How the Machines Were Assisted by Women

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Abstract

The following paper analyzes nature of skill in the cryptographic work performed by female employees of the World War II British cryptography program at Bletchley Park. Using anecdotes from women who worked to decrypt the Lorenz cipher, I show the hidden skills which were integral to their work and to the war effort. This paper aims to reconstruct their experiences and deepen our understanding of what it took to operate decryption machines, especially focusing on the Colossus computer.

1 Introduction

Even at the height of World War II, a new recruit to Station X, the Government Code and Cypher School (GC&CS)'s highly classified site dedicated to breaking Axis military codes located in the Bletchley Park estate, would be forgiven for assuming that the Bletchley train station was the wrong stop.[1] Arrival was typically inauspicious. Recruits were told to take the train on a designated date and call a designated number on a telephone at the Bletchley Station kiosk on arrival. A rare few were told to show whoever was in the small hut by the front of the station an envelope they had been given, but by no means were they to hand the envelope over. From there, they would be given further directions (and further individuals to show their mysterious envelope to) before they entered Bletchley Park itself (Hill, 2004: 24-25). Almost none knew what they would be doing; some had not even worked out where they were.

One of the best-kept secrets of the Second World War, the cryptography program that ran out of Bletchley Park reportedly shortened the war "by not less that [sic] two years and probably by four years" (Hinsley, 1993). This number may be exaggeration—it is certainly impossible to verify—but its meaning is clear. Bletchley Park was a critical part of Great Britain's war effort. Bletchley Park was more successful in cracking German codes than Japanese, but the information they gained proved critical for major Allied operations such as the 1944 Normandy landings.A more thorough account of this can be found in Kenyon (2019). The popular narrative around Bletchley Park focuses on Alan Turing and the breaking of the German Enigma codes. In comparison, the breaking of the German Lorenz codes and use of the Colossus machines has received less attention.

The work performed by Colossus operators, all of whom were women, was often described in caretaking, maternalistic terms. This is not a coincidence. Seth Koven and Sonya Michel (1990) have demonstrated how in the realm of politics and welfare, women utilized their authority as mothers to gain leverage and respect, and Paula Baker (1984) has shown how women's activism, particularly regarding welfare, allowed for a conceptualization of women as political actors that did not violate feminine norms or the Victorian doctrine of "separate spheres." So, caretaking language rendered the operator's work legible within existing gender constructs, and provided them authority regarding the machines, while positioning them as less skilled than and subservient to the men they worked under. Indeed, managers and labor officials leveraged stereotypes about women's natural inclinations and skills to argue that they were particularly well suited for early computing work. For an example of this phenomenon which intersects with race and culture, see Nakamura (2014). Margot Lee Shetterly (2016) demonstrates the significance of race, which is reinforced by Elsa Barkley Brown's (1992) argument that "women" inher-

[1] The location was also called Special Duties X (SDX) or HMS Pembroke V, depending on which organization was sending the recruit. For example, HMS Pembroke V was exclusively used by the Navy.

ently cannot be a universalized category, blind to race and class.

The Colossus operators' statuses as predominantly white, middle-class, educated women was important, as it allowed them access to particular professional networks that working class women and women of color could not participate in. For example, Mundy (2017) shows how women were selected for personality traits and demographic qualities as well as their technical skills. However, in an attempt to understand their work beyond the lens of maternalism and femininity I have found it useful to conceptualize these women as technicians, as described by Steven Shapin (1989). Additionally, Jennifer S. Light (1999) shows how female computer operators' lack of authority in both social and technical settings led to their erasure from the historical record by those who did have power. Shapin (1989) argues that scientific technicians are invisible when the apparatus is working and that the technicians' work are always subject to the scientist's decisions because the scientist had authority, not the technician. Similarly, even as Colossus operators accrued technical and tacit knowledge about the Colossus, they were still described as "mindless" workers who followed the instructions of cryptographers. Historians of science and technology have developed a robust history of management practices that examines the importance of social networks in the production of knowledge and technology as well as the manipulation of power structures in society to reify the authority of an "elite" group. For further reference, see Ensmenger (2010), Jones (2016), Schaffer (1988), Kasson (1977), Nelson (1995), and Roediger and Esch (2012). Feminist historians have further explored management practices, showing how the physical separation of men and women in the workplace served to reinforce the gendered division of labor in white-collar offices. For more on this, see Strom (1989) and Fine (1990). Taking Bletchley Park as a case study provides an example where managers were more concerned with completing tasks than they were with social management. For instance, administrators typically cited office romances as a reason to keep men and women separated at work—heterosexual friendships, courtships, marriages, and affairs all happened at the Park without much comment, as long as the work continued effectively. Additionally, Bletchley Park was a military operation, so Bletchley Park workers had to contend with a set of management practices and cultural norms which often ran in direct contrast to scientific and educational norms which they were familiarized with from universities.

In recent years there has been a growing focus on the history of "hidden labor(ers)" within the history of computing, with scholars examining the work of "human computers," early programmers (who were often women), and institutional support workers who helped make the personal computer industry viable. These works encourage us to expand our understanding of what it actually means to work with computers, as well as challenge our presumptive vision of what a "computer programmer" looks like. For further reference, see Irani (2015a, 2015b). Nooney (2020), Roberts (2019), and Rankin (2018). In addition, Anne Secord (1994) provides an early model for considering alternate locations of scientific practice by examining a working class, "artisanal" science. The women at the center of this paper would not have considered themselves "programmers," as the term did not yet exist, but it is important to note that the work they performed required a number of skills central to modern computing. In addition, the postwar masculinization of computing as a profession has been well documented, most notably by Janet Abbate (2012) and Mar Hicks (2017, 2021). Similarly, while not specific to computing, Oldenziel (1999) describes the construction of engineering as a distinctly masculine enterprise—this provides critical context for Abbate's description of the pivot to "software engineering." As a result, we are less aware of what women in early computing actually *did*. Both Hicks and Abbate discuss the Colossus operators, but Hicks focuses more on the challenges of their postwar work, especially the pay inequality and bans against employing married women. Abbate, on the other hand, describes the process by which women's work was undervalued at Bletchley Park. My aim in this paper is to examine the work of the Colossus operators in detail, in order to understand the tacit knowledge and skill necessary to perform codebreaking with machines.This relates to Ruth Schwartz Cowan's (1983) argument that, contrary to popular narratives, the introduction of household technologies made domestic labor more difficult through changing standards of cleanliness and increased technical skill required from housewives. Similarly, while the use of machines like the Bombe, Heath Robinson, and Colossus certainly shortened the time it took to crack ciphers, their use also mandated the mastering of an entirely new set of skills and new expectations regarding the pace of work. It is thus necessary to address the gendered dimensions of labor and the ways in which these influence the perceptions of women's work, but my goal is to look past these narratives in order to establish a sense of what it meant to operate a Colossus computer.

2 The Lorenz Cipher

In the summer of 1942 Helen Pollard (later Helen Currie) sits at a trestle table, head bent over her papers. She is accompanied by another young woman and a handful of "army boys," or young men of a lower rank. Occasionally, a man (either military or civilian) will deposit sheets of squared paper in front of her, with lines of dots and crosses drawn across them. She picks up her pencil and begins carefully adding the markings together. She has a chart to consult if she needs one, but by now, she can complete the calculations in her head. A few months later, Pollard and her companions moved from their room at the back of the Bletchley Park manor house to a hut on the property. Here, she meets the British Tunny machine for the first time.

Helen Pollard joined the Auxiliary Territorial Service (ATS) during the 1938 Munich crisis, which saw the nation of Czechoslovakia forced to cede territory to Nazi Germany through military pressure from Germany, Poland, and Hungary and diplomatic pressure from the United Kingdom and France. In 1942, she became a signals operator, or someone who operated teleprinters, switchboards, and cipher operators, earning a promotion to lance corporal for her efforts during her time at the signals school in Trowbridge.[2] That summer, she had her interview to work at Bletchley Park. Pollard only remembers two of the questions she was asked: "Would I like to work in the country? Could I keep a secret?" With her answers of "yes" and "I think so," respectively, her experience as a typist, training with military intelligence, and rank, she was assigned to the "Testery," the team headed by Major Ralph Tester. Solely dedicated to breaking the German Lorenz codes, the work of the Testery has received far less historical attention than Alan Turing and his Hut 8. However, the Lorenz ciphers demand attention, as it was reserved for communications amongst the highest levels of German High Command, including Adolf Hitler himself by early 1944.

Once assigned to operating the Tunny machines, Helen Pollard's day began by pressing the key numbers given to her by the cryptographers on her team to set the machine. Then, the rest of her shift was given over to typing. She would enter coded messages into the machine, and if her settings and typing was correct, out came a string of perfect German. In her own words, "It seemed like magic at first" (Currie, 2010: 266). Pollard could not read the German she produced, but she learned to tell when the machine was returning gibberish. More often than not this was an error in the interception of the message: reception was typically bad, meaning that there could be gaps in the message given to Pollard. She rarely made mistakes of her own. Incoherent messages required trial and error to get right. She would push the buttons again and start typing until she saw clear German. Finished messages went into an out-basket, off to who knows where. Pollard had only been told that her job was to type.

Despite assertions from Testery cryptographers that the work done by "backroom staff" like Helen Pollard was "very important, but often very boring and using very slow manual processes," Pollard enjoyed her work (Roberts, 2017: 83). As she describes it, "The work never got tedious. There was something about the atmosphere at Bletchley Park that generated an all-pervading excitement" (Currie, 2010: 266). She even describes the early stages of her time at Bletchley Park as idyllic, though this did not last. The war caught up with Helen Pollard in August 1943, when the airman she had married only ten weeks prior was killed. Sympathies abounded, but the only allowances she was given for her bereavement came from mathematician and fellow Testery employee Peter Hilton, who gave her "the best and clearest message he could find, which gave me no trouble to type. It was his way of bringing me comfort" (Currie, 2010: 266). Pollard does not identify this herself, but the episode reveals the fact that her work required skill. If it was truly mindless, then her grief would not have had any impact on her

[2] Women were drafted from volunteer organizations like the ATS to be signals operators in WWII to combat manpower shortages.

ability to type the messages and would not have needed accommodation.

Perhaps by the level of command of the men who used it, Lorenz was drastically more complicated than the Enigma codes. In terms of pure machinery, the Lorenz encrypting device had four times as many wheels as the Enigma machine, meaning that there were more possible encryption keys. As British Captain Raymond C. "Jerry" Roberts describes it, Lorenz "was the 'secret writer' of which Hitler dreamed. The Lorenz SZ40/42 was a wonderful machine: it should never, ever have been broken" (Roberts, 2017: 58). However, perhaps surprisingly, the Lorenz machines were easier to operate than Enigma machines. Enigma devices required someone to prepare the message, someone to convert it into Morse code, and someone to transmit it. Lorenz machines only needed one person, by comparison. An operator only needed to type the message on the machine's keyboard, and the machine did the rest (Roberts, 2017: 65). From this, it may seem counterintuitive that the Germans kept using Enigma once they had developed Lorenz, but every message sent was a chance for the Allies to intercept and break the code.

The Bombe machines, developed to crack Enigma codes, did not work on Lorenz. The British had no ways of even seeing a Lorenz SZ40/42, let alone acquiring one to take apart and analyze. How could they ever hope to break the code? It seems callous to attribute it to luck, but in truth, the Germans were careless during the relatively infrequent instances that they used Lorenz. Early on in the war, the wheel settings of the machines (which dictate the encryption) were not changed as frequently. It took until January 1944 for them to be changed daily, despite the fact that it was not tremendously difficult to change the wheel settings. By then, however, the British had already spent years attacking and solving Lorenz. On August 30, 1941, a Lorenz-encoded message of around 4,000 characters was sent from Athens to Vienna.[3] Then, a miracle: the message was not received correctly, and the receiving operator sent a plain-language request for it to be retransmitted. This piqued the interest of the British. They tuned in, to find that the message had been retransmitted using the same encryption settings. On its own, this would have meant nothing, but critically, the sender made a number of small alterations to the text. These edits, mainly switches to shorthand, allowed cryptanalyst Brigadier John Tiltman to decipher the two messages and determine their keystream.[4] To his dismay, though, Tiltman was unable to determine how the keystream was generated.

The problem was handed to young mathematician Bill Tutte. Captain Jerry Roberts (2017: 73) describes Tutte's process of breaking Lorenz as follows:

> Working with a sample of intercepted messages, Tutte, by intellect and intuition alone, deduced that the Lorenz code was generated by a machine with a series of rotors. He noticed that the first of these had forty-one teeth and then went on to work out all twelve rotors correctly. The Lorenz machine was broken – how the twelve wheels worked, their lengths and their functions – everything worked out.

And so, the British could crack Lorenz. The process was not streamlined in any way. Throughout the war, cryptographers were required to break Lorenz ciphers by hand. Machinery helped but could not solve the codes alone. Helen Pollard was right in the middle of this. Her new team, the Testery was the only team to work on Lorenz by hand. She joined surprisingly early, as well. In 1941, the team had eight or nine people, which jumped to a staff of 118 by the end of the war, "including twenty-four ATS girls, nine cryptanalysts and all kinds of support staff, all organized in three shifts working round the clock" (Roberts, 2017: 76).

The mismatch between Pollard's testimony of her work and Roberts' perception follows the pattern of mechanizing clerical work identified by historian Sharon Hartman Strom (1986: 64), namely that as machines were utilized more and more for bookkeeping and secretarial work, women were increasingly given those jobs as they were deemed less likely to protest the "deskilling" of that labor. This is not a perfect analogy, as women were overwhelmingly needed to occupy home front jobs in Britain during the Second World War, as most of the male labor force had

[3] Note that the average Enigma message ran around 300 characters.

[4] The string of characters used to encode the message.

been drafted. For one exceptional window, women were called to work jobs that would not previously have been available to them, travel, alone, into unknown spaces for the first times in their lives, and do everything they could to support the war effort. This is not to say that pre-war social mores vanished entirely. In fact, stereotypical views of women were used to justify giving them early computer work. The perception was that "Programming requires lots of patience, persistence and a capacity detail and those are traits that many girls have"(Gürer, 2002: 176). Indeed, the women of Bletchley Park were trusted to work eight-hour shifts in which the slightest inaccurate detail could have major ramifications, all with minimal breaks. Whether or not they held these traits innately (if at all), were trained into them, or simply rose to the occasion, the women did perform as needed, reinforcing beliefs about them. Moreover, "the expectations and ideals of peacetime society—particularly in regard to a patriarchal, heteronormative family—continued to influence how and where women were deployed and who was called up" (Hicks, 2017: 26). For instance, the majority of the women at Bletchley Park were young and unmarried. Some were married during their time at the Park, though in another moment of wartime exceptionalism, this did not inherently spell the end of their employment (Strom, 1986: 64). In general, as Mar Hicks (2017: 27) describes, "the government recognized and tried to mitigate the 'double shift' effect that accrued for married . . . in order to keep wartime factories running efficiently and keep factory floor accidents down," something it had not done during peacetime.

3 "Deskilled"

However, the perception that these forms of labor were "deskilled" did not necessarily translate to reality. Strom (1986: 64) describes the real-time decisions clerical workers had to make both to keep their machines running and to ensure that they were being used in the most effective manner. Helen Pollard certainly needed to apply forms of judgement to her work. She had to evaluate the messages that the machines returned and determine whether or not they were meaningful, even though she could not read German. In addition, the female Bletchley Park employees employed in traditionally "clerical" roles, such as registrars, were similarly required to make swift, critical decisions. They needed to keep track of all of the assignments and schedule them in such a way that prioritized more important codes and made the most effective use of the machines, which is a form of mathematical optimization (Hicks, 2017: 37). In a workforce where everyone's knowledge was limited for security purposes, these women had to juggle several moving parts, often with imperfect information at hand. For a similar analysis of the importance of administration in a mechanized office, see Strom (1986: 66). For example, after Wren and Colossus operator Dorothy Du Boisson's team expanded, she was reassigned to be a registrar, where she was responsible for assigning the paper tapes that both the Colossus and Heath Robinson machines used, and which held encoded messages and recording where each message was. She remembers that "We kept a register in which we recorded the date and identity of each tape. . . We knew exactly where every tape was, and how much machine time had been spent on it" (Copeland, et al., 2010: 163). So, Du Boisson needed to evaluate the priority of each code despite not knowing what they actually said, assign them in such a way that she maximized the information gained, and keep meticulous track of where everything was, even when the tapes had to pass through multiple people and stations.

Even the seemingly mundane act of mending the paper tapes was an essential job and high-skill job. Eleanor Ireland remembers using Bostik, a liquid adhesive, to put broken tapes back together. Even stretched tapes posed problems, though, as that could skew results. Operators had to keep a watchful eye on them, even as they spun at high speeds, in order to prevent errors. This was another hidden skill, and it came with the same pressure as every other task at Bletchley Park. Incorrect information could cost lives, and "Given that these young women had family and friends on the line of fire, the idiosyncracies of their machines were as frightening as they were frustrating" (Hicks, 2017: 33-34). Their ability to maintain composure and keep the machines running smoothly far exceeded the "patience" and "persistence" that supposedly made women such capable programmers.

The Tunny machines that Helen Pollard worked on were not the only technologies involved in deciphering the Lorenz codes. Built by engineer

Thomas "Tommy" Flowers, Member of the Most Excellent Order of the British Empire, and first made functional in December 1943, the Colossus machine was the world's first electronic computer.The narrative of ENIAC as the first electronic computer was promoted by Hungarian-American mathematician John von Neumann, who was not aware of the existence of Colossus. See B. Jack Copeland (2010: 101). A drastic improvement on its predecessors, the "Heath Robinson"[5] machines, Colossus quickened the statistical analysis necessary to break Lorenz (*Colossus*, 2012). In particular, the Colossus determined the patterns of the "cams," or the ridges on the wheels of the Lorenz encryption device which could be set to "active" or "inactive," and which would dictate the resulting code. The Colossus was also capable of determining the starting positions of the wheels of the Lorenz device. Those two pieces of information were essential for decrypting Lorenz encoded messages.

While developing the Colossus computer, Flowers faced numerous concerns over the glass valves that made up his digital switching techniques, as his doubters knew that the valves were prone to breaking. In response, Flowers posited that the valves were less likely to fail if they were kept working all the time (*Colossus*, 2012). His assertion was correct, and the valves proved sufficient for keeping up with the workload. In fact, labor at Bletchley Park ran twenty-four hours a day, seven days a week anyways, with workers taking one week with a nine a.m. to four p.m. shift, switching to a four p.m. to midnight shift the week after, then switching again to a midnight to nine a.m. shift. Working weeks were six days long, but many worked twelve days straight so that they could have a full weekend to visit home (Hill, 2004: 51). The Park was always active in some capacity, so there was no point in considering turning the Colossus off. In practice it was always running and always needed.

Much like the British Tunny machines, the Colossus was entirely operated by women. A full list of the Colossus operators can be found at "Computing Herstory - Computing History." Colossus computers were primarily operated by Max Newman's "Newmanry" team, which worked hand-in-hand with the Testery team on Lorenz. At the start of the war, the Newmanry team was comprised of one (male) cryptographer, two (male) engineers, and sixteen "Wrens" (the nickname for the Women's Royal Navy Service, or WRNS). By 1945, their numbers jumped to twenty-six cryptographers, twenty-eight engineers, and 273 Wrens (Copeland et al., 2010: 158). It should be noted that the cryptographers and engineers were still all men; despite the fact that some women received training to become engineers, they would have been classified as Wrens at Bletchley Park. So, the Newmanry and the Testery saw similar increases in staff, though the breakdowns of their respective personnel differed. The Testery team did not feature engineers and used ATS girls, not the more prestigious Wrens. Additionally, the majority of the Newmanry team was women, which was never true of the Testery.

Even if the majority of the Newmanry team were women, they still played second string to the men. Even the subset of the Wrens with university educations were never promoted to senior positions or made cryptographers (Copeland et al., 2010: 159). Yet, the women were incredibly capable. In a report on the Tunny machines, their "cheerful common sense" was noted, along with the fact that "'several' of the Newmanry's 273 Wrens 'showed ability in cryptographic work' and that 'several others were trained by the engineers to undertake routine testing of the machines'" (Copeland et al., 2010: 159). Moreover, Dorothy Du Boisson reports that at first, the Wrens operated the Colossi under the direction of the cryptographer. However, she adds, "After a while, a formula was developed so that the operator could [set the machines] herself" (Copeland et al., 2010: 163). She states that this freed the cryptographer for "more important work," which directly conflicts with the utility of the Colossus (Copeland et al., 2010: 163). The Colossus hastened code-breaking and allowed for forms of "brute force" cryptanalysis that a human being could not feasibly perform. Setting the machines properly was important, and the Wrens had learned how. Nevertheless, the Newmanry Wrens were not always utilized to their full ability, as they faced restrictions on what titles they were allowed to hold due to their sex.

Working on a team like the Newmanry proved an odd mix of ingrained hierarchy and social im-

[5]These machines were nicknamed "Heath Robinson" by the Wrens because they were reminiscent of the complicated machinery drawn by British cartoonist William Heath Robinson.

pudence. Women were barred from positions of authority, but typical boundaries of etiquette were frequently broken. For example, Du Boisson recalls the heat emitted by the machine's numerous glass valves, stating that "If we got too hot or sleepy we went out for a splash from the static water tank (for use in the event of enemy action or fire). Someone suggested that we [go] topless, but we did not take up the offer" (Copeland et al., 2010: 162-163). In another instance, engineer Ken Myers recalls a Wren propping her pocket mirror up on one of the Tunny machines' transformer panels to reapply her lipstick. The mirror fell, evaporating through contact with the extremely hot machinery, and the lipstick shot across the girl's throat, giving the effect that it had been cut (Copeland et al., 2010: 170).

4 Operating the Colossus

For Joanna Stradling, meeting the Colossus was love at first sight. Mere moments after she had signed the Official Secrets Act, she "saw this astonishing machine the size of a room. It was ticking away, and the tapes were going around and all the valves, and I thought, what an amazing machine. There were valves and transistors and flippy-flappy things. Like magic and science combined!" (Dunlop, 2015: 125-126). Barred from entering university by her distant and yet overbearing father, Stradling had settled for a domestic science college. For her, service to her country equally presented a personal opportunity. In 1944, at age 19, she walked into a WRNS recruiting office in Gloucester, a decision she called "the first time I had taken control of my own life" (Dunlop, 2015: 89). She chose to be trained in "light electrical work" before she was sent to Bletchley Park, because of this, she had a better sense of what she would be doing than most of her fellow recruits.

At first, Stradling's work in Bletchley Park revolved around the paper tapes that span through the Tunny, Heath Robinson, and Colossus machines. She delivered them, mended them when they tore, and loaded them into the machines. In the orbit of the Colossus which had so thoroughly captured her attention but kept from working directly with the machine, she was left unsatisfied. Her least favorite task was repairing the tapes, leading to a particular vendetta towards the Heath Robinson machines, since on that particular device "the tapes had to be put on wheels, and the wheels weren't sprung so you couldn't move them around and regulate the tension of the tape. It was always ripping or exploding" (Dunlop, 2015: 126). Throughout everything, she retained her desire to work on the Colossus.

It almost did not happen. The Colossus was named as such because of its size—only tall girls could operate it, because they could reach the top of the machines (Dunlop, 2015: 125; Slimming, 2021: 121). But luckily for Joanna, she had long arms and had arrived just after the D-Day landings. There were two Colossi at Bletchley Park by then, and neither could be turned off for fear of the vacuum tubes breaking. Their utility was becoming increasingly apparent, as well: "in the Newmanry some twenty-five Fish keys were broken in August, far more than any previous month. Computer power had come into a league of its own and Colossi were hatching at the rate of one a month" (Dunlop, 2015: 209). Women with Joanna's abilities were needed to staff the machines, and she was quickly promoted.

By the end of the war, there were ten Colossus computers, with an eleventh having been commissioned. They were not identical devices, though. Each iteration improved on the last, and they developed at such a rate that even seven decades later Joanna Stradling can remember that she worked specifically on numbers five, seven, and nine (Dunlop, 2015: 209). Whether truly necessary or not, she treated the machines tenderly, recalling that "You had to make sure it's little eye was clean or it wouldn't be able to see…I was interested in how it did what it did, so I was determined to look after it and make life easy for it" (Dunlop, 2015: 210). Stradling personified the Colossi, perhaps because her job led to her feeling as though she was communicating with the machines. Unlike Helen Pollard, who learned how to read the small signs that she was getting nonsense from the Tunny machines, Stradling knew "if [she] got a positive result; [the Colossus] would tell you. It would go click click click whizz, the tapes would all run down and you knew you had a fit" (Dunlop, 2015: 210). Much like Helen Pollard, Stradling never knew what the decryptions said, and she never asked.

Joanna Stradling was spared from dismantling the Colossi at the end of the war, which was a blessing, considering how much she loved them. She was allowed to keep a small part of one to remember the machines and the Park as a whole, as she was still sworn to secrecy and had no expectations of that changing. She "got a switch and kept it in my Wren belt-pocket for years" (Dunlop, 2015: 258).

There was some recognition that operating machinery required skill, but that skill was deprioritized in comparison to more theoretical abilities. In his 1944 article titled "Careers for Girls," published in the popular British journal for mathematics and math education, L. J. Comrie (1944: 92) writes that "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." Comrie assumes that this translates to the girl not knowing any theory, only the mechanical process she must perform, but as women like Helen Pollard and Joanna Stradling demonstrate, what it actually meant was that the women worked out the underlying principles on their own. The entirety of "Careers for Girls" is rife with sexist and derogatory ideas. Comrie (1944: 90-91) writes that computer operation "holds a peculiar fascination for those temperamentally suited for it, and that it is well within the capacity of properly trained…girls." He does not see this kind of work as particularly rewarding or engaging and is only promoting it for its economic utility. In addition, Comrie (1944: 94) does not see the women as having lasting intrinsic value. In his words, "they can be made proficient, give good service in the years before they (or many of them) graduate to married life, and become experts with the housekeeping accounts!" Comrie advocated training the women because they made his business easier, not because he thought they deserved socioeconomic mobility, work they could be proud of, or the right to skilled labor. The work was deemed valuable, but the women were not. Even marriage itself had economic utility: "Turnover through marriage was supposed to ensure women didn't tire of the work or require promotion to better—and better paid—work, as that would throw his system out of alignment," though this did not always work in practice (Hicks, 2017: 22).

Computer operation required genuine expertise, and in the case of Bletchley, this expertise had to be gained under high-stress and nearly inhospitable conditions. The Colossus' predecessors had warmed the spaces that they were in. The Colossus was warmer. They were built with more than a thousand vacuum tubes each and were never switched off, leading to an at times oppressive heat. In addition, Heath Robinson and Tunny machines were noisy, due to their use of paper tapes, and due to the nature of the codes being deciphered their surroundings were always chaotic and intense. The rooms they were housed in were also improperly ventilated as they were kept in hastily-erected huts on the grounds of the Bletchley Park manor house, built solely for utility and out of necessity when the decryption program outgrew the bounds of the house. These problems, too, increased after the Colossus was installed (Hicks, 2017: 35-36). Work shifts were grueling and led to exhaustion.

The women faced difficulties at "home," as well. Bletchley was a small place, and many of them needed to billet with locals. Some were sent to the equally hastily built (and therefore somewhat unsound) lodgings of the nearby army camp (Hill, 2004*colon* 111). Conditions varied, but many women faced a combination of "contaminated water, poor heating, and noisy living quarters" (Hicks, 2017: 36). At the very least, those in billets could not escape intertwinement with the personal lives of their host families, for better or for worse. The Wrens faced their own particular challenges, as for a short time their supervisors, "unaware of the skilled, nonphysical nature" of their work called for mandatory drills in the morning, "which resulted in exhaustion and illness for many workers until their supervising officers were eventually told to stop the drills" (Hicks, 2017: 36).

5 ENIAC

To further situate the women of Bletchley Park in the history of computing, it is helpful to take a short diversion into one of the Colossus' closest analogs: the Electronic Numerical Integrator and Computer, or ENIAC, built at the University of Pennsylvania in 1945 and primarily used for the United States Army's Ballistic Research Laboratory. Unlike the Colossus, ENIAC was not operational until December 1945 and therefore could not be used during World War II, but like the Colossus its first operators were women. Specifically, ENIAC was first programmed by six female mathematicians who had to learn how to communicate with the machine before ever laying eyes on it. The literature on ENIAC is far more robust than the literature on the Colossus, mainly due to how heavily classified the existence of the Colossi was. However, the discourse around the Colossi since their declassification has mirrored early conversations around ENIAC. For one thing, as Jennifer S. Light (1999: 473) identifies, "while the War Department urged women into military and civil service and fed the media uplifting stories about women's achievements during the war, its press releases about a critical project like the ENIAC do not mention the women who helped make the machine run." The result of this, Light argues, is that even though the ENIAC was classified as "intelligent" for its ability to perform calculations, women computers were never given the same esteem. Moreover, the female programmers were almost entirely written out of ENIAC's story.

Another aspect of ENIAC was that it "made a fundamental distinction between hardware and software: designing hardware was a man's job; programming was a woman's job" (Light, 1999: 469). This separation never took place at Bletchley Park, as women like Margaret Boulton were tasked with constructing Colossi. Regardless, early programming required a detailed understanding of the hardware. ENIAC's original operators could not practice on the machine, so "They learned how ENIAC worked by talking with the original design engineers, studying their logic diagrams, and sharing ideas with the other programmers" (Fritz, 1996: 27). By the time they were in front of ENIAC, they knew how it worked, and because of that they could make it perform as they needed it to. Rather than a monotonous plugging in of data, programming mechanical computers was dynamic, creative, and challenging (Strober and Arnold, 1986: 139). Colossus and ENIAC operators had no precedents to rely on and the information they were given about their respective machines was limited, sometimes to the point of insufficiency. They could ask mathematicians and engineers in their programs for help, but they alone were responsible for making the machines run properly. The Bletchley Park women would have been especially disincentivized from asking for support unless absolutely necessary, as doing so would have meant not only that they were not working, but that someone else on their team was pulled away from another task. Given how frequently they state that other members of their teams were doing "more important" work, they would have tried to fix everything that they could themselves.

6 New Skills

Cora Pounds, who was only seventeen when she began working at Bletchley Park in 1944, represents a trend of women found themselves capable of things that they had previously been told they lacked the skills for, as identified by historian Liza Mundy (2017). As Mundy (2017: 184) writes, "As they went about their assignments, women found competencies within themselves they had not known existed. Jane Case—told, growing up, that she was bad at math—turned out to have a ready facility with numbers." Cora had not been a good student. She had a poor memory and did not pass her School Certificate exam on her first try (Dunlop, 2015: 35). Cora's interests had always lay in fashion (influencing her choice to join the Wrens, who notoriously had the most stylish uniforms), not academics. Despite this, she performed to the high standards of Bletchley Park. Regrettably, her perception of her work aligned with the stereotype of meaningless drudgery, as she recalls "'There were so many messages being sent in, when one didn't come good you were sent another one.' She was checking for a match, but she didn't know why or what it meant. 'Checking checking. It was very boring. There were no written messages" (Dunlop, 2015: 124). Cora never really learned what she did, which meant that she never really understood her own worth (Dunlop, 2015: 125). Furthermore, when asked about Max Newman, the head of her team, she does not remember meeting him. Historian Tessa Dunlop interprets this as Newman believing that the Wrens who worked for him did not want to have their work explained to them, and so he made no efforts to. The men who worked for him enjoyed a much closer relationship, as he encouraged collaboration and informal brainstorming sessions. Dunlop's (2015: 125) interpretation of this is that "Professor Max Newman was a model employer—unless you were a low-status girl, that is." It could be the case that Newman disregarded the women under him due to their gender, but it seems more likely that it was due to compartmentalization. As Captain Roberts noted, even when the Colossus was put in use, cryptographers still worked on breaking Lorenz codes by hand. In problem-solving, more heads are often better, so Newman's encouragement of group thinking makes strategic sense. On the other hand, the female Colossus operators were working on a different part of the decryption process. Information was heavily compartmentalized in Bletchley Park, and it was not unusual for members of the same team to not know what the other was doing. Time was also a factor. Eleanor Ireland remembers being trained to operate the Colossus by another Wren, and she remembers that "when I was given a new Wren to instruct, I was worried about leaving her alone for very long, and would hurry back from meal-break to make sure nothing awful had happened" (Copeland et al., 2010: 164). Mistakes and breaks cost time, and as Ireland continues, "We knew we were working against the clock and that people's lives depended on what we were doing" (Copeland et al., 2010: 164). The Wrens were far more familiar with the Colossus than Max Newman (who likely never operated one himself), and so in the name of efficiency it was better for them to teach each other than to turn to their team leader. It is true that female Bletchley Park employees were limited in ways that male employees were not, but in the case of Max Newman and Cora Pounds, pure sexism is an insufficient, even misleading, explanation for what Pounds experienced.

7 Conclusion

It is easy to forget the network of people necessary to maintain the Lorenz decryption project. The fact that a great deal of decryption was relegated to a select group of men, as well as the fact that these men have traditionally written the accounts of what went on at Bletchley Park, has resulted in a misunderstanding of what this labor actually looked like. Women are often excluded from the narrative, and when they are mentioned (often in passing) it is generally assumed that what they were doing was dull and tedious. In truth, while not every woman who worked at Bletchley Park enjoyed her time there, there were many who found their work fulfilling and meaningful. They found excitement in learning to operate technology like the Tunny machines and the Colossus computers. They kept themselves motivated with an understanding that what they were doing was of critical importance, even if they were not given enough information to know where their efforts fit in or even what they were doing. They formed attachments to the environment, the people, the devices, and the work that characterized so much of their wartime experiences. Once an individual was assigned to Bletchley, the chances were slim to none that they could be transferred. The stakes of secrecy were too high.

All of the Bletchley Park employees understood the importance of silence. They hid the true nature of their work from their friends, families, and even each other, both during and after the war. Even when the Bletchley Park program was declassified, though, more accounts came from men than women. The work done by women was seen as less glamorous, dynamic, and compelling than that of their male counterparts, but it was equally important and meaningful. The decryption of the Lorenz ciphers was a critical part of Allied success in the Second World War, and speed was essential. Even the Colossus computers have been recognized for their ability to expedite the code-breaking process, but they needed the women to function.

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