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1

The 'Glamour' of a 'Wrangler': Women and Mathematics at Girton College, Cambridge¹

Emily Davies, principal founder of Girton College, the Cambridge College of higher education for women, observed in 1868 that 'the best girls' schools are precisely those in which the 'masculine' subjects have been introduced'.² The subjects that she was referring to were mathematics, Latin and Greek. When it came to the contentious issue of higher education for women, Davies was convinced that only if women succeeded in subjects held to be prestigious for men would their educational achievements be recognised as equally valid. She rejected any idea of a special system or curriculum for women because, to opponents of women's higher education, 'different' would automatically mean 'inferior'. Davies put her ideas into practice the following year when she opened a residential college for women at Benslow House in Hitchin; these premises soon proved too small and in 1873 a move was made to new purpose-built buildings, some four miles distant from Cambridge, and Girton College was born. Here Davies encouraged her students to study for the most highly-regarded triposes, especially mathematics, a subject that had long been a symbol of masculine success and which was to remain the elite Cambridge degree until the 1890s.

The connections between Cambridge mathematics and notions of superior English masculinity were long-standing and profound. To mid-century and beyond, the middle and upper classes sent their sons to study mathematics at Cambridge in order to train them as gentlemen, not to turn them into mathematicians. Mathematics, as an essential component of a 'liberal education', was believed to train the character and the intellect, producing the fair judgement and unclouded mind necessary for men who were to assume their rightful, elevated place in society and Empire. Unlike leading European centres of mathematics, Cambridge adhered to a proud Newtonian tradition of 'mixed mathematics' which

shunned newer, more specialist techniques of abstract analysis in favour of solid, physical and geometrical approaches to problem solving. So important was such training believed to be that, until 1850, it was mandatory even for those taking final honours in classics to have taken the mathematical tripos first.

Accounts left by candidates leave no doubt as to the physical and psychological pressures experienced both in preparing for and sitting this highly-competitive examination. On the day(s) this involved working against time to find solutions to problems which became ever harder as the examination progressed. These problems ranged across a wide range of topics and were presented in the form of open-ended papers sat over a series of consecutive days. Students were 'trained like racehorses' as the tripos 'rivalled the Newmarket races, and the bets on the outcome were just as keen'.³ As befits such a competitive sprint, students were then individually ranked according to their performance in an order of merit which was announced publicly at Senate House, often before a rumbustious crowd. After 1882, when papers were made available to women on a formal basis, female students were ranked alongside the men, although women had the right to examinations only, not to degrees. To be 'senior wrangler' (or first among the first class) was for the man who achieved it a path to opportunity, often leading to a coveted Cambridge fellowship or high office in another field or profession.⁴

A small collection of scholarship exists on the mathematics tripos at Cambridge University in the second half of the nineteenth century. Special attention has been paid to the development of teaching methods, its relationship to the natural sciences tripos, and the connections between the severe mental and bodily drill involved in preparing for the examination.⁵ Little attention has been given to the experiences or significance of women training for the tripos and, for the most part, the history of mathematics, and of mathematicians, has been written as an unthinkingly gendered narrative. Such approaches to the history of mathematics seem to rest on an assumption that the discipline is, by its very nature, intrinsically masculine. Towards the end of the nineteenth century such views were not just assumed tacitly, but argued loudly. Rational, often abstract, eminently cerebral and never emotional, mathematics was a man's subject generally held to be altogether too hard for women. Sciences informed by Darwinian understandings of male and female nature were becoming increasingly influential and these pointed to woman's less evolved brain, decreased capacity for abstraction, and greater subjection to the emotions. Her

biology had evolved for reproduction and her brain worked on instinct; put her in an environment designed for men, set her to masculine intellectual work – especially mathematics – and her health, even her feminine appearance, could be at risk.⁶ As Sara Burstall, a ‘graduate’ of the 1881 tripos recalled, ‘... to much of Cambridge ‘Varsity opinion there was something comic in teaching girls mathematics at all’.⁷ Indeed, the familiar cartoons of the time featuring stern, manly and monocle-wearing women, often ‘Girton girls’, played specifically to the idea that college-educated women would ‘adapt’ to their male environment, just as Darwin taught. One of the reasons that Emily Davies encouraged her students at Girton to take the mathematics tripos was because this was the most prized degree for men and a subject generally held to be beyond the capabilities of women. When her students beat the men at mathematics it added ammunition to her argument for intellectual equality between the sexes.

This chapter aims to examine the Cambridge mathematics tripos with reference to women’s participation. This will involve presenting the social context within which women approached mathematical study and exploring issues surrounding the tripos training regime that, prescribed for male students, could be ambivalent for women: rigorous mental and bodily training, competition, and close study relationships with men. As well as mathematics having an impact on women and notions of femininity, women’s participation in mathematics had significant influence on the tripos itself and affected its relationship with the natural sciences tripos. These latter concerns will be addressed in more detail in Chapter 6, here the emphasis will be on the experiences of female mathematics students, the social context of those experiences, and the negotiations that were necessary to accommodate women (to a certain extent) within the mathematical life of the University. It will be demonstrated that women were not coached in the same way as men, that gendered notions of success were applied to students according to their sex, and that women’s performance in the tripos adversely affected the prestige of the examination and contributed to reforms introduced in the later years of the nineteenth century. This chapter will also serve as an introduction to the two women whose lives provide a guiding window through which to view gender, mathematics and science around 1900. Both Hertha Ayrton (1854–1923) and Grace Chisholm Young (1868–1944) studied for the Cambridge mathematics tripos at Girton College in succeeding decades. Hertha became a well-known physicist and electrical engineer; Grace made her life work research in pure mathematics.

Hertha Ayrton

Hertha Ayrton, then Sarah Phoebe Marks, entered Girton College in October 1876, supported by the financial generosity of women's rights campaigner Barbara Bodichon and her circle of feminist friends.⁸ She had lived a respectable but impoverished life with her Jewish immigrant family near Portsmouth before moving to London, at around nine years of age, to be educated alongside her cousins in the small school run by her better-connected aunt, Marion Hartog. According to her friend and biographer, Evelyn Sharp, Hertha first became interested in mathematics through the example of her elder cousin Numa Hartog. Hartog, who had attended Trinity College, was the first Jew to attain senior wrangler status in the mathematical tripos (1869) and was admitted to his degree without having to take the usual religious oath.⁹ Since receiving political rights in 1858, many of England's Jews had attained positions of status and with her move to London Hertha became part of a comfortable Jewish community which included the family of Sir Francis Goldsmid, the first Jew to become a barrister and an MP. Goldsmid was a financial supporter of Girton College (when Grace Chisholm entered Girton in 1889 she did so as Francis Goldsmid Scholar) and it was probably through this connection that Hertha became aware of the opportunities available there. Despite acceptance of those Jews who had become assimilated into middle-class society, anti-Semitism was on the rise in the late 1870s onwards, ostensibly in response to the arrival of poorer refugees from Eastern Europe. The coming of these immigrant groups coincided with the development of evolutionary approaches to science which codified and reified racial differences, creating a hierarchy of racial groups.¹⁰ In 1905, the Government responded to escalating fears of an 'influx' with an 'Aliens Act' that limited Jewish immigration by excluding those without financial support or suspected of having a 'bad character'. Subliminal fear of the Jewish 'other' has even been implicated in the genesis of the vampire genre, which experienced a resurrection around turn of century, and it has been shown that representations of 'Dracula' and the anti-Semite's 'Jew' are strikingly similar.¹¹ Whatever the reality of this, it is clear that the new 'Jewish aristocracy' of which Hertha was on the periphery could, by its very conspicuousness, become a potential focus for hostility.¹²

Hertha was the first Jewish woman to attend Cambridge and there is some evidence that her Jewish origins were an issue for her, both at Girton and during the start of her career. Hertha had been rejected

initially by Emily Davies, probably in part because of the latter's Anglican leanings. At the time when Hertha entered Girton the celibacy restriction on fellows was still in place (repealed in 1882) and colleges required (male) students to attend chapel. Cambridge was still a firm part of the Anglican establishment and Davies wished Girton to be run on exactly the same lines as the men's colleges; when the new college buildings were constructed in 1902 she insisted on the inclusion of a chapel, despite objections from some of her secularising supporters.¹³ Hertha later wrote that at college religion was the great divide with the evangelicals ranged against the anti-clericals and a fellow student recalls her independence and disregard as to whether people liked her or not.¹⁴ Hertha's 'bush' of thick, black, curly hair was an attribute coded Semitic and was used as a defining feature by others. Even her patron, Barbara Bodichon, advised that when she went out to teach she should put her hair in a net as 'it would be worth £50 a year to you'.¹⁵ As well as representative of Jewishness, long, thick, dark hair was also a cultural symbol of wild, instinctive femininity and these kinds of representations jarred with Hertha's later efforts to present herself as a rational, empirical scientist no different from her male colleagues. Hertha's dark looks would often feature in reports of her public lectures and may have enhanced her attraction for the press, at least in the early years of her career, as it added to her exoticness as a female scientist. When she read a paper before an audience of men at the Institution of Electrical Engineers Hertha was described as a little dark-haired, dark-eyed lady who 'created a sensation'.¹⁶ In similar vein, the memoir of a fellow Girton student describes Hertha as 'A poetic and romantic figure, with piercing dark eyes, and wonderful hair ... whose deep voice had extraordinary cadences ... she might well have been the heroine of a story'.¹⁷

The second Jewish woman to attend Cambridge University was writer Amy Levy (1861–1889) who attended Newnham College and committed suicide at a young age. In her novels and short stories, Levy explored ideas of Jewish self-hatred. In 1886 she published an essay on *Middle Class Jewish Women of Today* asserting that, if they wished to pursue interests beyond the home, Jewish women had to break ties with their religion and its notions of family, race and the importance of marriage. Hertha is named as a high-achieving Jewish woman who traded broken ties for career success by renouncing her religion and marrying a gentile, the electrical engineer William Edward Ayrton.¹⁸ Levy knew Hertha personally; they were friends and fellow members of the University Women's Club, so Levy's opinion on Hertha's choice to renounce Judaism was an informed one. That Hertha seems to have rejected participation in

any of the Jewish philanthropic movements that proliferated at the end of the nineteenth century, despite her involvement in many other causes and committees, adds weight to Levy's view. It is also strengthened by a fictionalised account of Hertha's life by her stepdaughter, Edith Ayrton Zangwill, which makes no mention of Hertha's Jewishness and implies a Christian faith.¹⁹ It seems clear that Hertha did not embrace a Jewish identity and that breaking away from Jewish custom helped her in the feminist ways suggested by Levy; it also assisted her assimilation into middle-class, scientific society.

The completion of Hertha's change of name from Sarah Phoebe Marks seems to have taken place upon her marriage to William Ayrton – up until then she was still calling herself Sarah Marks on college records and on patent applications. The adoption of a new first name is usually attributed (perhaps with some romanticisation) to the influence of her friend Otilie Blind. Blind is said to have given Hertha this new name after a Swinburne poem and because she resembled the Teutonic goddess Erda.²⁰ Why Hertha chose to adopt this name as a public identity (instead of as an affectionate name used by friends) is significant. The change underlined her desire to break away from, or at least render nominally invisible, her Jewish past. It may also be interpreted as representing a rejection of religious modes of explanation in general in favour of a new code of scientific rationalism (Sarah was the biblical wife of Abraham and mother of Isaac). Later in life, Hertha termed herself an agnostic which she claimed was the 'scientific' approach to religion as one 'cannot say that these things are not true, only that they have not been scientifically proved'.²¹ In one of the few extant photographs of Hertha, a 1906 portrait of her in her home laboratory (a formal portrait that was carefully posed to commemorate her winning a Royal Society medal) a painting with a Christian theme is clearly visible in the top right hand corner.²² (Figure 5.2)

Grace Chisholm Young

By the time that Grace Emily Chisholm arrived at Girton in 1889 the College was fairly well established with an increasing number of women seeking admission. A scheme of extension had commenced in 1886 and this had resulted in twenty-seven new student rooms, bringing the total to 104. In Hertha's time facilities had been more modest, for example a library was not established at Girton until 1884. Relations with the University had developed too and now women were allowed access to examinations on a more formal basis and, in mathematics, were ranked

alongside the men on the order of merit. Hertha had sat the mathematics tripos in 1880 when women were only allowed to do so unofficially and had to rely on sympathetic male dons to send them the papers. Had Hertha taken her examination a year later she would have been able to apply for a degree in 1921 when Cambridge began awarding women titular degrees only without membership of the University or voting rights; in 1948 Cambridge finally allowed women degrees on the same basis as men.

Grace was twenty-one years old when she first entered Girton, the average age of entry of women to Cambridge prior to 1900. She was leaving an affluent, middle class, privileged family; her childhood had been spent in Hazlemere, Surrey, where she had been acquainted with the Tennysons and William Morris. Grace had been educated at home by her mother, née Anna Louisa Bell, who had taught all her children Latin, mathematics and music from an early age. Grace's elder brother Hugh had studied classics at Oxford, while her elder sister, Helen, was fragile having been disabled by polio as a child. In her romanticised autobiographical jottings, Grace presents herself as precocious from an early age, outshining her siblings and becoming the favourite of her father, Henry Chisholm, a gifted mathematician who had until retirement applied his talents to Weights and Measures in his Civil Service post as Warden of the Standards. Grace idolised her father as an intelligent, affectionate man who encouraged her mathematical interests, designed three-dimensional models with her and introduced her to geometry. Grace's mother and aunt were sympathetic to women's issues and the family were known to Emily Davies who arranged for Grace to try again for a scholarship after she had under-performed in the Cambridge Senior Examinations due to illness.²³

Different women, similar choices

Why did these two women from such different backgrounds aspire to Girton College? Martha Vicinus has demonstrated that from the beginning the women's colleges included a relatively wide range of young women from various levels of society. An obvious distinction was between those from wealthy families who attended for the sake of learning, and those who came in order to qualify for a better teaching post.²⁴ Grace wrote in her memoirs that she went to Girton because she had 'visions of intellectual cloisters like Plato's Athens' and yearned to meet 'the men of intellect of Cambridge' (when she finally arrived at Girton she still preferred the 'intellectual men' to the 'childish girls around

her').²⁵ This romanticism and adulation of intellect as inherently male came to inform the culture of pure mathematics and was, for Grace, a factor in her later devotion to the discipline. Love of learning may have been just as important to Hertha, but her first need was to support herself. She had been working as a governess in London prior to her application to Girton College and, having found being a resident governess onerous, began to attract her own students prior to commencing her studies. Had they been students simultaneously, it is unlikely that Hertha and Grace would have been close friends. Despite attempts by Emily Davies to equalise conditions amongst students,²⁶ both Hertha and Grace report class divisions. For Grace, the influx of girls from the new high schools 'lowered the intellectual tone';²⁷ for Hertha, that some students looked down upon one of their fellows because of her shop-keeping background was a reason to proclaim her own origin from the rooftops.²⁸

Grace achieved the equivalent of a first-class pass in part one of the mathematics tripos in 1892; she returned to score highly in the more specialised part two the following year, an advanced examination usually taken in a student's fourth and final year at college. In response to a challenge from her brother Hugh who wanted to prove the superiority of an Oxford education, after their success in part one of the tripos, Grace and fellow student Isabel Maddison²⁹ sat for the final Honours School of Mathematics at Oxford where, according to family legend at least, Grace obtained the highest mark for all students at Oxford that year. Grace's participation in the Oxford examination was purely an informal arrangement and her achievement did not enter the record book.³⁰ However the fact that Grace and her fellow student were allowed to sit the examination is indicative of women's marginal (even inconsequential) status at Oxford and Cambridge at this time.

Hertha gained a disappointing third in the mathematics tripos in 1880 and did not go on to part two as this specialist extension examination was not available at that time. Like many of the early students, she was ill prepared for university as she had not benefited from the preparatory education, similar to that available in boys' public schools, which was beginning to be offered by the end of the following decade in the new high schools for girls. The growth of these schools was in part fuelled by the growing availability of teachers from the new women's colleges. Hertha had spent time away from Girton due to illness and, while there, preferred to study in the morning and spend the afternoons engaged in more practical work. While still a student she had devised a sphygmometer (device for measuring the pulse) which was to be the first

of several inventions for which she took out patents during her life.³¹ Given these leanings towards practical science and technology, why did Hertha not choose to study natural sciences in preference to mathematics? The answer lies in the culture of learning at Girton and the perceived importance of mathematics to the campaign for higher education for women.

Special significance of mathematics for women

The combination of mental and physical excellence that success in the mathematics tripos was believed to demonstrate, plus its acknowledged connections to elite masculinity, made the discipline a target for campaigners such as Emily Davies in their strategy to demonstrate women's intellectual equality with men. The culture at Girton, informed by this desire, privileged mathematics over other disciplines; if any student showed a talent for it she was firmly discouraged from dissipating her energies on any other subject. Sara Burstall was dissuaded from taking history because of the mathematical aptitude she exhibited in the early May examinations and, '... it being then still specially desirable that women should prove they could be Wranglers', she was given additional scholarship funding to enable her to spend the vacation preparing for the tripos. Unfortunately she just missed out on a first-class pass, although 'The College authorities were very kind about the disappointment, and the Cause was strong enough to do without a woman Wrangler that year'.³²

Although this privileging of mathematics had lessened to an extent by the time that Grace arrived at Girton in the early 1890s, the mathematics tripos was still regarded as somewhat 'special'. Such was its reputation that any woman perceived to be on course to achieve a first-class pass was said to have a certain 'glamour' about her. Grace's autobiographical notes and letters also convey the (sometimes none too sisterly) competition between Girton and Newnham to produce wranglers. Newnham scored a high profile win with the outstanding performance of Philippa Fawcett, a success celebrated with genuine and high-spirited jubilation by staff and students at both colleges alike. Fawcett, daughter of Newnham pioneers Millicent and Henry Fawcett, was placed 'above the senior wrangler' in the 1890 tripos; her success a testimony to the significance of mathematics to the early campaigners for women's higher education. Philippa's mathematical talent had been recognised when she was a child since when she had been tutored with the Cambridge mathematical tripos in mind. From the age of fifteen, her well-connected family arranged special

coaching provided by a don from Trinity Hall, Cambridge; Philippa then attended courses at Bedford College and University College London. She was therefore, unusually for a woman, as well prepared as the men and this made her an acceptable proposition for her Cambridge coach, the well-respected Ernest Hobson.³³ (Indeed, a fellow classmate at University College was Geoffrey Bennett, the senior wrangler of 1890, a man whose fate was to be forever after linked to Fawcett's name.)³⁴

The news that a woman had beaten the 'senior wrangler' made headlines in the local and national press, with the *Telegraph* suggesting that there was now no longer any field of learning in which the lady student does not excel as 'Miss Fawcett has added the last, and possibly most coveted laurel wreath to grace the lofty brows of womanhood'. The report continues (with some ambiguity and a compliment cloaked in irony) to make another implied reference to mathematics:

We are more than gratified by this result because it removes from our minds one of those lingering doubts which have sometimes interfered with the full and frank admission of feminine superiority.

Across the Atlantic too, the *New York Times* ran an article several columns long.³⁵ The publicity habitually given in national and provincial media to the results of the Cambridge mathematics tripos was another factor in making women wranglers of particular importance to the 'Cause'. With profiles and pictures of the top wranglers and their coaches commonplace, when a woman was highly placed alongside (or above) the men in this difficult discipline, a message of feminine intellectual excellence was sent out loud and clear.

Mathematics and femininity

But there were other reasons why mathematics could be viewed as an appropriate discipline for women in addition to its power for demonstrating that intelligence was not solely the preserve of the male sex. Women's campaign to make their presence felt coincided with changes at Cambridge that enabled students to transfer directly to the advanced part of the natural sciences after part I of the mathematical tripos. The former also increased its mathematical component and began to rival mathematics as a key route into laboratory-based science – a route increasingly popular with men. As will be addressed in Chapter 6, by end-of-century so many men were taking advantage of this that the decreasing number of male candidates taking the specialist part II of

the mathematics tripos became a serious concern to Cambridge's pure mathematicians. This trend helped to inform a new impression of mathematics as more at ease with femininity, both in contrast to its history and to the natural sciences.

This 'feminisation' of mathematics was further emphasised by a 'masculinisation' of the more worldly, practical sciences and a contrasting understanding of mathematics as more 'passive' and suitable for women. By its very nature, mathematics was clean, sedentary, safe (unlike the laboratory) and (mostly) removed from the grim and sometimes immoral realities of the real world. In the 1890s a questionnaire was circulated to Cambridge lecturers canvassing their opinion on opening lectures to women. Respondents in classics and the natural sciences complained that the subject matter of lectures had to be modified if given in the presence of ladies.³⁶ Earlier, the Vice Chancellor of the University had argued that the study of Greek authors was 'bad enough for men, let alone women'.³⁷ Here the very abstraction of mathematics could be perceived as of benefit to women, rather than an obstacle. This perception was reinforced by the use of symbolic language which ensured the discipline's remoteness from unpleasant aspects of the world, preserving innocence and purity. Mathematical notation may also relieve women of the need to assume uncomfortable and 'unwomanly' authority in their use of language; they could take refuge in impersonal, supposedly objective, symbols instead. No wonder Cambridge women targeted mathematics in their campaign for intellectual equality with men. Paradoxically, it was viewed as the elite 'masculine degree', yet it could also preserve a woman's femininity, which other more 'knowing' disciplines may threaten.

Despite aspects of mathematics that could make the subject a comfortable choice for women, there was still much debate as to whether the discipline was too hard for the female sex or detrimental to femininity and health. Even women such as Sara Burstall, a mathematician herself and firmly committed to girls' and women's education, could be ambivalent to mathematics' place within female programmes of study. Echoing Herbert Spencer's principle of the 'conservation of energy', she argued in 1912 that teaching girls mathematics required too much teaching for too little return, consequently 'We ought to recognise that the average girl has a natural disability for Mathematics. One cause may be that she has less vital energy to spare'³⁸ Spencer believed that female evolution, meaning *intellectual* evolution, had stopped at a stage before man's in order to preserve vital organs for childbirth. If a woman undertook rigorous 'brain work' such as mathematics, energy

could be diverted from her reproductive system, threatening fertility and general well-being. Informed by these Darwinian ideas, Burstall advised that mathematical study should be kept at a minimum for girls, not least because of the 'hardening influence' it may have on their femininity.³⁹ Mathematics, she seemed to be implying, with its logical processes and cold unemotional reasoning, may also tempt girls to subvert their 'emotional' nature and neglect feminine ideals of service. These opinions were shared by the mathematics mistress of Roedean who argued in the *Association of Mathematics Teachers' Journal* that mathematics was of little practical use and 'too difficult for the average girl'.⁴⁰

Some of the most strident voices against women's higher education were those of the medical profession making a case from science for its detrimental effects on the 'less robust' sex. Particular concern was caused by the medical theory of 'menstrual disability', a belief that spawned a condition coined 'anorexia scholastica' which was believed to be a debilitating thinness and weakness resulting from too much mental stimulus, especially during menstruation.⁴¹ Pioneers of higher education took these warnings seriously. When Henry Maudsley published his oft-quoted 'Sex in Mind and Education' in 1874, arguing that women would suffer immense harm to their health by following study regimes similar to men's, Emily Davies and her group were worried that it could hurt their plans as 'there is much truth in it'.⁴² They were moved to action when William Withers Moore made similar arguments in an 1886 presidential address to the British Medical Association prompting calls for protective legislation for women of the educated classes analogous to that introduced for women working in factories and mines. In response, women's colleges at Oxford and Cambridge carried out joint research on the health, marriage and child-birth patterns of former students. Their findings contradicted medical opinion in concluding that college-educated women were healthier and less likely to have childless marriages than their less-educated sisters and cousins.⁴³ Another way in which educational pioneers sought to counter health fears, and to reassure female students and their families, was to include medical facilities within women's colleges, as was done as part of Girton's expansion in 1876. Equivalent facilities were not considered essential at men's colleges.⁴⁴ The physical and psychological robustness of women was an issue addressed habitually in references produced by colleges for their female students. For example, when Grace applied for a Fellowship at Cornell University, Girton's Mistress Elizabeth Welsh felt the need to stress her 'great vigour and energy both physically and mentally'.⁴⁵

Negative views about higher education for women were by no means universal however, and as significant numbers of female students succeeded at college with no ill effects such arguments began to lose their credibility and power to cause alarm. In 1884 Edwin Abbot, a headmaster and strong supporter of female education, published a mathematical social satire in which he parodied the resistance to women's education and the tenets of social Darwinism. Abbot's aim was to challenge what he saw as injustice (or sexism, to use a modern term) in contemporary society by taking such views to their logical extreme and so illustrating their absurdity. Based on the notion of the fourth dimension derived from non-Euclidean geometry, in *Flatland* women were represented as straight lines because they were incapable of education or rational thought; men were represented as geometrical shapes with sides and angles – the more sides they had, the higher their social and evolutionary standing. Women had no angles because they had no brain power and were, therefore, inferior even the lowest of the men – an isosceles triangle. *Flatland* proved very popular and many editions were produced into the next century.⁴⁶

Women's access to coaching

To compete successfully in the mathematics tripos candidates needed to be adept at rapid problem solving and drilled ruthlessly in memorisation and examination technique. These were all skills for which a private coach was essential. Coaches had been the most important teachers at Cambridge at mid-century; although their importance had declined in other disciplines, they were still indispensable in mathematics due to the continuance of the order of merit. It was the College's prerogative to appoint coaches, although the women could express a preference among the small pool of tutors who would consent to take on the role. The College acted as an intermediary and accounting point and, in this way, saved women from the social awkwardness of having to arrange a financial transaction. Receiving payment for intellectual work could still be cause for embarrassment and even male students and coaches may suffer anxiety during the collection of fees. For some coaches, the student was required to hide payment somewhere in the room so that both student and coach could communicate as if no financial exchange had taken place.⁴⁷

The reputation of a coach (and the fees that he could command) was measured by the performance of his students, drawn from varying colleges, and their ranking on the pass lists. Coaches wanted students

with high potential; students wanted coaches with a record of drilling high-placed candidates. There is evidence that women were not attractive as students to coaches who sought to maximise their reputations. A coach's standing was dependent upon the performance of his pupils; that the women were often starting from a lesser state of preparedness than their male counterparts compounded coaches' fears that they may not do well.⁴⁸ Sara Burstall remembered that

We mathematical people were perhaps the worst off. All our work was private coaching with such Cambridge men as could be induced to come out three times a week, nearly two miles of dull walk along the Huntingdon road, to take on the teaching of young women, often ill-prepared and unlikely to reflect honour on their teachers.⁴⁹

One leading coach of the time, Edward Routh, declined to train Charlotte Angas Scott who went on to be placed equal to the eighth wrangler in 1880 (unofficially as this was prior to women's inclusion on the order of merit).⁵⁰ According to Hertha, who was her fellow student at Girton, Angas Scott was third on the pass lists after the first three days of examinations but dropped position later due to 'not having read enough, the result of having read so very little before she came up ...'.⁵¹ Even Philippa Fawcett, who had been trained as well as the best men and marked out as a high achiever, had been refused permission by another top coach, Robert Webb, to attend his classes. Such was Webb's antagonism towards women that he maintained that if Fawcett beat his candidate, Geoffrey T. Bennett of St. John's College, both he and his pupil would emigrate to the new University of Chicago.⁵²

Webb's refusal to coach Fawcett had more to do with propriety and concerns about having a woman in the coaching room than any fears about her ability. One of Webb's male pupils remembered that he had had 'a rough tongue' and that he had refused Fawcett because 'he considered that the presence of a lady in his classes would prevent that freedom of language necessary for teaching mathematics'.⁵³ The environment of the coaching room was rough, individualistic, competitive and frank – not a place where the polite conventions and middle-class etiquette required for social intercourse between the sexes could be maintained. The coaching room was simply not a place for a 'lady' and, moreover, her presence could cause unease, discomfort and concern about correct behaviour amongst the men. As late as 1911 a book entitled *The Intellectual Life* had testified to the difficulty of authentic communication between the sexes due to the requirements of etiquette,

requirements which were 'hereditary and instinctive' for men. These rules made it 'quite impossible for men to speak to ladies in the manner which would be intellectually most profitable to them' as 'we may not contradict because it is rude'. The author concludes that 'Men will never talk to women with that rough frankness which they use between themselves. Conversation between the sexes will always be partially insincere'.⁵⁴ Concerns such as these all too often resulted in women's exclusion from the coaching room of the top coaches who typically ran large and regimented training regimes for their male pupils.

Another outcome of coaches' reluctance to teach women was that it became very difficult to maintain both the quality and continuity of coaching for Girton and Newnham's mathematicians. Sara Burstall was trained by various coaches for 'short periods' and attributed her failure to achieve a first-class pass, in part, to the shortcomings of the 'inexperienced coach' assigned to her prior to the examination.⁵⁵ The men who lectured and coached the women, unsurprisingly, tended to be supporters of women's higher education and, often, critics of the Cambridge system too. Grace was tutored mainly by Arthur Berry of Kings (1862–1929) who served on the Executive Council of Girton College and who, as Secretary of the University Extension Syndicate, moved to allow women lecturers in 1893. Arthur Cayley was active in the foundation of the 1869 lecture series for women which eventually led to Newnham College; he taught many of the early students including Charlotte Angas Scott.⁵⁶ Angas Scott attended Cayley's lectures in the 1880s and he was also instrumental in opening Grace's eyes to mathematics beyond the tripos by welcoming her, and a fellow student, into his home and taking them to a special lecture he was giving in Cambridge. This was unusual, especially for women. There was a huge gulf between undergraduates and professors and the former rarely attended College lectures as they were largely irrelevant for part I tripos examinations, becoming important only for the specialist part II. Students were required to pay extra for attending these events, but the less well off women could sometimes dispense with this expense by attending lectures as a chaperone – something Angas Scott, daughter of a Congregational minister, took advantage of.⁵⁷

Hertha, who sat the mathematics tripos in 1880, received the fragmented training that was typical for early students. She was taught at one stage by Richard Glazebrook who had also tutored Burstall for a while. Despite being fifth wrangler in 1876, Glazebrook was critical of the tripos system, particularly its separation of mathematics from experimental work and the continuance of the order of merit. At the

time he was coaching the women he was working as a demonstrator at Cambridge's Cavendish Laboratory and, given his preference for experimentation, Glazebrook was not considered by ambitious candidates as a coach likely to push them towards a top place on the list. Like Glazebrook, many of the coaches and lecturers who visited the women's colleges came with a reform agenda which made them hesitant simply to replicate the education that was given to the men. These 'youthful and enthusiastic young gentlemen ... were more concerned to advance general culture than to coach for exams' and this led to protest from Emily Davies at Girton and some of her early students.⁵⁸ One of those students was Grace Chisholm who wrote a letter of complaint about one young mathematics lecturer, stressing his youth, inexperience and 'lack of seriousness'.⁵⁹

One answer to these problems was to recruit women into the coaching role and there are suggestions that parallel systems were seen as a solution to questions of propriety as well as of access. After her high placement on the pass list, Charlotte Angas Scott was told by one of her examiners that 'if she would stay in Cambridge she should have his sister to coach at once'.⁶⁰ Scott did remain as a lecturer at Girton for a short while, as did Fawcett at Newnham for nearly nine years. However, despite reforms to university teaching that lessened the power of coaches in the latter decade of the nineteenth century, there remained a mythology surrounding the most celebrated coaches, usually based on their eccentricity and the robustness of their teaching techniques, that the female tutors found hard to emulate. The position of the female don was not of an equal status to her male counterpart: she tended to be poorly paid, isolated and with little say in the curriculum or governance of the University. For Grace, even in the 1890s, 'nearly all the head lecturers are men and, as for the female dons, they are chiefly there to quiet the anxiety of parents for their daughters and act as chaperones. Nobody with any pretensions coaches with them if they can help it'.⁶¹ Coaches won work according to their reputation, based in part on the number of wranglers they coached; it was difficult therefore for female tutors, teaching comparatively few less-prepared students and with pastoral duties to perform as well, to compete in this arena. Fairly or not, the reputation of some female mathematics tutors was not high – Grace's notes also record rumours circulating that the coaching offered at Newnham by 'Miss Fawcett' was not good.⁶²

There is no doubt that the long-held associations of the mathematics tripos as a vehicle for testing manliness as well as mathematical skill posed a barrier to women being accepted as effective coaches. However

this association was in the process of being eroded in the last two decades of the nineteenth century as increasing numbers of women were successful in mathematics, giving that examination a more feminine colouring while the mantle of masculinity passed to the newer natural sciences tripos. Despite this (and Davies' desire to see women coached to compete successfully with the men) there is evidence of tension in the coaching room between female students and their male tutors and signs that the teaching techniques used for women were different from those used for men.

Tensions in the coaching room

There are many accounts left by male wranglers describing their experiences in the coaching room, both in memoirs and obituaries, which are alike in recalling the immense hard work required and the relentless need to compete with one's peers. These accounts collectively comprise a shared mythology, with communal terms of reference, which was used as a model and added to by succeeding generations. A.R. Forsyth sat the tripos in 1881, the same year as Sara Burstall, but his memories of being coached are very different. Forsyth was trained by the legendary coach Edward Routh⁶³ – an experience which he described as 'a marvel even of physical endurance, let alone intellectual effort'. Routh's 'system' was to offer one-hour classes, three times a week, on alternate days during term time and the long vacation. Classes were attended by a crowd of some twenty ambitious young men who were required to complete exercises and solve problems between sessions, their answers graded and displayed publicly. Teaching was devoted entirely to how to frame an examination question as speedily as possible and this involved 'scribbling hard ... not a moment spent in diversion or extraneous illustration ... there [was] little leisure for thinking, because we were all being taught'.⁶⁴ In similar vein, Robert Webb laid claim to practically all the time and energy of his pupils and could be harsh with students who failed to meet his exacting demands.⁶⁵

Women's memories of being coached seldom convey this sense of relentless pressure, or any indication of sharp words or recriminations. Unlike Routh's industrialisation of the coaching process with some twenty men in the coaching room, women were generally taught in pairs in a more gentle style. For the students at Girton days were highly structured and the avoidance of mental strain and undue competition was paramount. Hertha was restricted to five hours study a day⁶⁶ and Grace expected to attend just one lecture each day, in the morning or

afternoon, completing no more than six hours work with nothing after 6pm.⁶⁷ She also records receiving one hour's coaching a day, three days a week. Control, not work to the point of exhaustion, was similarly a hallmark of Fawcett's methodical study regime. This was composed of 'six hours work, *very rarely exceeded*, plenty of regular exercise and always to bed at 11.0 (sic)'.⁶⁸ Coaches were wary of pushing the women as hard as the men: while Forsyth records being coached at a 'wonderful pace ... not a moment was wasted ... (just) grim doggedness and unrelenting drill',⁶⁹ Grace recalls a more leisurely, although hardworking, pattern that included a break halfway through when the tea tray came in and she poured.⁷⁰ Grace was given problems to solve between lectures, but she did not experience the pressure of repeated, public competition against peers in mock examination papers (as was Forsyth's lot).

Relationships between coaches and the women they taught could be uneasy; Girton and Newnham's students tended to be taught by younger, 'greener' and less experienced fellows who may have only just sat the mathematics tripos themselves. Many of these young men were not much older than their pupils (for example Hertha was exactly the same age as her coach Richard Glazebrook) and, for women and men, being in such close proximity to a member of the opposite sex, especially in an academic context, could be unsettling. Although Grace's autobiographical account of her Girton years is romanticised and written with hindsight, her identification of a strong thread of novelty and tension within the female student/male coach relationship is plausible:

It was quite a new experience ... to come into contact with these male lecturers. She had danced and played tennis with young men of her own age, but here she was seated at a long table with a young man, crammed full of that mathematical knowledge for which she thirsted, and who poured it out for her, at the end of a quill pen, without any touch of familiarity, for the space of an hour, three times a week.⁷¹

In addition to avoiding 'familiarity', the 'young men' had other strategies for coping with a difficult situation: one walked straight into the lecture room at Girton and, without any greeting or acknowledgement, proceeded straightaway with his lecture. Interaction such as asking questions was frowned upon, it could threaten the formality of the proceedings and it held up the class. If students got lost or did not understand, they asked a fellow student.⁷² This strict sexual protocol

could result in episodes bordering on the surreal. Beatrice Cave-Brown-Cave of Newnham College recalled a coaching session with William Young (who briefly coached Grace and later became her husband) during which he kept tilting his chair until it slipped and he went under the table. With great difficulty Beatrice and her fellow student refrained from laughing as Young righted himself, ignored what had happened, and merely told them to take out a fresh sheet of paper.⁷³

Reconciling competition with femininity

Competition was a key element of the Cambridge mathematics tripos; it was made manifest in the annual – and very public – celebrations surrounding announcement of the order of merit and it informed the close relationship that was perceived between competitive sport and the examination. For women competition, especially with men, threatened contemporary feminine ideals of modesty, selflessness, domesticity and service. A concern to connect with the domestic, instead of to the assertive and individualistic ideals of male academia, has been identified even in the architecture of Girton. Instead of being built to mirror the men's colleges with their grand, confident, institutional designs, Girton's purpose-built premises relied instead on a domestic architectural model which featured inglenooks, bay windows and roof dormers.⁷⁴

While anticipation of a high place in the mathematics tripos could give a woman the 'glamour' of 'probably a wrangler', there was also ambivalence in the students' attitudes to success and even the most high-achieving female students were praised for 'never displaying their cleverness in the wrong way'.⁷⁵ Delivering a paper to the Girton Mathematical Club, Charlotte Angas Scott warned her audience against being tempted to 'win a name for yourselves' and, instead, encouraged them to develop a genuine love for mathematics.⁷⁶ Reflecting similar concerns, a contemporary chose humility as Philippa Fawcett's most outstanding characteristic and praised her for being 'modest and retiring, almost to a fault ... so as to appear like a very ordinary person'.⁷⁷ But reticence to compete with men was not so evident when it came to competing with each other or against another women's college. Grace's autobiographical notes are full of remarks about fellow students' abilities, while Hertha felt it particularly unjust that Newnham students, unlike Girtonians, were not obliged to adhere to the same examination conditions as the men. To follow the men's programme required passing the Previous Examination (or Little Go) in the first year, which tested Latin, mathematics and Greek, and sitting the tripos examination within three

years and one term. As Hertha complained to Barbara Bodichon about the 1879 tripos: 'Newnham has two students in, one has been up four years and hasn't taken her Little Go, so of course she will take the shine out of ours. I think it's horribly unfair ...'.⁷⁸

Women's concern to present themselves as humble and unexceptional can be interpreted as a strategy to counter hostility against them, hostility which increased in relation to women's success. Rita Tullberg suggests that it was only in the 1890s, when women were revealed to be as able as the men, that resentment against them competing with their male peers at Cambridge increased.⁷⁹ This bad feeling culminated in the infamous and overwhelming vote by University Members against giving women degrees in 1897. It is also reflected in the differing accounts of Philippa Fawcett's 1890 success. Unlike the celebration which is the hallmark of reports in the women's college magazines, memoirs written by male mathematicians tend to represent her achievement as odd and treat it with amusement and indulgence. Her coach, Ernest Hobson, is remembered in an obituary as having 'enjoyed one theatrical triumph' by having the female senior wrangler as one of his pupils.⁸⁰ A later account by Grace's son, possibly coloured by loyalty to his mother, recalls that this 'daughter of a radical economist and of a most militant feminist ... achieved unique fame in the annals of feminism' and 'ruined the life' of Bennett and his coach.⁸¹ This sceptical indulgence of women's intellectual ambitions would have been recognised by Charlotte Angas Scott; she wrote the following words in 1898 to her principal at Bryn Mawr in the States, but she may well have been reflecting on her Cambridge experiences too:

I am most disturbed and disappointed at present to find you taking the position that intellectual pursuits must be 'watered down' to make them suitable for women ... I do not expect any of the other members of the faculty to feel this way about it; they, like (nearly) all men that I have known, doubtless take an attitude of toleration, half amused and half kindly, on the whole question; for even where men are willing to help in women's education, it is with an inward reserve of condescension.⁸²

The competitive mental exertions required of male students by their coaches was accompanied by a harsh regime of physical drill; both were believed necessary to produce what Warwick has identified as the manly ideal of the elite mathematics student in whom the rational mind and strong body were perfectly combined.⁸³ Although this ideal

was losing some of its influence by the 1880s and 1890s, hard work, competition and regular physical exercise were still felt important to achieving top mathematical honours. However, for women these prescriptions were problematic and clashed with contemporary notions of femininity which accepted that women's bodies and minds were not as robust as men's. When Henry Maudsley warned about the threat posed to women's well-being by hard intellectual toil, Dr. Elizabeth Garrett Anderson in reply did not deny that nervous breakdowns and ill health were genuine problems; instead she argued that they were caused by a *lack* of mental stimulation, not too much. She then reassured that steps were being taken by educational reformers to guard against these problems and develop girls physically, by which she meant that controlled study was complemented by a programme of exercise.⁸⁴ However, whereas strenuous physical exercise was deemed desirable for male mathematicians to prepare *for* the strain of the tripos, women took gentle physical exercise to guard *against* strain. At first they took up gymnastics because it was thought that this would build up their delicate frames for study. Athleticism increased towards the end of the century, but women were still obliged to show restraint and conform at all times to 'ladylike' behaviour.⁸⁵ New activities such as hockey, golf and tennis were taken up with enthusiasm by students at the women's colleges, and it is significant that these were mostly 'domesticated' games which substituted rules, team work and co-operation for the aggressive individualism of running or rowing. Tennis was played by Hertha and Grace, and they both participated in drills of the Girton Fire Brigade – 'the first really masculine piece of organisation devised by Girtonians'.⁸⁶ Girton had a golf course in the 1880s; in the 1890s hockey was played, but only sedately, in full dress, away from male eyes.

At the end of the nineteenth century, sport was still overwhelmingly a symbol of masculinity; it was seen as an arena in which to develop courage and competitive instinct, both essential for success in the tripos. However, for male candidates physical failure in the face of the examination could also be interpreted as a sign of asceticism, abstraction and increased intellectuality. Warwick has written of 'funking fits' (collapses in the examination room) and notes that as early as mid-century being pale and ill could be a sign of intellectual strength.⁸⁷ Moreover, the 'genius' of leading scientific and mathematical figures of the late nineteenth and early twentieth centuries was often contextualised by contemporaries in similar ways. Rayleigh recalled that J.J. Thomson could not stand up to the day after day physical strain of

the tripos⁸⁸ and G.H. Hardy remembers missing out on showing his talent for sport at school as 'no one thought it worth looking for in the school's top scholar, so frail and sickly, so defensively shy'.⁸⁹ It is suggestive of the power of gender stereotypes that failure to stand up to the rigours of the tripos or competitive sport could be interpreted as a sign of intellectual strength among male mathematicians, while for women a purported lack of physical stamina was interpreted as symbolic of precisely the opposite. Both Hertha and Grace experienced bouts of ill health and headaches while students; by the end of the nineteenth century women were constantly defined by their reproductive bodies and for university women, singled out for their minds, there was a special tension that conflicted the requirements of rationality and femininity. Grace experienced this tension acutely, believing that she had 'had a certain career in the University world, and have managed to be one of the few women who do so without sacrificing health'.⁹⁰

Gendered notions of success

Just as a failure of nerve or health was interpreted differently according to whether it was manifested by a man or a woman, so success in the tripos became associated with different, gendered explanations. As women became increasingly visible by winning high places on the order of merit, wrangler status became linked to a student's capacity for hard work but lack of originality; conversely, failure of men to achieve a top place could be rationalised away as indicative of mathematical creativity and a marked potential for research.⁹¹ Similarly, originality in a mathematician was underscored by stressing that he 'never gave a thought to the tripos'.⁹² The examination itself, with its requirement for wide knowledge, speedy problem solving and the memorisation of formulae and model answers, became indicative of hard work and dull minds – a characterisation particularly aimed at women. This criticism became more endemic after the introduction of the specialist mathematics extension examination (part III, later to become part II) in the early 1880s which, for the first time, allowed students to choose a narrow area to study in depth.

The idea that women were 'faithful followers', 'diligent' and 'paid meticulous attention to details' but were 'not capable of great creative work' had been a well-rehearsed argument since the 1870s.⁹³ This commonly-held assumption that women worked harder than the men to achieve their results, making 'the air' at the women's colleges 'tense',

reflects this characterisation of women as conscientious but not original.⁹⁴ A testimonial for Sara Burstall, in support of her application to teach mathematics at Manchester High School for Girls, exhibits a similar subtext in its praise of her ‘unwearying power of work ... industry, intelligence and enthusiasm’.⁹⁵ Such views were summed-up succinctly by William Henry Young (later husband of Grace Chisholm) when he argued in a 1913 critique of late nineteenth century Cambridge that the fact that a woman (Fawcett) had already succeeded in beating the senior wrangler had destroyed the prestige of this award and contributed to the abolition of the competitive merit system.⁹⁶

That some women did well in the mathematics tripos, then, helped to devalue the examination rather than to raise the reputation of the women themselves; candidates from Girton and Newnham were understood to have done well due to their diligence, but this did not imply women were capable of original work. To use a modern term, women’s success indicated that the tripos had been ‘dumbed-down’. In her later years, even Girton wrangler Grace came to find the faults of the tripos ‘repulsive’ and, revealing a hint of resentment, wrote that ‘if you do well at exams then you are not original ... Philippa Fawcett was not, who she beat, Geoffrey Bennett, was ... curiosity about unscheduled mathematics is depravity’.⁹⁷

These conflicting views on the merits of the tripos need to be understood within the context of wider debates about the reform of Cambridge mathematics which will be explored in Chapter 6. However, concern about the worth of the tripos examination system had antecedents from early in the century when the ‘objective’ ranking of mathematics students was facilitated by Charles Babbage’s and John Herschel’s introduction of symbolic analysis to Cambridge. This was a technique which attempted to industrialise the thinking process by reducing mathematics to skill in manipulating abstract algebraic notation.⁹⁸ While this conception of mathematical intelligence had the potential to democratise thinking by making it a skill that could be acquired, its opponents referred back to a more romantic view of intelligence as a special gift that was inherited, not learned. Although critics, such as William Whewell,⁹⁹ affirmed that mathematics should be applied to the world, they feared that abstract ‘analytics’ was trying to distort that world by forcing it to conform to a mistaken and confining structure which did away with any notion of inspiration or the divine. The arguments over the tripos at the end of century paralleled these earlier debates and also marked the beginning of an inversion of the issues that created antagonism between pure mathematics and applied, con-

structuring each in opposition to the other. It will be argued in Chapter 2 that the association of romanticism with abstract mathematics was a late nineteenth century phenomenon which inverted earlier hierarchies. When a new style of continental analysis was introduced to Cambridge around 1900, its supporters derived this new mathematics' legitimacy and moral currency from its irrelevance to the real world and from the fact that, like Art, it was the product of 'great minds'. Like Whewell before them, pure mathematicians warned that mathematics pursued solely for utility's sake, not for its own, devalues the practitioner and leads to social decay.

A wider context: Oxford and London

Cambridge's unique place in the history of mathematics, especially with reference to its mathematical women, is put into sharp relief by an assessment of the situation at the Universities of Oxford and London.

Oxford University had been less receptive than Cambridge to the idea of women's colleges. According to Janet Howarth, supporters of women's education in Oxford did not seek the role of pioneers and by the time that Somerville and Lady Margaret Hall opened in 1879, with twelve and nine students respectively, over 300 women had already passed through Girton and Newnham colleges.¹⁰⁰ Although Somerville and Lady Margaret Hall were joined by St. Hugh's in 1886 and St. Hilda's in 1893, the number of women students at the Oxford colleges remained small compared to those at Cambridge. This slighter presence was reflected in the lack of formal connections between the women's colleges and the University. Whereas Cambridge had opened mathematics and other examinations (although not degrees) to women on an official basis in the early 1880s, the Oxford halls for women remained independent and unrecognised until 1910. Although women were allowed to sit some examinations from 1884, including mathematics, the University was careful to distance itself from any seeming public endorsement. Technically, the Oxford women were still examined by the 'Delegacy of Local Examinations' which had merely been granted the right to make use of undergraduate examination papers.¹⁰¹

For ambitious mathematicians of either sex however, Oxford was not the first choice for study. The University had an especially strong reputation for classics and the humanities and its mathematics school suffered in the shadows; neither could it compete with the towering reputation of the Cambridge mathematics tripos. The most popular subject for women

at Oxford was Modern History, followed by English and Modern Languages, with natural sciences and mathematics proving least popular. Whereas women at Girton were steered towards mathematics, at Oxford the situation was reversed. 'Not mathematics, you simply can't come to Oxford and do mathematics' was the exclamation made by Miss Wordsworth of Lady Margaret Hall to one of her new students.¹⁰² Even at Somerville, named for the mathematician Mary Somerville, the situation for ambitious mathematicians was hardly better. It was reported in 1881 that the mathematics students were 'in a terrible commotion' because they were being taught by a professor who was 'lazy, lacks sense, and has no interest in the girls' work'.¹⁰³ The lack of status of mathematics at Somerville at this time is also suggested by the experience of Margery Fry who was appointed librarian in 1899 and found herself 'entrusted with a range of tasks from marking hand-towels to coaching in mathematics'.¹⁰⁴ Indeed, figures suggest that in the years 1881–1913 just a handful of Oxford women were successful in examinations of the honours school of mathematics (a comparative figure for Cambridge is 480 women between 1882–1914).¹⁰⁵ However between 1891–1909 many women from Royal Holloway College were successful in the mathematical honours examinations of the University of Oxford, as discussed below. At Oxford itself however, there was not a strong mathematical culture around turn-of-century and this translated into limited opportunity and encouragement for mathematical women.

The University of London is usually credited as the first institution to open its degrees to both sexes on an equal basis (except for medicine) in 1878, but as Carol Dyhouse would caution, the 'pattern of women's admission is complex, and much depends on definitions'.¹⁰⁶ London's evolution was very different to that of its ancient counterparts; it was formed in 1836 as an examining body (offering services predominantly to students of University College and King's College London) and because of this imposed no residential requirement on candidates presenting themselves for examination. This not only benefited women wishing to study independently at home, it also became a route for 'graduates' of Cambridge and Oxford to gain the formal degree qualification denied them by their former institutions, including some women mathematicians.¹⁰⁷ After 1898 the University became a federal 'Teaching University' and began offering courses in its constituent colleges. In 1907 University College London (which in 1878 had also opened degree programmes in the Faculties of Sciences, Arts and Laws to women) ceased to have a separate existence and was incorporated into the University of London. Prior to this, in the years 1898–1900,

women's colleges in London and Surrey had been incorporated. The latter comprised Bedford College (established 1849), Westfield (established 1882), Royal Holloway (founded 1879 and opened by Queen Victoria in 1886) and King's College which had offered a 'Ladies' Department' since 1885. However this expanded University of London still retained its role as an examining body and distinguished between 'external' candidates and 'internal' ones drawn from its own colleges or schools. Just a handful of women graduated in the early years, however by 1900 there were 169 women awarded degrees, representing over 30% of the total.¹⁰⁸ The first women mathematicians to graduate were Sophie Bryant (1881) and Charlotte Angas Scott (1882), who sat the examination after her tripos success and, three years later, became the second woman to be awarded a DSc from London.¹⁰⁹ By end of century there had been only eight female mathematics graduates, but by 1914 eighty-six women mathematicians can be identified, plus two women MAs.¹¹⁰

The University of London's constituent colleges had a longer history in providing courses and research. At UCL the physical and natural sciences had been dominant since the early days and this continued into the twentieth century, with a scattering of women graduating in subjects such as botany and zoology. (Karl Pearson, following in the footsteps of Francis Galton, set up Biometrics and Eugenics Laboratories at UCL in 1903 and 1907 respectively and employed a handful of women mathematicians as researchers and statisticians, as referenced in Chapter 6). Although UCL had some eminent mathematicians as professors in its early days, including Augustus De Morgan who tutored Ada Lovelace as a private pupil, mathematics was not a popular subject for either sex in the first years of the new century.¹¹¹ Elizabeth Larby Williams entered Bedford College in 1911 and remembered that mathematics was not a subject studied by many and in order to provide a sufficiently large audience 'there was a combined programme of lectures for students from Bedford, Kings, University and Westfield colleges. Even so the class was barely twenty strong. Yet there was almost as many women as men.'¹¹²

However a strong culture of women's mathematics prior to 1914 can be identified at Royal Holloway College which produced over forty women graduates of the University of London between 1903 and 1913.¹¹³ In addition, up to 1909, seventeen women were successful in the Final Honours examination of the Oxford School of Mathematics, with many others passing mathematical 'moderations' (intermediate examinations).¹¹⁴ This flowering may have been due to the influence of Ethel Maude Rowell

who had been an outstanding student at Royal Holloway and went on to teach there from 1899 to 1939, and to other enthusiastic women mathematicians who joined her at various times on the staff. It was also encouraged by Royal Holloway's 'Founders Scholarships' (in 1892 for example, four of these were awarded in mathematics while two were awarded for other subjects) and by annual prizes for both pure and mixed/applied mathematics. Rowell (d. 1951) was a veritable institution at Royal Holloway, having been intimately connected with the College for over forty years. She was a philosopher and poet as well as a mathematician and had been introduced as a child to mental exercise and logical thinking by the Rev. Charles Dodgson (Lewis Carroll). She remembered him objecting to her plans to study at Royal Holloway for the final honours examination in mathematics at Oxford because 'the work was far too exacting and would impose a strain which may even upset my mental balance!'.¹¹⁵ Fortunately, this did not deter the young Ethel.

Conclusion

An exploration of the culture of mathematics at Cambridge in the decades around 1900 illustrates that gender was a key determinant in the training provided for students of the mathematics tripos. Although an affinity between mathematics and femininity can be detected towards the end of the nineteenth century, it is clear that studying for the mathematics tripos was a very different experience for women than for men. Not only did the type and quality of coaching given to female students differ from that provided for their male counterparts, but the gendered meanings that became attached to women achieving a high place on the pass list resulted in this 'feminine' success being effectively devalued. This, in turn, had a reciprocal effect on the status of the tripos itself. Towards the end of century, the examination lost much of its prestige and reputation as an elite qualification due (in part) to an increasing recognition that women were able to compete successfully alongside the men and, in some cases, surpass even the best of them.

The culture at Girton among students studying for the mathematics tripos was informed by a pattern of tensions and attitudes that helped set the course for Grace's and Hertha's future careers. Grace's repudiation of tripos competition was key to her later espousal of elitist ideas concerning the male intellect; it also informed her decision to put her mathematical skill at the service of her husband and her belief in the absolute superiority of pure over practical mathematics. Hertha's

experiences at Girton a decade earlier were more problematic; her love of experimentation and practical science did not make for an easy life at college at a time when the mathematics tripos, which had little experimental content at the time, was privileged above all others. Grace can be seen as representing the romantic traditions now attached to pure mathematics conceived as an abstract enterprise for gifted individuals; Hertha embraced the newer sciences, such as electrical engineering, which promised new opportunities as they began to challenge older hierarchies and made use of a practical, utilitarian and 'manly' mathematics. These hierarchies also intersected with notions of class: in a culture and educational context in which 'hand' and 'brain' had long been opposed, practitioners of engineering and the more practical sciences sought to raise the status of their professions and challenge the assumptions of superiority of the pure mathematicians.

Hertha's choice of the practical, and Grace's championing of the pure, may have been influenced by their very different backgrounds. It could be argued that Hertha, as daughter of a Jewish-émigré watchmaker, would have acquired none of the prejudice against practical or manual labour that was one of the defining features of the educated, English middle class. The differences in the culture, material practices and gendering of pure mathematics and the practical sciences become more evident as we follow, in the succeeding two chapters, Grace to the 'Shrine of Pure Thought' in Göttingen and Hertha to Finsbury Technical College and the Central Institution at South Kensington. Despite their differences in outlook and choice, both women found themselves caged in by prescriptions of femininity which limited their participation within their chosen disciplines and affected their options, reputations and scientific credibility.

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