Calculating Machines, Calculting Women:
Redesigning astronomical and scientific computation in Britain, 1925-1946

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In 1943, *The Mathematical Gazette*, the journal of the British Mathematical Association, published a request, under the headline "Careers for Girls," for ideas about employment of young women with mathematical abilities and a Sixth Form education.[1] The goal was to put together a list of ideas to be published in the *Gazette*, a journal largely devoted to methods of teaching mathematics. The only response to appear in later editions was an article by Leslie John Comrie, founder and head of Scientific Computing Service Ltd. of London and a former superintendent of Her Majesty's Nautical Almanac Office, the British office devoted to production of nautical and astronomical ephemerides.

Comrie's July 1944 article, also carrying the headline "Careers for Girls," describes jobs in "mechanised scientific computing. I use the word mechanised rather than mechanical, because the latter may give the false impression of routine and drudgery, whereas the former correctly conveys the fact that mechanical aids are used to lighten the labour."[2] Here, Comrie gives a glimpse of his career-long passion: the application of calculating machines to scientific computing, and the development of efficient, centralized methods of doing the massive calculations needed to produce an almanac or a set of mathematical tables more accurately than earlier efforts. Comrie's achievement was to find ways to use calculating machines, such as the Hollerith punch-card tabulator—designed for business and the tabulation of census data—for the involved, multi-part calculations related to astronomical tables of the moon and other mathematical equations. He also developed computational methods designed for various types of calculating machine and published his methods widely. Herman Goldstine calls Comrie's application of commercial calculating machines for scientific work a "giant step forward" in the prehistory of the computer.[3]

While advocating the mechanization and centralization of scientific computing, Comrie also advocated hiring women for the jobs of running the machines and doing parts of the calculations that still had to be done by hand. Comrie's articles reveal that he believed in setting up computations so they could be done by workers with high-school-level mathematical skills and some additional training using unspecialized business machines. In this, he emphasized the creation of a calculating system rather than the individual skill or intelligence of his computers. I will argue that Comrie linked calculating machines and women operators to legitimize the use of these machines to the Admiralty and the scientific community. This link emphasized the "skill" of the machines by de-emphasizing the intelligence and skill of their operators. But Comrie did not make the next leap: to machine intelligence. Rather, he promoted the "intelligence" of a centralized system of humans and machines subordinate to a larger system of calculation. By emphasizing that the calculation work done by these machines could be done with female operators only if women, machines, and calculations were carefully managed, Comrie moved the locus of intelligence from workers to the system of the production of knowledge.[4] The legitimization of commercial machines for scientific calculation, as well as its centralization was a small, but crucial, step toward the development of "intelligent machines." It also was a step toward writing women out of computer history by devaluing the skills needed to do the calculations and run the machines, and by stressing that women would only be capable of doing the work with training and placement in a calculating system.

Astronomy and machines

Centuries before calculating machines were commonplace, the overwhelmingly repetitive and difficult calculations required to determine positions of stellar bodies, as well as to create mathematical tables, encouraged mathematicians and astronomers to seek mechanical help. Goldstine describes a computational device invented in the fifteenth century by al-Kashi, an astronomer in Samarkand, to simplify the calculation of the dates of lunar eclipses.[5] Four centuries later, Charles Babbage, industrial philosopher, forefather of modern computing, and a founder of the Astronomical Society of London, linked his ideas about machine intelligence to astronomy in an 1822 letter titled "On the Application of Machinery to the Purpose of Calculating and Printing Mathematical Tables":

> The intolerable labour and fatiguing monotony of a continued repetition of similar arithmetical calculations, first excited the desire, and afterwards suggested the idea, of a machine, which, by the aid of gravity or any other moving power, should become a substitute for one of the lowest operations of human intellect.[6]

Already by 1822, Babbage suggested that machine intelligence could substitute for some types of human intelligence. Simon Schaffer has argued that Babbage's work to mechanize intelligence fits with his industrial philosophies and with the heated debates of the 1830s over the ownership of the skills needed for production: "To make machines look intelligent it was necessary that the sources of their power, the labour force which surrounded and ran them, be rendered invisible."[7] One step toward making the workforce doing astronomical calculations invisible was to debase the work itself, to make it "one of the lowest operations of human intellect." A century later, Comrie performed a similar operation: By recreating the work of human computers as women's work, attaching to it the gendered stereotype that women's work requires patience but little skill, he enhanced the skills embedded in the machines and in the managers who designed calculations for machines.

Babbage's engines never did render the worker invisible because Babbage began imagining revisions before making his visions reality. He wore out the patience of several chancellors of the Exchequer and wore out his funding. In a 1946 article in the journal *Nature* titled "Babbage's Dream Comes True" Comrie called the government's failure to continue funding Babbage's machines a "black mark" that "cost Britain the leading place in the art of mechanical computing."[8]

Only a few copies of Babbage's difference engine were built and other calculating machines were considered too clumsy and unreliable to be widely used until the late-nineteenth century. Lorraine Daston argues that machine-aided calculation also lost favor in Victorian England because the attention to detail and repetition required by computers took on the flavor of duty and, therefore, became a test of will and moral character.[9] When Comrie entered the Nautical Almanac Office in 1925, the only calculating machine in use was a Burroughs Adding and Listing machine.[10]

Women and astronomy

The association of calculation with dull, repetitive labor had reasserted itself by the late nineteenth century.[11] With this association came women computers in, for example, the *bureaux de calculs* in France and in some astronomical observatories in the United States.[12] John Lankford and Rickey L. Slavings describe the rise of women workers in "factory observatories" starting in the 1880s as photographic and other techniques increased the workload.[13]

Women were hired to scan photographs of stellar phenomena, work that generally was considered repetitious, routine, and unskilled. Some American women also worked as computers in observatories and at the U.S. Nautical Almanac Office, but most of them had college degrees in astronomy and few other outlets for their education and skill. Maria Mitchell, one of America's earliest women astronomers, worked as a computer in the U.S. Nautical Almanac Office starting in 1849.[14]

Although the sex of computers working in H.M. Nautical Almanac Office at the time of Comrie's arrival is unknown,[15] he would have encountered women working in observatories during a three-year stay in the United States during which he taught astronomy and practical computing at Swarthmore College and Northwestern University.

Women and office work

The entrance of women into the clerical workforce in Britain paralleled similar developments in the United States in many ways, including the development of gendered stereotypes about office work and sexual divisions of labor. The clerical workforce in Britain began to shift from a middle-class, male-dominated, relatively educated workforce in the years after 1870 when Britain introduced compulsory education for all children.[16] As Lisa Fine explains in her history of clerical work in Chicago, the rise of industrial capitalism, including separations of production and management, increased the demand for clerical help.[17] Young, unmarried women also poured into Britain's clerical workforce as the nineteenth century came to a close because hundreds of thousands of men left the country to manage the affairs of empire.[18]

From the 1880s until World War I, the number of clerical jobs in Great Britain, and the percentage of women filling them, rose steadily. During World War I, women filled jobs traditionally held by men and, in a phenomenon that recurred in Britain and the United States after World War II, most were forced out of those jobs when the war ended. [19] As Jane Barker and Hazel Downing show, unlike industrial jobs, British women tended to remain in clerical jobs after World War I.[20]

Women and machines moved into offices together. Women were associated with the typewriter almost from its invention in the 1870s. And the great cost savings available to employers who hired women typists became evident soon after. The *Morning Post* of January 30, 1889, reported that the British Civil Service's Probate Office could reduce its cost of copying titles from 3,000 pounds per year when done by male workers to 300 pounds per year when done by women with typewriters.[21] Margery Davies explains that women were able to move into the role of typist because newly invented typewriters had not been "sex-typed" as machines to be run by men.[22] Barker and Downing, as well as Fine, describe how women demonstrated typewriters to potential buyers and how they were marketed to middle-class women as a tool they could easily learn to use, especially if they already had experience playing the piano.[23] An 1875 advertisement for typewriters that appeared in the *Nation* said: "And the benevolent can, by the gift of a "Type-Writer" to a poor, deserving young woman, put her at once in the way of earning a good living as a copyist or corresponding clerk."[24] American-made typewriters were distributed worldwide by 1882 and were quickly picked up in Britain.[25] By 1921, Britain had nearly 1.3 million employed clerks; nearly two-thirds of them were female.[26]

Somewhat more slowly, women also became associated with book-keeping and its attendant calculating machines. Sharon Hartman Strom describes how, in the United States, advertising campaigns during World War I urged companies to buy their calculating machines so women could keep up with book-keeping work left behind by men at war. [27] The Burroughs Adding and Listing machine, the same machine that Comrie found in the Nautical Almanac Office in the mid-1920s, was advertised in 1925 with the perky "Monroe girl": "the Monroe girl turns out more figure-work in a day's time, smoothly and pleasantly, without mental or physical effort. Any girl in your office can be a Monroe girl if you provide a Monroe Adding Calculator."[28]

In Britain the connection between women and machines also was strong by the 1920s. F. D. Klingender describes a 1921 edition of the *Bankers' Magazine* devoted to mechanization in which the magazine envisioned a future for banks divided into a routine section of women working with machines and a professional section handling management.[29]

Reasons for hiring women for clerical work included lower pay and the presumption that women would accept jobs with few or no opportunities for advancement.[30] The wage differences between men and women clerks in Britain is striking; in 1914, wages for male clerks averaged 143 pounds to 221 pounds per year, while the average for female clerks was just 39 pounds to 65 pounds per year.[31] Even within the tiered system that existed in the civil service, women received less pay than men in the same tiers and women faced a strict rule in the civil service against being allowed to continue working after marriage, a rule that was not changed until 1948.[32]

Some scholars have argued that the rise of industrial capitalism and scientific management after the turn of the century meant the creation of more jobs that were less skilled, a process known as "deskilling."[33] More recently, scholars have argued that the skills needed by workers in mechanized offices often changed, but this did not always mean that the levels of skill needed to do a job changed. However, when women entered these jobs, the perception of skill levels changed because women were doing them.[34] Rationalization and routinization of clerical jobs according to principles of scientific management occurred only after women entered the workforce, Fine argues.[35]

Thus, precedents existed for hiring women as computers and operators of calculating machines within astronomy, business, and the British civil service. But the structure of the Nautical Almanac Office as Comrie found it in 1925 suggests that the shift toward defining scientific computation as women's work was not as obvious as it might seem.

The Nautical Almanac Office

Comrie joined the Nautical Almanac Office as deputy superintendent in 1925. Born in 1893, he had served in the New Zealand Expeditionary Force in World War I. After the war, he did a doctorate in astronomy and computation at St. John's College, Cambridge, finishing in 1923.[36] By that time, he had achieved a reputation as an expert in computational astronomy and as a pushy innovator impatient with methods he considered inefficient.[37] W.M.H. Greaves, Comrie's brother-in-law and an astronomer himself, wrote in Comrie's obituary that while working on his doctorate, Comrie spent several months at the Royal Observatory in Greenwich, where he made his mark by telling Sir Frank Dyson, the Astronomer Royal, that he did not approve of the observatory's computational methods.[38] Greaves paints Comrie as fanatically devoted to improving methods of computation, including becoming an expert in typography to improve the presentation of nautical almanacs. He also says that Comrie's life-long pet project was the discovery of errors in existing mathematical and astronomical tables, some of which were corrected in tables printed in the late 1940s by his company, Scientific Computing Service.[39] Greaves also says that Comrie did not stop at using business machines for scientific calculation, but also redesigned the calculations to take advantage of the machines: "He was not content to apply commercial machines to astronomical computation; he developed powerful new methods for use with the machines, particularly in the field of interpolation and subtabulation."[40]

When Comrie entered the Nautical Almanac Office, he found a decentralized organization in which most computing work was done by a dozen highly trained "arithmeticians," most of them retired computers who worked outside the office.[41] Greaves says this organization could not have continued: "There were no facilities for training new staff, and there were immense difficulties in introducing new ideas into the almanacs and new methods of computation."[42] This organization also did not lend itself to mechanization because the weight and expense of the machines meant they were practical only in a centralized office. Comrie saw that the calculating work could be done by clerical workers with a high school education aided by commercial calculating machines.[43]

According to Greaves, the staff Comrie found at the office consisted of skilled computing professionals who had well-established computational skills of their own and needed little supervision to do their jobs.[44] And, as Comrie noted in a 1946 article, a wide variety of calculating machines existed with widely divergent capabilities. To apply these machines to scientific work, Comrie had to choose the right machine, sometimes retool it slightly, and often revise the methods of calculation needed to do the job: "The computer's art lies mainly in his ability to manipulate the problem and to apply ingenuity and low cunning in developing techniques that take advantage of the mechanical features of the machine."[45]

British computing historian Mary Croarken says that Comrie initially brought modern calculating machines into the Nautical Almanac Office and applied them to existing methods, but that by the late 1920s, he was creating numerical methods that allowed calculations to be carried out by machines and clerical workers in ways that reduced the office's workload.[46] Thus, Comrie ultimately changed the whole system of calculation, including workers, machines, calculations, and office organization. Comrie's organizational changes reduced the relative importance of the worker and increased the importance of machine, manager and system. He began to push for more changes in the office's management after his appointment as superintendent in 1930. This was when his troubles with the Admiralty really began, less because his superiors were uninterested in change than because they wanted to change to occur more slowly and with more deliberation than Comrie thought necessary.[47]

Among the visitors to the newly reorganized Nautical Almanac Office was Ernest W. Brown, compiler of *Brown's Tables of the Moon*. Brown, a Harvard professor, took back to the United States, and ultimately to IBM, the idea of using punch-card machines for scientific calculations.[48] Comrie describes this visit: "He had done a great deal of this synthesis himself by hand, and I shall ever remember his ecstasies of rapture as he saw his figures being added at the rate of 20 or 30 a second."[49] Comrie, perhaps overstating the case, credits this 1928 visit as the spark that led Brown to inspire his student, Wallace J. Eckert, to pursue computing and, ultimately, to create the computing bureau at Columbia University that is notable for its collaboration with IBM.[50] Regardless of the extent of this inspiration, Comrie's methods certainly had some influence in the United States.

According to Greaves, Comrie's push for innovation wasn't accepted by the Admiralty as quickly as Comrie wanted and the tensions, combined with Comrie's contentious personality, ultimately led to his departure from the office in 1936.[51] In 1937, Comrie founded his own company, Scientific Computing Service Ltd., which was organized in a hierarchical system with Comrie at the head, a few senior mathematicians immediately below him, a couple of highly skilled computers next, and a large staff of mostly women computers who had high-school mathematics and the training they received in-house.[52] The timing of the company's creation was lucky for Comrie because it came just before Britain's entry into World War II and the huge increase in the need for computation related to the war.[53]

The promotion of machines for science

One of Comrie's earliest papers about machine-aided calculation appeared in the journal of the Royal Astronomical Society and described the use of the Hollerith tabulating machine for calculating Brown's tables of the moon, used by navigators for the calculation of longitude. The article describes the calculations necessary to compute the positions of the moon over time according to a formula developed by Brown. The formula involved calculating positions of the moon at regular intervals described by a harmonic equation. Much of the work of updating these tables involved copying and adding 120,000 values each year, creating many opportunities for error. According to Comrie, the work, "before the advent of the Hollerith machine, represented the continuous work of two skilled computers."[54] Comrie stressed that the work could be done in one-tenth the time and at a quarter of the cost using the Hollerith. The machine could be used to tabulate and print these values. "The totals from 44 tables for two years (1,460 dates) were done by three girls and the machines in one day."[55] Comrie's use of the term "girls" is significant. By highlighting that the work was done by women, he removes the work of tabulation from the realm of skilled computers and places it in the realm of clerical work. He also subtly underscores that it is the machine doing the important labor, not the women workers.

From the mid-1920s through the 1940s, Comrie wrote many articles in scientific journals in several fields, focusing on astronomy, but including agriculture and statistics, as well as in office machinery journals. He also publicized his work in Britain and in his native New Zealand, on at least one occasion playing up his use of women workers, as evidenced by the headline "Girls Do the World's Hardest Sums," in a 1942 story about his activities that appeared in *Illustrated*, a London periodical.[56]

The Hollerith paper was the beginning of a process of redefining computation as "women's work," a process that became more complete and explicit during World War II, when women workers were desperately needed. By highlighting, even briefly, that operation of the Hollerith was work for "girls," Comrie played on stereotypes that defined women workers as having relatively insignificant skills and restated the reduced expenses of mechanization brought about by the use of female labor. This helped him legitimize the use of these machines, despite their novelty and relatively high costs of rental. Why would Comrie have had to legitimize the use of these machines? I propose three reasons. First, he was overhauling the methods of an office whose practices had changed very little since Babbage's time. The retired computers contracted by the Nautical Almanac Office were getting the work done, and administrators and computers alike may not have seen the need to change. Second, Comrie had to entice the Admiralty's budget officers to pay for rental of the machines. This wasn't easy, as shown by Comrie's attempt to develop tables for the moon up to the year 2000 using the Hollerith punch-card tabulator. He had all the needed cards punched and workers ready to go, but couldn't complete the job because he couldn't get permission to extend the rental of the machine.[57] He had to convince his budget officers that efficiencies would be created in money and time needed to do the job. By tying the work to low-cost female labor, he bolstered the argument that mechanized computing was less expensive. Third, the application of the Hollerith machine and other business machines to scientific computing were among the first applications of punch-card technology for scientific work. Thus, Comrie had to justify the machine's use to the scientific community for which he was publishing. By noting that the operation of the machines was done by women, he plugged into a network of associations of women with routine, unskilled labor. By playing off the associations of women's work with unskilled labor, he shifted the locus of intelligence to the machines, making the workers' skills less visible.

Comrie himself also made this link more explicit in his 1944 article "Careers for Girls" in *The Mathematical Gazette*. In the introduction cited above, he wrote that careers for girls were available in "mechanised scientific computing. I use the word mechanised rather than mechanical, because the latter may give the false impression of routine and drudgery, whereas the former correctly conveys the fact that mechanical aids are used to lighten the labour."[58] But as Comrie later made clear, he expected machines to lighten women's labor, labor that would be considered routine and drudgery by more highly trained mathematicians, presumably men:

> If she is not told that pure mathematicians dread interpolation, mechanical quadrature and the numerical solution of differential equations, she will never dread them herself—indeed, at the hands of an enthusiastic teacher, she will regard them as a pleasant, useful and skilled occupation.[59]

Comrie creates a division of labor between "pure" mathematicians and the women doing machine-aided computation. He also downplays female computers' intelligence, suggesting that, if properly trained to the task, they will be satisfied with doing the routine calculations that "pure" mathematicians would dread. And he emphasizes the teacher's role (Comrie himself was teacher, manager, and designer of calculations). This creates the impression that women were modeling clay, to be molded to fit the job of computer, or perhaps more aptly, machines to be programmed for the job. This emphasis on programming or molding computers to the job is found later in the article: "In my view it is also necessary to 'catch them young,' because it is little use trying to make computers out of people who have left school or college for several years; if they are over thirty, the effort might as well be abandoned."[60] Comrie does not say exactly why he believes computers ought to be young, but such a belief underscores two points: that computers should submit to and be molded by expert managers within the system, and that the skills associated with age—wisdom, judgment, experience—are not what is needed. This statement tends to downplay the intelligence of the worker in favor of the system that "produces" them and the machines they use.

In "Careers for Girls," Comrie describes the solution to a differential equation, saying it is "well within the capacity of properly trained ... girls." He apparently felt it necessary to underscore women's abilities to do the work, despite the fact that they had been doing the work at the Nautical Almanac Office and in his own Scientific Computing Service for nearly two decades. Comrie also pointed out that women computers needed special training to make them capable of the task:

> No employer would engage an untrained girl to take dictation and type, but if his research department gets a new calculating machine he is, in general, forced by circumstances to engage a girl who has never seen a machine before. The result is that the girl is shown ... just the processes she has to perform. She has no grasp of principles, no variety of method, no discrimination, no power of adaptation, no knowledge of lay-out, no insight into the art of checking, no guide to lean on, and may even, before long, have no interest in her work.[61]

Comrie creates a clear sexual division of labor between male employer/manager and female operator of machines. He uses this argument to push the idea that women need special training in the use of mechanical calculating machines; training that ought to take place in the same type of commercial schools that taught other clerical skills, funded by the government. But his argument can be looked at another way. Simon Schaffer, in his discussion of the political economy of Babbage's ideas about intelligent machines and factories, says Babbage's ideas highlighted the role of the "analytic manager."

Babbage's factory and calculating machinery "precisely *embodied* the intelligence of theory and abrogated the individual intelligence of the worker."[62] By emphasizing the need for a rigorous training program for female computers, Comrie emphasized the role of the system, including the educational system, in the production of calculations. Simultaneously, he de-emphasized the intelligence of the women who would be trained as computers. He also stressed that to perform calculations adequately, women with high school certificates needed training and supervision by an experienced computer. Again, the emphasis is on the training and management system, not on the intelligence of the women.

Comrie winds up "Careers for Girls" with speculation about the future of such jobs for women. It should be remembered that the article was written at the height of World War II when computing jobs were plentiful, and a few years before research into true digital computers made human computing obsolete. Indeed, in 1946, in a review of the Harvard Mark I computer, Comrie called for more complicated tests of the machine to determine whether it would truly be capable of replacing human labor.[63] In "Careers for Girls," he states his faith that women would find jobs as computers:

> I cannot predict the future, although I have faith in it, and think that girls are suitable for and can successfully hold their own in this field. With a training no longer than that of their sisters who cultivate secretarial or accounting work (but *not* without the training) they can be made proficient, and give good service in the years before they (or many of them) graduate to married life, and become experts with the housekeeping accounts![64]

Many workplaces, and the entire British civil service, required that women leave the workplace upon their marriage.[65] Indeed, Comrie himself apparently found the strict civil service rules highly frustrating during his tenure at the Nautical Almanac Office because he wanted to retain some women computers after they married.[66] Several other parts of this statement also bear analysis. First, Comrie reassured his readers that women can do the work, the second reminder in a five-page paper that he did not believe that women's skills were comparable to men's skills. Second, he again emphasizes training. Third, for Comrie, women do not become proficient, they are "made proficient." This emphasizes that women are caught young, trained by experts, and fitted into a system of centralized computation; in other words, women are constructed by their teachers the way machines are constructed by engineers. Their skill is not their own, it is created and designed for the system. It should be stressed that Comrie's statements were not particularly outrageous for the time; rather, he played on common stereotypes to emphasize his creation of a system of calculation in which workers' skills and intelligence were made invisible in order to legitimize the use of calculating machines, and to make both workers and machines subordinate to a larger system of calculation.

Did a computer's work really require few skills? Comrie's writing seems to hinge on the idea that the work was relatively unskilled. But a closer look at the skills Comrie described gives a strong indication that scientific computing, even aided by machines, was skilled work. Among the mathematics skills he expected computers to possess were the ability to solve differential equations numerically, to do simultaneous equations, statistical analyses, triangulations for geodetic work, and harmonic analyses.[67] The mathematical skills described are now taught in several high-school and college-level courses in the United States and are by no means simple. He also says computers should receive training in the use of several calculating machines and have a sense of how to choose the right machine and structure the computation to make the best use of it. He suggests that students should understand processes, rather than specific applications, so they would be flexible enough to do a variety of computations.[68] Clearly, this is not a description of an unskilled laborer. Yet, as shown above, he repeatedly downplayed the skills acquired by the worker in favor of those embodied in the machines and in the system of production.

Comrie's beliefs about the "intelligence" of the system can be seen in his views about the differential analyzer. While he generally appreciated this machine designed to solve differential equations, he argued that in many cases, specialized machines were unnecessary: "I do not feel that it will ever oust finite differences and render numerical skill a thing of the past."[69] Comrie's beliefs about machines reflected his beliefs about workers: he argued that physicists and engineers should exhaust commercial possibilities before inventing specialized calculating machines: "Too often the only tangible result has been a pile of blue prints, and perhaps a single machine that reaches old age with teething troubles—a machine that benefits only a few people and often impoverishes the inventor…"[70] Not only does Comrie use a human metaphor—the association of age with teething troubles—for these machines, he also stresses that, like calculating workers, calculating machines should be well-organized generalists.

Dozens of calculating bureaus organized along lines similar to those pioneered by Comrie were set up immediately before and during World War II, when the need for calculation of ballistics tables and for war research mushroomed. Jennifer Light argues that the women who did computation at the University of Pennsylvania's Moore School of Electrical Engineering, as well as those few integral to design and programming of the ENIAC, were written out of the history from the earliest press releases and news articles to later histories.[71] Comrie did not write women out of his chapter of computing history. Rather, he laid the groundwork by defining computation as women's work, thus shifting the emphasis away from the intelligence and skill of the human computer and into the machines and the system for the production of knowledge. By 1946, Comrie argued that specialized machines had yet to prove themselves capable of replacing humans aided by more common calculating machines. But, in his discussion of the Mark I, he also mentioned the machine's "brains" and compared its output to that of a "manual computer," so the shift from human brains to machine brains in some ways appeared complete.[72]

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Notes

[1] Anonymous, "Careers for Girls," in *The Mathematical Gazette*, 27, No. 277, Dec. 1943, 170. A Sixth Form education in Britain would be roughly equivalent to the completion of one semester of college in the United States.

[2] Leslie John Comrie, "Careers for Girls," in *The Mathematical Gazette*, 28, July 1944, 90-95.

[3] Herman Goldstine, *The Computer from Pascal to Von Neumann*. Princeton: Princeton University Press, 1972, 107.

[4] Simon Schaffer in "Babbage's Intelligence: Calculating Engines and the Factory System," in *Critical Inquiry*, 21 (Autumn 1994), discusses the "sites of intelligence" as both the place where intelligence is embodied—machine or worker—and the physical spaces of production, such as factories and workshops. By using the word "locus," I am emphasizing the former. Although there is some evidence that Comrie also reorganized the physical spaces of production, at least to the extent that he brought computers back into the office, this is not a focus of my argument.

[5] Goldstine, 5.

[6] Charles Babbage, "On the Application of Machinery to the Purpose of Calculating and Printing Mathematical Tables," in Philip Morrison and Emily Morrison, eds., *Charles Babbage and His Calculating Engines*, New York: Dover Publications, 1961, 298.

[7] Schaffer, 204.

[8] L.J. Comrie, "Babbage's Dream Comes True," in *Nature*, No. 4017, Oct. 26, 1946, 567.

[9] Lorraine Daston, "Englightenment Calculations," in *Critical Inquiry*, 21 (Autumn 1994), 200.

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