likely to dissociate from subject areas even when their performance is strong.

In addition to the inequities in students' placement into groups and Key Stage tests (the former heavily influences the latter), which has very serious consequences, the widespread practice of ability grouping in mathematics and science perpetuates a culture of exclusivity and elitism that limits the numbers of students continuing to higher levels. This is a particular issue in mathematics where students often develop the idea that only a small selection of students are suited to the subject and to higher levels of study (Rodd & Brown, 2005; Solomon, 2007). Wright (2006) found that students gave lack of confidence in their own ability as one of the key reasons for not liking mathematics at GCSE and Bell *et al* (2003) found that mathematics A-level has increasingly become dominated by pupils with very high levels of prior attainment. Mathematics classrooms, more than other subjects, seem to create a culture of exclusivity which limits the enjoyment of students and the participation of many students who could be successful in the subject and contribute much to it. In Boaler, Attendorff and Kent's (in preparation) study of 80 secondary school departments in which particularly high numbers of students took A-level mathematics and/or sciences, they found that the most important and widespread factor among the successful schools was the presence of a culture of inclusivity, accompanied by more flexible and lower amounts of ability grouping than typically found. Many of the successful schools, particularly those that were fully comprehensive, encouraged a wide range of students to be successful and put into place a number of strategies to support students, including those gaining B grades at GCSE who were encouraged to choose A-level. A priority for the future in mathematics and science should be the encouragement of a more inclusive culture, and communication of the idea that all students can be successful, with schools working to encourage as many students as possible.

Studies of underachievement among different ethnic groups in England (Cassen & Kingdon, 2007; Strand, 2007) have identified a range of factors at work, including social class and its impact on home, peer and school environments; racism, both institutional and individual; and cultural orientations towards academic achievement. It seems reasonable to deduce that many of these factors impact the inequitable patterns we have noted in this report. The data analysis we have conducted, examining participation in mathematics and science, combined with studies of underachievement in England, (Cassen & Kingdon, 2007; Strand, 2007), highlight Caribbean students as facing particular disadvantages. Caribbean students are being precluded from entering high-level tests (and presumably ability groups) in mathematics and science, despite high achievement and they are not choosing mathematics and science at 16, even when performing at high levels. These two facts seem highly related, suggesting that Caribbean students are identified as weak, for reasons other than academic achievement, and assigned to lower than appropriate tests. Inaccurate labeling and low expectations create negative reactions among students and parents and some have claimed that these push students into forming identities that are in opposition to academic goals (Cassen and Kingdon, 2007). This may be a particular issue for mathematics and science, and is worthy of further investigation.

White British boys remain the ethnic group that face the biggest disadvantages in the UK, after controlling for factors such as poverty (Cassen and Kingdon, 2007) and it is noticeable that white students were participating at very low levels in mathematics. Analysts have noted the particular disadvantages that working class boys face, such as not being able to be seen to be trying hard, for fear of appearing too pro-establishment, or “nerdy”. As mathematics is currently presented and viewed as a difficult and abstract subject, in many secondary classrooms, this probably makes it less accessible to working class students than other subjects. White, Western students are also known to develop the idea that success in mathematics comes from being naturally gifted, whereas students from Chinese and other Asian cultures more typically believe that success comes from hard work (Stigler & Hiebert, 1999; Andrews, 2007). The idea held by many white, British students, that mathematics success is available to the talented few, is one that is communicated by some classrooms and teachers and is also one that has severe negative consequences for learning. Andrews (2007), for example, found that English mathematics teachers tended to work within a model of education that placed limits upon learner's attainment and differentiated curricula accordingly. Students whose parents come from other cultures, particularly those of Asian countries, are known to encourage their children into mathematics and science and to communicate the message that success comes from hard work, rather than innate ability (Stigler & Heibert, 1999). Such messages are particularly important in schools that communicate very different ideas, of exclusivity and fixed intelligence (Dweck, 2000). White British students are less likely to receive positive messages about the accessibility of mathematics for all those who work hard, especially if their parents have attended schools in which they also received the same negative messages about the exclusivity of mathematics. If more white students, and students more generally, are to be encouraged to take mathematics, then the messages that are communicated about mathematics success need to be changed. When teachers communicate the idea that mathematics success comes from hard work and that everyone can be successful, and they combine such messages with equitable teaching methods, then many more students are successful in mathematics and choose to take it to higher levels (Boaler & Staples, 2008).

At the other end of the spectrum some ethnic groups, such as Chinese and Pakistani students, are particularly encouraged and are represented in mathematics and science in very high numbers. One important factor in their success and participation is the value placed upon mathematics and science in their cultures. Woodrow (1996) found that Asian students were particularly oriented towards mathematics and science because of the value placed upon scientific and mathematical careers by their parents and families. In Boaler, Altendorff and Kent's study (in preparation) of 80 secondary school departments that were promoting high numbers into mathematics and science the heads of science and mathematics in the schools reflected upon the motivation of Asian students to do well in their subjects because science and mathematics were strongly valued by their families. In many cases they contrasted high motivation to study mathematics and science among Asian students, who they reported started secondary school with the desire to study medicine at University, with that found among white students who were more oriented towards Arts subjects.

A focus on the ethnic differences in participation in mathematics and science highlights the importance of beliefs, both about the value of the subjects for students' lives and the nature of learning and success. An important priority area for the UK in the future concerns the messages that students receive about the nature of success in mathematics and science, and the opportunities that are provided for widened and more equitable participation.

Conclusion.

In highlighting some of the research that may contribute to understandings of inequality we have only been able to select a few studies, overlooking other promising work on for example, the importance of role models (Royal Society, 2004; Jegede & Aikenhead, 2004) or teaching that purports to cross social and cultural barriers (Snively, 1995; Jegede & Aikenhead, 2004). We have also walked a fine line, as do all researchers of equity, between furthering understandings of the barriers faced by certain groups of students, and essentialising these groups (Boaler, 2002a; Archer & Francis, 2007). Despite the fact that we have drawn conclusions about the importance of inquiry based teaching for girls, in particular, and messages of inclusivity for white, British students in particular, we are sensitive to the dangers of concluding that any approach is needed for *all* girls or boys or for students of any particular ethnicity or class. We also recognize that while we have discussed categories such as gender, ethnicity and social class as though they are separate, the different categories overlap significantly and are much more complex than we have been able to portray in this brief paper (for a more complex and post-structuralist account of race, gender, class and achievement, see Archer and Francis, 2007). At the same time it seems dangerous to ignore evidence that some students are systematically disadvantaged by the approaches used in schools, leading to the inequalities evidenced in the first part of this paper, and we offer this brief overview of the inequities that prevail in mathematics and science in order to highlight the need for attention and change.

Two of the most important messages that emerge from our review of the data and research regarding mathematics and science inequities concern the teaching environments offered to students. A significant amount of evidence points to the conclusion that 'good' teaching – teaching that engages learners actively, links subjects with the world, encourages all students to high levels, and communicates positive messages of malleable intelligence and hard work, rather than fixed intelligence and ability, is also equitable teaching. It is fortunate that we do not have to decide if certain approaches are better for girls or boys or students of different ethnicities or social classes, as some brain researchers have erroneously concluded (see for example Sax, 2005) as inclusive teaching has been shown to advantage all students. Our second, less fortunate conclusion is that there remains some distance between the nature of effective, equitable teaching and the teaching that predominates in mathematics and science classrooms in England today. In many mathematics and science classrooms across England, the teaching that takes places is narrow, procedural, based upon fixed rather than changing notions of intelligence, and examination driven (OFSTED, 2008b; 2006; The Royal Society, 2008). The evidence we have presented in this paper suggests that such teaching is also skewed in its appeal and opportunity, systematically disadvantaging students by ethnicity, class and gender, producing the stark inequalities that characterise mathematics and science achievement and participation in the United Kingdom, (and most particularly England), at the present time.

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