“A Woman can win the victory, though she may not wear the wreath”

Women and mathematics in late 19th century Cambridge

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Outline of talk

• A brief history of the Cambridge Mathematical Tripos

• Striving for equality: the struggle for women to obtain degrees

• Three 19\textsuperscript{th} century mathematics students
  • Charlotte Scott (1858–1931)
  • Philippa Fawcett (1868–1948)
  • Grace Chisholm (1868–1944)
The Mathematical Tripos

Originally the examination was officially known as the Senate House Examination.

The name Mathematical Tripos dates from 1824, although for more than 30 years the name Senate House Examination continued to be printed as a heading to the papers set.

**Tripos**

15th C  a three-legged stool
16th C  a man → a speech → a set of humorous verses
18th C  a sheet of paper → a list of names → a system of examination

[In 1824 the first Classical Tripos examination took place; until 1850 only those who had already passed the mathematical examination being admissible as candidates.]

**Wrangler**

Student placed in the first class of the Mathematical Tripos

The term was used in the printed lists of results from 1753
History of the Mathematical Tripos Examination

- c.1725  Senate House [oral] Examination
- 1747  
  - Order of merit lists printed and distributed.
- by 1750  One day [oral] examination recognised by University.
- 1753  
  - First class divided into wranglers and senior optimes.
- By 1772  Three day examination. Some questions dictated, answers to be written.
- 1779  System of ‘brackets’ introduced.
- c.1790  Problem papers printed.
- 1808  
- 1827-28  
  - 23 hrs of examination: 16 bookwork, 7 problems. All papers printed.
- 1832-33  
  - 27½ hrs of examination: 20 bookwork, 7½ problems.
- 1838-39  
  - 33 hrs of examination: 24½ bookwork, 8½ problems.

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- 1848  Board of Mathematical Studies constituted.
- 1848  
  - 44½ hrs of examination (over 8 days): 32½ bookwork, 12 problems.
- 1873  
  - Reform to increase number of topics of study.
- 1878  
  - Revisions to compensate for errors in 1873 reform.
- 1882  
  - Examination in three parts, Part III open only to wranglers.
- 1886  
  - Examination in two parts, Part II open only to wranglers.
- 1907  
  - Order of merit abolished.
The two types of Tripos question

**Bookwork**  Required students to write out standard definitions, laws, proofs, and theorems from memory.

Sometimes followed by a ‘rider’ – a simple problem requiring application of the bookwork.

**Problem**  More difficult, provided the more severe test of student’s ability, and, from c.1800, effectively determined his place in the order of merit.

“Tricks to shew the stretch of human brain
Mere curious pleasure, or ingenious pain.”

ALEXANDER POPE, *Essay on Man*
Wolstenholme’s *Mathematical Problems* (1867; 1878)

**Joseph Wolstenholme** (1829-1891)

3rd wrangler, 1850

**Tripods examiner:** 1854-1874 seven times

The first and second editions contained 1,628 and 2,815 problems respectively.

**Example Mathematical Problem:**

1991. Prove the following equation for Bernoulli’s numbers:

\[
\left(\frac{z}{e^z - 1}\right) = 1 - \frac{z}{2} + B_1 \frac{z^2}{2} - B_2 \frac{z^3}{3} + \ldots
\]

\[
\frac{1}{z} = nB_1 - \frac{n(n-1)(n-2)}{3} B_3 + \frac{n(n-1)(n-2)(n-3)(n-4)}{5} B_5 - \ldots
\]

up to \(\frac{n-1}{2}\) terms, where \(n\) is an odd integer. The equation will still be true when \(n\) is an even integer if we multiply the last term by \(\frac{n+1}{n}\), \(\frac{n}{2}\) being then the number of terms.

1992. Two equal circles have radii \(2a\), and the distance between their centres is \(4a\), a series of circles is drawn, each touching the previous one of the series and touching the two given circles symmetrically: prove that the radius of the \(n^{th}\) of such a series is

\[
e \sin^2 a + \sin (n \alpha + \beta) \sin (\frac{n-1}{2} a + \beta),
\]

where \(\alpha = e \cos a\). Deduce from this the result when \(e = a\),

\[
a + (n+\lambda)(n+\lambda-1);
\]

and the result when \(e < a\).

\[\text{If } e = 2a + (p + p^{-1}), \text{ the } n^{th} \text{ radius is } \frac{4 (a^n - e^n)}{(bp^n - b'p^{-n}) (bp^{n+1} - b'p^{-n+1})}, \]

where \(bb' = e'\).
It will be useful to give here a brief statement [7pp] of the process of the solution of equations by the method of least squares, and then to work out the above question as an example.
Lectures

- **College lectures**
  - Lecturers: e.g. I Todhunter (1849-78); E Routh (1855-1904); H Lamb (1872-75); J Larmor (1885-1903); HF Baker (1890-1914)

- **Inter-collegiate lectures** (from 1868)
  - Informal system; students paid small fee
  - Lecturers were young College fellows teaching advanced topics

- **University lectures** (from 1884)
  - Lecturers (first appointees): JJ Thomson; AR Forsyth; RT Glazebrook; EW Hobson

[Professors’ lectures]

- 1860-62: Hydrostatics, pneumatics, & optics or optics with special reference to physical theory of light (*Stokes*); practical astronomy (*Challis*); lunar theory (*Adams*)

- 1863: as above +
  - Analytical geometry – history & theory from Descartes to Cramer (*Cayley*)
**William Hopkins (1793–1866)**

7th wrangler (1827) (aged 33)

1828-1849 trained 108 (c.50%) of the top 10 wranglers, including 44 in first three, of whom 17 were senior wranglers.

*Students:* Cayley, Thomson, Todhunter, Tait, Maxwell, ...

**Edward Routh (1831–1907)**

Senior wrangler (1854)

1862-1888 trained almost 50% of the 990 wranglers, including 26 senior wranglers.

*Students:* Strutt (Lord Rayleigh), Lamb, Hobson, Pearson, Larmor, Thomson, Forsyth, ...

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Routh and his pupils for the Mathematical Tripos of 1880
The first women’s colleges

**GIRTON**

1869 A college for women opens in Hitchin, about 30 miles from Cambridge. In 1873 this transfers to new buildings in Girton, on the edge of Cambridge.

1873 Girton College opens.

**NEWNHAM**

1870 Lectures for ladies begin in Cambridge, organised by a committee. In 1871 a house in which women students could live under supervision while attending the lectures was rented. This became Newnham College and was replaced by a purpose-built building at Newnham in 1875.
Women’s first successes in the Tripos

1880 Charlotte Scott declared equal to the 8th wrangler in the Mathematical Tripos.

1881 Women gain the right to take the Tripos examinations, and are offered University certificates if they pass.

1887 Agnata Frances Ramsay of Girton College heads the list in the Classical Tripos.

1890 Philippa Fawcett of Newnham College heads the list in the Mathematical Tripos.
1897 Graces proposing to give women the titles of degrees are defeated.
Women finally achieve equality

1921  Women are given the titles of degrees but no associated privileges (i.e. no participation in University government). Women undergraduates are given the right to attend University lectures.

1926  The first women University Teaching Officers are appointed.

1947  6 December - Full membership for women is granted with no contrary votes.

1948  21 October - Her Majesty The Queen (the late Queen Mother) becomes the first woman to receive a degree in the Senate-House. Other women follow in November.
Women and the Mathematical Tripos in the 19th century

1880  Charlotte Scott (= to 8th wrangler)
1881  Women allowed to be ranked with men
1882  Women listed (separately) on the Tripos lists
1884  First woman (Perrin of Girton) to pass Part III
1887  First woman (Frost of Newnham) to pass Part II
1890  Philippa Fawcett above Senior Wrangler
1891  Philippa Fawcett  Class I (Div 1), Part II
1892  Grace Chisholm (23rd/24th wrangler); Isobel Maddison (= to 27th wrangler)

“The Woman of the Future! She'll be deeply read, that's certain, With all the education gained at Newnham or at Girton; She'll puzzle men in Algebra with horrible quadratics, Dynamics and the mysteries of higher mathematics.”

*Punch*, 10 May 1884
The class of 1880

1. Joseph Larmor
   (Lucasian Professor 1903–1932)

2. JJ Thomson
   (Cavendish Professor of Physics 1884–1918; Nobel Prize 1906)

3. WB Allcock
   (Physician to St Thomas’s Hospital)

= 8 Charlotte Scott

102 male students sat the examination
Celebrations welcoming Joseph Larmor home to Belfast after his success in becoming senior wrangler in 1880
30 January 1880 (2nd edition); 31 January 1880
List of wranglers – no mention of Charlotte Scott

31 January 1880
Short paragraph about success of one (unnamed) Girton student

2 February 1880
Article about success of four (named) Girton students.

3 February 1880
Letter from Charlotte Scott’s mother

4 February 1880
Leading article about Charlotte Scott and the pros and cons of women studying for the Tripos
“Charlotte Angus Scott (born 1858) is the daughter of the Rev. Principal Scott of Lancashire Independent College, Manchester. From her earliest childhood she has given evidence of unusual mathematical ability. Until her entrance at Girton, three years ago, her education had been carried on almost entirely in her own home. Her tutor at Cambridge was Mr. Temperley of Queens’, until last summer, when he was appointed Moderator. Mr. Routh was then applied to, but on account of his numerous engagements, was unwillingly obliged to decline. For the last three months she has read with Mr. Walker of Queens’.”
“Miss Scott has answered papers set for the mathematical tripos in a manner which would have brought her high on the list of Wranglers, an achievement of no common kind. ... We hope that the ability which the new system brings out and fosters in women, will not be of a kind to give to those who possess it a character for deficiency in feminine gentleness. We do not believe that it will be so. But even in the rare cases where it is so, the world should remember that there have always been women of the masculine type—only that they have hitherto lacked the means of proving what they could do, though possessing amply the means of proving what they could not be.”
1880–1885
Attended Cayley’s lectures

*Modern Algebra* *Abelian Functions*
*Theory of Numbers* *Theory of Substitutions*
*Theory of Seminvariants*

“His lectures differed strikingly from his memoirs in that the subject was presented in less synthetic style. It was a recognized fact that he lectured on what he himself was working out at the time, and consequently his class was privileged to obtain some insight into the workings of his mind.”

1882–1885
Lecturer at Girton College

1882  London University BSc
1885  London University DSc

Arthur Cayley
*(1821–1895)*
Sadleirian Professor 1863–1895
President of Newnham College
1880–1890

Charlotte Scott: after the Tripos
"[Scott] has taught for four years at Girton College with marked success ... Professor Cayley gives her a high recommendation for her attainments and her capacity for original work. [The] Mistress of Girton College testifies to C.A.Scott's popularity as a teacher, her success in organising the mathematical department of the College, and her personal courtesy and friendliness to students. . . With these admirable qualifications, C.A.Scott has two defects, – she is decidedly hard of hearing and is in delicate health."
1894

Had *Plane Analytical Geometry* required references, Scott wrote, “it would have been alike my duty and my pleasure to write on every page the name of Professor Cayley.”

**Student song**

S is for Scott
Superior Scott
She is kind in the main
If you have any brain
But if you have not
Superior Scott!

1909 Appointed as the College’s first full professor
Supervised 7 PhD students

*American Mathematical Society*
Founder Member
Vice President 1905–1906

*American Journal of Mathematics*
Co-editor, 1899–1926

1907
“[She] was a geometer who whenever possible brought to analytical geometry the full resources of pure geometrical reasoning. She was also an enthusiastic searcher and propounder of new ideas and an interpreter of the work of others . . . . Her rank as a writer was of the highest and all of her writing was singularly clear and attractive. . . . A favourite topic of Miss Scott's was higher singularities, on which she wrote several papers.”

Macaulay felt he was “exceptionally fortunate” to have his work “so clearly described and explained” by Charlotte Scott
The class of 1890

“Above the Senior Wrangler” Philippa Fawcett

Senior Wrangler G.F. Bennett
(Fellow of Emmanuel College, 1899–1943)

Second Wrangler H.W. Segar
(Professor of Mathematics, University College, Auckland, 1894–1934)
7 June 1890

“The list of the Cambridge Mathematical Tripos was published this morning. The sensation of it is the extraordinary triumph of Miss Philippa Fawcett whose place was adjudged “above the Senior Wrangler,” thus capping the success in classics of Miss Ramsey three years ago.”
“After one term under that veteran among mathematical teachers, Dr Routh, and some instruction from Mr Atkinson of Trinity Hall, she has been coached by Mr EW Hobson. Miss Fawcett has not, therefore, enjoyed the assistance of the gentleman who is now, in succession to Dr Routh, the recognised turner-out of all high Wranglers – Mr R Webb. It was generally said that Mr Webb had no sort of prejudice against teaching lady mathematicians, and would gladly have included Miss Fawcett among the budding wranglers who occupy his day; but that he apprehended some embarrassment from the presence of a lady in the atmosphere of freely-expressed criticism which is a well-recognized part of his educational method.”
9 June 1890

“The strife of Wranglers is a grapple of intellectual thew and sinew, and the Tripos list registers sheer mental strength and staying power of the candidates with the exactitude of a superior try-your-strength machine. “No” it was often said, “at any rate, a woman will never be Senior Wrangler.” … A woman, indeed, cannot be Senior Wrangler, there they are right; for that is a title which the university reserves for candidates who fulfil an additional qualification of sex. But a woman can win the victory, though she may not wear the wreath; and the magnificent achievement of Miss PHILIPPA FAWCETT stands out only the more clearly in the phrase which places her “above the Senior Wrangler.””
“Hail the triumph of the corset, 
Hail the fair Philippa Fawcett, 
Victress in the fray 
Crown her queen of hydrostatics 
And the other mathematics 
Wreathe her brow in bay.”

... 
May she increase in knowledge daily 
Till the great Professor Cayley 
Owns himself surpassed 
Till the great Professor Salmon 
Votes his own achievements gammon 
And admires aghast.”
Philippa Fawcett: after the Tripos

1891  First Division, First Class.  Tripos Part II.

1893  “Note on the Motion of Solids in a Liquid”,  
       Quarterly J. Pure & Applied Maths

1894  Mathematics Lecturer, Newnham College

1902  Training teachers, Johannesburg, South Africa

1905  Principal assistant to Director of Education,  
       London County Council

1920  Assistant Education Officer (Higher Education)  
       London County Council

Newnham College hockey team, 1891
Grace Chisholm on the state of Cambridge mathematics in 1889 (from her Reminiscences)

“Mathematical science had reached the acme of perfection. Through the long future ages, no new ideas, no new methods, no new subjects were to appear. The edifice of mathematical science was complete, roof on and everything. All that remained to be done was to consolidate and repair the masonry, and add to and correct the ornamentation.

This was the view in those days, and the atmosphere was stifling to the young mathematician. Cayley, unconscious himself of the effect he was having on his entourage, sat, like a figure of Buddha on its pedestal, dead-weight on the mathematical school of Cambridge.”

• Home educated
• Entered Girton with a scholarship in 1889

Girton coaches
Arthur Berry  senior wrangler, 1885
William Young  4th wrangler, 1884
“I was talking about polyacra,” said Professor Cayley. It was the beginning of a flow of words. Grace’s pen flew over the paper. Polyhedra with vertices constantly springing from triangular faces, like crystals growing in a solution, trees with branches forking in all directions succeeded one another without intermission, twining this way and that round the professorial head, or emerging from under his flapping sleeves as he stood with his back to the listeners chalking and talking at the same time at the blackboard. The lecture came to an end as suddenly as it had begun.”
Letter from Grace to the Girton Mathematical Club, 1894

“There are lectures given here by University professors outside the University itself to women, and there are about thirty women who go to these lectures; naturally some of these would like to be admitted to the University and allowed to go to any lectures they please. In a German University there is none of that organization of colleges, and tutors, and coaches, and examinations which makes it easy at Cambridge to systematize and control the studies of the students, and this makes the question of the admission of women here one of much greater difficulty than the corresponding one at home. Prof. Klein’s attitude is this, he will not countenance the admission of any woman who has not already done good work, and can bring him proof of the same in the form of degrees or their equivalent, or letters from professors of standing; and, further, he will not take any steps till he has assured himself by a personal interview of the solidity of her claims. Prof. Klein’s view is moderate. There are members of the Faculty here who are more eagerly in favour of the admission of women, and others who disapprove altogether.”
Grace Chisholm writes home, 1895

“[Klein] is certainly one of the most sterling people, he never shirks trouble and responsibility. He says it is his opinion that the admission to the examination and doctorate is a matter only for the consideration of the Faculty. Nothing is said in the charter about the recipients being men, simply because such a thing was never dreamt of; but it is possible that it may be necessary to apply to the Government.

Oh! Glory! how I wish the rich people in England cared more about education, in America they would simply jump upon me with their Fellowships to enable me to stay and feel free and not be a burden!”

1895 PhD  The algebraic groups of spherical trigonometry
“A Mathematical Union”

- 1896 Marriage to William Young
- In 25 years they published between them three books and over 250 papers

Letter from William to Grace, c.1900

“I hope you enjoy this working for me. On the whole I think it is, at present at any rate, quite as it should be, seeing that we are responsible only to ourselves as to division of laurels. The work is not of a character to cause conflicting claims. I am very happy that you are getting on with the ideas. I feel partly as if I were teaching you, and setting you problems which I could not quite do myself but could enable you to. Then again I think of myself as like Klein, furnishing the steam required - the initiative, the guidance. But I feel confident too that we are rising together to new heights. You do need a good deal of criticism when you are at your best, and in your best working vein. The fact is that our papers ought to be published under our joint names, but if this were done neither of us get the benefit of it. No. Mine the laurels now and the knowledge. Yours the knowledge only.

Everything under my name now, and later when the loaves and fishes are no more procurable in that way, everything or much under your name.”

William Young (1863–1942)
Grace Chisholm Young: “a true pioneer”

1897  Birth of first child; move to Göttingen

[Age 35 William begins research]

1906  The Theory of Sets of Points co-authored with William

1908  Birth of sixth (last) child; move to Geneva

1914  Begins publishing in theory of real functions

“If we accept the view of Hobson's career as a pure mathematician drawn by Hardy that his interest in the modern theory of functions was largely due to his intercourse with W. H. Young, and that the present position of real function theory at Cambridge is very largely due to Hobson, then it all began with the Youngs’ move from Cambridge to Göttingen. No doubt the ideas of real function theory would have found a place in the Cambridge Tripos sooner or later; but perhaps never such an important place if Mrs. Young had not pushed her way into Göttingen.”

Mary Cartwright 1944
Some Questions

• To what extent was the Cambridge Mathematical Tripos good preparation for a career in mathematics for men/women in the 19\textsuperscript{th} century?

• What factors enabled these particular women to succeed:
  In the Mathematical Tripos? As mathematicians?

• What can studying these women tell us about women and mathematics in 19\textsuperscript{th} century British society?