The Real Enigma: The Top-Secret Codebreakers of Bletchley Park

Grace Minakowski

Junior Division

Individual Exhibit

Process Paper: 500 Words

Student-Composed Words: 500

I have always been drawn to the field of computer science and been puzzled with the wonder that is modern technology. My father, being interested in the European secret operations of World War 2, mentioned a topic I had never heard of before: cracking the enigma code. Upon doing a quick google search of enigma, I soon realized that this topic both challenged my prior knowledge of the computer's birth and connected perfectly to this year's theme, "Communication in History: The Key to Understanding." In the early stages of World War Two, the Nazi regime encrypted their intelligence with the commercial enigma machine, allowing the party to communicate without risk of enemy compromise. Germans later developed the Lorenz machine in addition to the enigma to send high intelligence 'Ultra' messages. The inability for Allied forces to intercept such substantial communication came at the expense of British dominance over the Atlantic Ocean and reception of goods from the US. As a result, codebreakers recruited by the GC&CS quietly got to work deciphering German code at Bletchley Park, Buckinghamshire, and so came the creation of the "Bombe" & "Colossus" machines.

I began by digging into reliable secondary resources to provide myself a basic understanding of Bletchley Park. Once I took notes on various parties involved in the operation and established a basic timeline of events, I searched for primary resources from Bletchley veterans. Due to the Official Secrets Act which prohibited those involved from speaking on the matter, most prominent figures in the affair had already passed away before they got the chance to share their stories. I used multiple interviews and books written by codebreakers/Y-Service members to get a better idea of Bletchley's culture and community.

I created my project using a standard backboard that I transformed with photographs and personal/supporting primary text. I utilized color-coded poster paper on the backing of text to

illustrate comprehensible sections. Finally, I utilized recycled scraps to make the letters of my title resemble that of an Enigma machine keyboard.

My historical argument is that with the creation of the "Bombe" and "Colossus" to unravel German communication (not conceivable without the research of Alan Turing who mechanicalized cribs to find the root settings of an enigma code & developed Turingery), millions of civilian & military lives were saved, and WW2 was shortened. Bletchley's advancements provided vital information to Allied fighting forces whose success was reliant on knowing the enemy's intelligence/plans. Additionally, combatting Lorenz code resulted in the creation of Colossus, the first large-scale electronic computer, fathering modern computer science by laying the foundation for future electric computing machines.

My topic is significant in history in that the work of codebreakers at Bletchley Park not only shaped the outcome of Allied success in World War Two, but also made research breakthroughs in the field of computer science which affect our world today. Seeing how few know about the incredible task accomplished by Turing and his fellow code breakers, I knew Bletchley's story had to be told.

Annotated Bibliography

Primary Sources

"Alan Turing, Enigma, and the Breaking of German Machine Ciphers in World War II." *Prologue Quarterly of the Nation Archives and Records Administration*, vol. 29, no. 1, Spring 1997, pp. 203-19 Accessed 4 Mar. 2021.

This section of the NARA magazine which was written by Bletchley veteran, Lee Gladwin, helped me understand just how imperative Turing was to the general operations of Bletchley and how his work on the Bombe/Colossus fed into the achievements of his fellow codebreakers. It also provided me information on what cribs were and how codebreakers used the human nature of Enigma operators to their advantage. I was able to use a quote from this passage on my exhibit to display how the carelessness of one German operator in setting up his machine allowed the codebreakers to arrive at the final steckers later.

"Bletchley Park - Britain's Great Code Breaking Secret." uploaded by National Computing Science Project, 10 Feb. 2014, www.youtube.com/watch?v=8vKPZUMLYjI&ab_channel=NationalComputingScienceProject. Accessed 4 Mar. 2021.

This video explained the importance that the work at Bletchley Park had on significant WW2 battles including, but not limited to, D-Day as told by multiple Bletchley codebreakers/historians. This video provided my exhibit with primary quotes which will help the viewer understand just how significant cracking German communication was to the success of land, sea, & air attacks outside Bletchley Park and provided information

about the complex and tedious process that a single encrypted code went through for my self-written portion on challenges codebreakers faced.

"Bletchley Park Code Breaker Reveals How She Kept War Secrets for Over 60 Yrs | Good Morning Britain." *Youtube*, uploaded by Good Morning Britain, 8 May 2020, www.youtube.com/watch?v=SM9Jf0IP40s&ab_channel=GoodMorningBritain. Accessed 2 Mar. 2021.

This video was a personal account from a Bletchley Park codebreaker, Better Webb, who was forced to retain secrecy for years after the war. It helped me to understand the tedious process in which a code went through to be deciphered and I was able to utilize a quote from Webb to emphasize said point.

Bombe Operator. *NSA CSS*, National Security Agency & Central Security Service, www.nsa.gov/News-Features/Photo-Gallery/igphoto/2002136460/. Accessed 7 Mar. 2021.

This photograph shows a female operator utilizing the Turing-Welchman bombe machine. I utilized this photograph within my exhibit to show both the huge size/complexity of these machines and the fact that women could be operators of bombes at Bletchley Park, differing from the role of women in other military fields during World War two.

British (Red) and Foreign (Black) Merchant Shipping Losses by Different Forms of Enemy Action. A.S.W. Division, 1942. *The National Archives Learning Curve*, The National Archives, www.nationalarchives.gov.uk/education/worldwar2/theatres-of-war/atlantic/investigation/battle-of-the-atlantic/sources/docs/1/. Accessed 28 Feb. 2021. Infographic.

This primary-source graph showed how British and foreign merchant ships were being targeted during the Battle of the Atlantic by German submarines at a disproportionally higher rate than by any other form of enemy action. It also showed how serious the situation was in the Battle of the Atlantic in 1941-42 and how the supplies coming from the US/Canada like medicine, food, and other goods weren't making it to Britain, harming the economy/citizens who relied on them.

"Capt Jerry Roberts: Did Alan Turing help break Tunny? Code-breaking machine reliability." *Youtube*, uploaded by Tnmoc, 24 Mar. 2014, www.youtube.com/watch?v=ggmQdYGVAw4&ab_channel=tnmoc. Accessed 28 Feb. 2021.

This source was a personal account from Captain Jerry Roberts of the Lorenz Testery group in regards to Turing's impact on his personal job. It confirmed that despite what many secondary sources try to convey regarding the influence Turing had on the creation of the Colossus machine, his role was necessary and significant in the deciphering of Tunny. A quote by Roberts is included on my exhibit to affirm the role that Turing played in cracking Lorenz code through Colossus.

Churchill, Winston. Telegram to Harry Truman. June 1945. *The National Archives Learning Curve*, The National Archive, www.nationalarchives.gov.uk/education/worldwar2/theatres-of-war/atlantic/investigation/battle-of-the-atlantic/sources/docs/3/enlarge.htm. Accessed 28 Feb. 2021.

This telegram from Churchill to Harry Truman showed me just how great of a threat was posed to Allied Forces, specifically Britain, by the Battle of the Atlantic. It also helped

me to understand how the progression of tone from early first-hand documents written by Churchill to later documents changed with the contributions of Bletchley. A copy of the telegram is included on my exhibit to encompass the potential devastation that was posed by the German Kriegsmarine.

"Collections uncovered 14, Traffic Analysis." *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-14. Accessed 7 Mar. 2021.

This webpage featured a collection of primary source photographs dedicated to the SIXTA section of Bletchley that focused on volume, direction, broadcast patterns, call signs and other characteristics of enemy message traffic. This collection helped me understand the vitality of the traffic analysis section to the operations which occurred within Bletchley Park and how said section worked with the external characteristics of enigma deciphering. I included multiple photographs from the collection on my exhibit to emphasize that traffic analysis was equally as important in the movement of codes from the enemy's hands to Allied military forces as the actual codebreaking itself.

"Collections uncovered 9, ATS 80th Anniversary." *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-9. Accessed 7 Mar. 2021.

This webpage was a primary photograph collection to recognize the over 400 female Auxiliary Territorial Service members and their contributions to signals intelligence work at Bletchley Park. Two primary source photographs from the collection are included within my exhibit to show how women's work within the SIXTA section of Bletchley fed into the success of more prominent figures like Alan Turing and also how the cracking of Lorenz code was heavily female dominated, contrary to popular belief, as ATS women were employed to operate the Colossus machine.

"Collections uncovered 20, The First Huts." *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-20. Accessed 7 Mar. 2021.

This webpage featured a collection of primary source photographs of the different huts at Bletchley Park, including the original huts from early August 1939 and the new huts which were built during late August 1939 to accommodate for the growing Bletchley population. These photographs gave me a better visual representation of the Bletchley mansion and were included within my exhibit to show how the normality of the estate contributed to the secrecy of the codebreaking operation as a whole.

Cross & Connecting Plug Assembly. *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-3. Accessed 7 Mar. 2021.

This photographed blueprint of plugs in the Bombe Machine which correlate with the bombe drums were created by engineers at the British Tabulating Machine Company who were in charge of building the machines designed at Bletchley. This photograph was utilized in my exhibit to demonstrate the immense and precise effort put into creating the Bombe machine and how the blueprints translated into the final machine.

Elliott & Fry. *Alan Turing*. 29 Mar. 1951. *National Portrait Gallery*, www.npg.org.uk/collections/search/portrait/mw165875. Accessed 4 Mar. 2021.

This is a portrait of Alan Turing from 1951, roughly 6 years after World War 2. I included this portrait on my exhibit to show the imperativeness of Alan Turing in deciphering German Enigma/Lorenz code and how he was a prominent figure at Bletchley Park that deserves to be highlighted in the telling of Bletchley's story.

Elsie Booker and Dorothy du Boisson operating the Colossus machine. *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-13. Accessed 7 Mar. 2021.

This photograph of two Bletchley veterans from the Women's Royal Naval Service, Elsie Booker and Dorothy du Boisson, shows the women operating the Colossus machine to decipher German Lorenz code. This primary source showed me exactly what the electronic valves who stored information for statistical analysis looked liked and is included within my exhibit to highlight how the first electronic computer has changed from the modern perception of a what a computer looks like. I also included this photograph to help my exhibit viewers grasp how a machine of such high complexity & size was designed/built in a relatively short period of time when information on digital computers was limited.

A German 'Enigma' Cipher Machine. *IWM*, Imperial War Museums, www.iwm.org.uk/collections/item/object/205193087. Accessed 7 Mar. 2021.

This photograph shows German General Guderian's command vehicle in France as he shows his Enigma machine to soldiers. I included this primary photo within my exhibit to show how German military officials utilized the enigma machine in their everyday tasks and how communication using these devices was not exclusive to the German SIGNIT network or experienced cryptanalysts.

The German Enigma Machine. *The National Archives Learning Curve*, The National Archives, www.nationalarchives.gov.uk/education/worldwar2/theatres-of-war/atlantic/investigation/battle-of-the-atlantic/sources/photos/2/. Accessed 28 Feb. 2021.

This primary source photograph shows a German enigma machine and the components which give the machine the appearance of a typewriter. The photograph provided me a visual idea of an enigma machine's size, appearance, and complexity, and I chose to

include said photograph to help the viewer of my exhibit visual where a message would have been imputed via the key-buttons and outputted via the lightboard.

Gladwin, Lee A. "Alan Turing, Enigma, and the Breaking of German Machine Ciphers..." *Prologue*, Fall 1997. *SIRS Issues Researcher*, explore.proquest.com/sirsissuesresearcher/document/2250210601?accountid=2414.

This article produced by Lee A. Gladwin, a Bletchley veteran, runs through the progression of the Polish 'bomba' all the way to the creation of the first large-scale electronic computer called Colossus as knowledge of codebreaking progressed at Bletchley Park. This article specifically helped me to understand how Alan Turing utilized the tools & information given to him by the Poles in his development of the Bombe with Gordon Welchman and how the combination of Lorenz/Enigma intelligence affected the outcome of WW2 in Europe.

Good, I. J., and Donald Michie. Interview. Conducted by David Kahn and Karen Frenkel. *From Codebreaking to Computing: Remembrances of Bletchley Park 50 Years Later*, produced by J. A. N. Lee and Golde I. Holtzman, Virginia Polytechnic Institute and State University, 1992.

This interview with I.J. Good and Donald Michie, both of whom were tasked with the mathematical research required for the creation of the Colossus machine to decipher German Lorenz code, helped me to understand the collaborative effort that took place at Bletchley Park and how the combined contributions of Bletchley minds helped lay the foundation of modern computer science. Tommy Flower's Colossus would not have been possible had it not been for Turing's revelation of Turingery or Good/Michie's help in applying Turingery to a mechanicalized computing system as explained in this interview.

I.J. Good was quoted within my exhibit for his explanation of early cribs as to elaborate on the use of cribs through the perspective of someone who actively partook in the theory's development.

Haufler, Hervie. "The Miracle of Bletchley Park." *Warfare History Network*, Sovereign Media, warfarehistorynetwork.com/2016/10/03/the-miracle-of-bletchley-park/. Accessed 6 Jan. 2021.

This article, written by Hervie Haufler who was a cryptanalyst that helped operated a radio intercept station at Hall Place in Bexley, Kent, explained the signifcance of Bletchley Park through the perspective of someone who directly contributed to the effort of codebreaking with no knowledge of what he was actually doing until about 30 years later due to his demobilization pledge. Haufler and other cryptanalysts like himself scanned radio nets for enemy messages being sent in the form of Morse code and recorded the figures heard. Unbeknownst to Haufler, these records were then sent to Bletchley Park for decryption. This source was quoted within my exhibit to represent the vital role that hidden war figures played who did not directly decipher messages played in the overall operation of Bletchley Park.

Hilton, Peter. "Reminiscence of Bletchley Park, 1942-1945." *A Century of Mathematic in America,* edited by Peter Duren et al., e-book, Providence, Rhode Island, American Mathematical Society, 1988, pp. 291-300.

This chapter by Peter Hilton, British mathematician and Bletchley codebreaker, focuses on the vitality that Alan Turing's research played, starting with the creation of the Bombe, in the success of different codebreaking sectors at Bletchley. Turing's development of cribs and later Turingery aided in deciphering Enigma produced from machines with a

variety of rotor numbers, naval and air enigma, and eventually the Lorenz cipher. Language from this source is quoted on my exhibit to illustrate the significance of Turing as a codebreaker/ early computer scientist in addition to both the short and long term effects that Bletchley's breakthroughs had on the world.

Hinsley, Francis Harry, et al. *British Intelligence in the Second World War: Its Influence on Strategy and Operations*. Vol. 1, London, H. M. Stationery office, 1979.

This account, written by Francis Harry Hinsley who's work at Bletchley as a cryptanalyst focused on the external features of enigma like traffic analysis and German Kriegsmarine communication structure, helped me understand how Germans developed a system of changing machine steckers that was mutual between operators & receivers and worked around the troubles that might come in the event of an enigma machine being captured by Allied forces. A quote from Hinsley is featured on my exhibit to fully encompass the challenge that was deciphering Enigma in regard to both the machine's encoding capability and the precise steps taken by German operators so that their communication would not be compromised.

John A. N. Lee and Golde Holtzman. 1995. 50 Years After Breaking the Codes: Interviews with Two of the Bletchley Park Scientists. *IEEE Ann. Hist. Comput.* 17, 1 (March 1995), 32–43. DOI:https://doi.org/10.1109/85.366512

This interview with Bletchley scientists John A. N. Lee and Golde Holtzman helped me understand the challenge posed by sudden use of Lorenz codes and how said challenge was able to be worked through with the utilization of previous Enigma research & collaboration of different huts at Bletchley Park. Their perspective in this interview also provided me details on the culture/climate of the estate with specific remarks on the

personality of prominent figures like Alan Turing, Tommy Flowers, & Gordon Welchman.

Knox, A. D., et al. "Enigma report, November 1939." 1 Nov. 1939. *Alan Turing: The Enigma*, Andrew Hodges, www.turing.org.uk/sources/nov39.html.

This report on Enigma from November 1, 1939 came soon after Germany invaded Poland and provided information about Enigma wirings and groundbreaking cryptanalytic methods using machines learned from the Poles. Signed by top codebreakers Turing, Welchmen, Knoxx, & Twinn, this primary document helped me understand direct value of the Polish intelligence on Enigma decipherment and the rapid speed at which Bletchley got to work on cracking Enigma code.

A letter from John Herivel. 10 July 1945. *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-28. Accessed 7 Mar. 2021.

This photograph is of a letter from John Herivel, a Bletchley codebreaker from January 1940 until October 1945 who worked on deciphering both Lorenz and Enigma code. The letter photographed wishes the staff at Bletchley Park goodbye and recognizes the vital work they did while suggesting that one day their story would be told, despite the Official Secrets Act. I included this photograph within my exhibit to demonstrate how telling the story of Bletchley Park is important to both explain the lasting impacts that deciphering had on the war/computer science and honor the wishes of Bletchley veterans who have been kept quiet for so long.

A list of common military abbreviations with their German full form and English translation. *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-25. Accessed 7 Mar. 2021.

This document from GC&CS training provided to codebreakers working at Bletchley Park features common German military phrases in their abbreviated form along with in their English and German form. This document helped me to understand the training that new Bletchley recruits underwent and connected to information I had learned prior regarding how common plain text such as that listed above were used as cribs to determine Enigma machine settings.

Mahon, A. P., and John Jackson. *Naval Enigma: The History of Hut Eight, 1939-1945*. 2009. Accessed 7 Mar. 2021.

This book from codebreaking-colleague of Alan Turing, A.P. Mahon, provided me more information on the complicated work on Naval enigma conducted in Hut 8 of Bletchley Park and how the breakthroughs made within the research group had significant impacts on the Battle of the Atlantic and later, computer science. Although I was not able to read the entirety of the book, the primary perspective of Mahon is quoted within my exhibit to attest to the importance of Turing in cracking Naval enigma from someone who worked with him directly.

Newspaper cutting and xerox copies from The Guardian relating to the forthcoming biography of AMT (Alan Turing : the Enigma) by Andrew Hodges. 14 Jan. 1980. *The Turing Digital Archive*, www.turingarchive.org/viewer/?id=58&title=1. Accessed 7 Mar. 2021.

This photograph shows an excerpt from the Guardian magazine about the upcoming biography of Alan Turing by fellow codebreaker, Andrew Hodges. This was included within my exhibit to show how the stories of Bletchley Park veterans began to be popularized once the pledge of demobilization/secrecy was lifted and how huge figures

like Alan Turing were left in the shadows of history for years despite the massive impact they had on the war/computer science.

Personnel of Special Communications Unit NO. 1 at "Windy Ridge", The Special Operations Group Wireless Station Whaddon, Buckinghamshire, 1945. 1945. *IWM*, Imperial War Museum, www.iwm.org.uk/collections/item/object/205124675. Accessed 7 Mar. 2021.

This photograph shows the "Windy Ridge" special communications group who were responsible for transmitting 'Ultra' information received from Bletchley Park to the Special Liaison Units attached to Allied headquarters in the field. I included this photograph within my exhibit to help the viewer understand that Bletchley Park did not directly act on intercepted communication and the path of a code was tedious/complex.

Roosevelt, Franklin D. Telegram to Winston Churchhill. Nov. 1943. *The National Archives Learning Curve*, The National Archives, www.nationalarchives.gov.uk/education/worldwar2/theatres-of-war/atlantic/investigation/battle-of-the-atlantic/sources/docs/2/enlarge.htm. Accessed 28 Feb. 2021.

This telegram from Roosevelt to Churchill was apart of a series of telegrams between the two sent during the course of the Battle of the Atlantic. This specific telegram details how the tides of the battle were beginning to turn as more German U-Boats were being taken down than Allied merchant ships. This source provided me details how top military officials began to see quantifiable change in the ratio of Allied to German ship sinkings when more codes were intercepted during 1943, and a copy of the telegram is included within my exhibit to show how significantly the tides of the Battle of the Atlantic were turning when British code breakers could read German naval signals.

Rowland, Margaret. A group of WAAFs (Women's Auxiliary Air Force) from Bletchley Park. *Bletchley Park*, Bletchley Park Trust, bletchleypark.org.uk/news/collections-uncovered-28. Accessed 7 Mar. 2021.

This photograph from veteran Margaret Rowland shows a group of WAAFs (Women's Auxiliary Air Force) from Bletchley Park who traveled to Trafalgar Square for VE day. This photograph helped me understand the diverse population that collaborated at Bletchley Park and is included within my exhibit to show that women too played a vital role in cracking of German wartime codes.

Shipping Sunk by U-Boats in the Atlantic. A.S.W. Division, 1942. *The National Archives Learning Curve*, The National Archives, www.nationalarchives.gov.uk/education/worldwar2/theatres-of-war/atlantic/investigation/battle-of-the-atlantic/sources/docs/1/. Accessed 28 Feb. 2021. Chart.

This chart from 1942 published by the A.S.W. Division showed the quantity of U-Boat-induced Allied ship sinkings on a map during different months of the year. It also showed the concentration of Allied ships sunk by Germans in different areas of the Atlantic (represented by dots on the map) during different points of the year, specifically how boats were being sunk closer to the United States coast towards the end of the year as opposed to the beginning of the year when they were frequently sunk near Britain's coast. This map is included within my exhibit to represent how serious the Battle of the Atlantic was in 1941-42 for Allied forces.

Terdiman, Daniel. "Breaking the Nazis' Enigma codes at Bletchley Park (photos)." *CNET*, 20 Mar. 2012, www.cnet.com/pictures/breaking-the-nazis-enigma-codes-at-bletchley-park-photos/. Accessed 4 Mar. 2021.

This website provided me photographs of the Enigma and Colossus machines and showed the many features of each machine. I used a primary-source photograph included on the webpage on my exhibit to better show the scale and sheer complexity of the Colossus machine.

Turing, Alan. "Turing's Treatise on the Enigma." catalog.archives.gov/id/2807108. Accessed 4 Mar. 2021.

This primary source written by Alan Turing himself was imperative in providing me an explanation of how Enigma worked and although I could not read through all 119 pages, it showed the progression of knowledge regarding Enigma at Bletchley from 1939-1942. I used two direct quotes from the treatise to help tell Bletchley's story, one of which explains the early idea of cribs before mechanicalized and a second which shows Turing's understanding of the Enigma Machine utilizing personal information and information from the Poles.

Secondary Sources

"Alan Turing - Celebrating the life of a genius." *Youtube*, uploaded by University of Cambridge, 21 June 2012, Alan Turing - Celebrating the life of a genius. Accessed 6 Jan. 2021.

This video about Alan Turing helped me understand the contribution that Turing made to both codebreaking and computer science during his time at Bletchley & beyond. It also

gave me background on how Turing specifically went about creating the Bombe machine and how he helped apply Turingery to Colossus.

"Battle of the Atlantic - WW2 Timeline (September 3rd, 1939 - May 7th, 1945)." *Second World War History*, MilitaryFactory.com, www.secondworldwarhistory.com/battle-of-the-atlantic.php. Accessed 21 Feb. 2021.

This website provided me a general timeline of the Battle of the Atlantic beginning in September 1939 and how German U-Boats posed a huge threat to Allied forces by attacking merchant ships. I utilized information regarding the German attempted economic blockage and submarine "wolf pack" attacks on my exhibit to show just how peril the situation in the Atlantic was and how it fed into the birth of Bletchley Park.

"Bletchley codebreaker Raymond 'Jerry' Roberts appointed MBE." *BBC News*, BCC, 29 Dec. 2012, www.bbc.com/news/av/uk-20863205. Accessed 4 Mar. 2021.

This webpage provided me with information about one of the core members of the Testery section at Bletchley Park, Captain Jerry Roberts, who worked to decipher German high-intelligence Tunny code created by the Lorenz machine. Roberts among others are often overlooked in the story of Bletchley park and his contributions to Testery helped to shorten WW2 by up to two years. I used an image of Roberts from this article in my exhibit along with used information regarding Tunny to develop my Lorenz section of my project & show the code's impacts on Allied forces.

Britannica, The Editors of Encyclopaedia. "Enigma." Encyclopedia Britannica, 14 Jun. 2019, https://www.britannica.com/topic/Enigma-German-code-device. Accessed 25 February 2021.

This source provided me in-depth details on how an Enigma machine is built, how the electromechanical process can generate such a large number of outcomes from one input, and the commercial history of the enigma machine. This source also helped me understand the impact that the Poles prior work on Enigma before the war helped codebreakers like Turing in creating an effective bombe machine.

"The Codebreakers' War in the Atlantic." *Warfare History Network*, Sovereign Media, warfarehistorynetwork.com/2019/01/01/the-codebreakers-war-in-the-atlantic/. Accessed 4 Jan. 2021.

This article drew the connection between the Battle of the Atlantic and the work of Bletchley Park. German U-Boat attacks were easily coordinated by exploiting the Royal Navy's outdated set of codebooks that had already been cracked by the German SIGNIT network and communicating plans in secret with Enigma code. The battle only began to turn around in favor of the Allies once naval enigma was deciphered and used to direct convoys away from coordinated attacks. This connection was especially important in explaining the short-term impacts cracking the enigma cipher had on the war.

Collins, Jeremy. "Alan Turing and the Hidden Heroes of Bletchley Park: A Conversation with Sir John Dermot Turing." *The National World War II Museum New Orleans*, The National WWII Museum, 24 June 2020, www.nationalww2museum.org/war/articles/alan-turing-betchley-park. Accessed 23 Feb. 2021.

This interview of Sir John Dermot Turing who survives Alan Turing as his nephew brings light to not just the work of Turing at Bletchley but other key players including, but not limited to, the Y-Service staff who intercepted the messages in Morse code, Hut (research groups) who focused on Enigma aside from naval enigma, and the Tunny

Testery group. He also elaborates on the unique culture of Bletchley Park which differed from one's perception of wartime heroes (those at Bletchley were chosen simply for intellectual ability & not social class, military rank, gender, etc.) and the process of recruiting a melting-pot of top mathematical minds. I included a quote from J. Turing on my exhibit to elaborate on the Bletchley recruitment process and how the process, despite what one might believe, was a rushed affair.

Copeland, B. Jack. *Colossus: The Secrets of Bletchley Park's Code-breaking Computers*. New York, Oxford University Press, 2010. Accessed 5 Mar. 2021.

This book explained the importance of the Colossus Machine in fathering computer science and how the secrecy of Bletchley Park often downplays the role of the Tunny codebreakers in what we consider to be the beginning of computing. I used quotes from Bletchley veterans exclusive to this book in my project to convey how Colossus had lasting impacts on the modern world besides just shortening WW2.

Copeland, Prof. Jack. "Alan Turing: The codebreaker who saved 'millions of lives.'" *BBC News*, British Broadcasting Corporation, 19 June 2012, www.bbc.com/news/technology-18419691. Accessed 6 Jan. 2021.

This article, written by Prof Jack Copeland who helped build the Turing Archive for the History of Computing, explained to me the impacts that cracking enigma code actually had towards shortening the war and saving lives in the process through aiding D-Day/other significant battle efforts with thought-to-be classified German information. It also helped me differentiate between the Bombe machine and Turingery, though both extremely important research contributions made by Alan Turing during his time at Bletchley Park.

"Enigma." *The Mariners' Museum*, www.marinersmuseum.org/sites/micro/battle_of_the_atlantic/cc.htm#:~:text=The%20Battle%20of%20the%20Atlantic%3A%20Allied%20Naval%20Intelligence%20in%20World%20War%20II&text=Anticipating%20enemy%20attempts%20to%20intercept,the%20text%20of%20radio%20messages.&text=Best%20known%20by%20its%20commercial,was%20a%20uniquely%20complex%20device. Accessed 21 Feb. 2021.

This webpage explained how the German navy developed codes and cipher machines to hide the content of radio messages, expecting Allied attempts to intercept radio signals. It also explained to me the differences between 3 & 4 rotor enigma machines, and how the complexity of enigma only intensified with the elevated ranks of German vessels. This resource was especially useful in helping develop a basic timeline for the understanding of enigma by Bletchley codebreakers in relation to the dominance over the Battle of the Atlantic.

"Historic Eisenhower letter praising code breakers goes on display." *BBC News*, BBC, 15 Mar. 2016, www.bbc.com/news/uk-england-beds-bucks-herts-35804433. Accessed 6 Mar. 2021.

This article expressed Eisenhower's appreciation of the Bletchley code breakers and how their contributions to the war extended past Britain to the US. This webpage provided me a primary source document of a letter Eisenhower wrote to Sir Stewart Menzies which I quoted to help the viewer understand the impact deciphering at Bletchley Park had on the length of the war & lives saved as a result.

"How Alan Turing Cracked The Enigma Code." *Imperial War Museums*, IWM, www.iwm.org.uk/history/how-alan-turing-cracked-the-enigma-

code#:~:text=But%20the%20work%20of%20Bletchley,the%20war%20by%20several%20years. Accessed 6 Jan. 2021.

This article provided a brief overview of Alan Turing's work at Bletchley including his background in mathematics at Cambridge in the 1930s, his research on and creation of the Bombe machine, his work solving Naval enigma in Hut 8, and his development of Turingery in July 1942. This article helped me understand the difference between Alan's work on enigma which was aided by his creation of the Bombe and his work on deciphering Lorenz code which fed into the Colossus machine with the creation of Turingery.

"The Lorenz and the Colossus." *The Alan Turing Internet Scrapbook*, www.turing.org.uk/scrapbook/electronic.html. Accessed 28 Feb. 2021.

This webpage described the development of the Colossus machine for deciphering Lorenz using Turingery after W. T. Tutte exploited a dramatic German transmission error on August 30,1941. This webpage helped me understand that Colossus depended upon Alan Turing's statistical theory developed for deciphering naval Enigma, however Colossus was *not* used to crack enigma but Lorenz ("Tunny") code.

Prasad, Kalika, and Munesh Kumari. *A review on mathematical strength and analysis of Enigma*. Department of Mathematics, Central University of Jharkhand, India, 22 Apr. 2020. *Cornell University arXiv.org*, arxiv.org/pdf/2004.09982.pdf#:~:text=Since%20in%20the%20new%20enigma,total%20possible%20combinations%20are%20264.&text=To%20increase%20the%20irregularity%20of,to%20some%20rings%20in%20order. Accessed 22 Feb. 2021.

This report explained the innerworkings of an enigma machine from a mathematical perspective and examined the total potential outcomes from one enigma input under differing circumstances like plugboard settings (steckers) and number of rotors within the machine. This helped me to fully understand just how complicated an enigma machine is with its variety of internal/external structures and why the electromechanical process actually produces such a large variety of outcomes being the path for electrical circuits are constantly changing.

Rosa Johnston-Flint, Rosa. "An Interview with Bletchley Park's Oral Historian." *Culture Calling*, www.culturecalling.com/uk/features/an-interview-with-bletchley-park. Accessed 26 Feb. 2021.

This interview with Jonathan Byrne, Oral History Officer at Bletchley Park, details the reason the Government Code and Cypher School decided upon Bletchley Park in the first place and how Deniston went about recruiting codebreakers to the GC&CS, starting with top-college scholars from Oxford and Cambridge. This article also helped me understand the height of the operation and how Bletchley Park grew from a small pool of scholars to a working community of roughly 10,000 codebreakers.

Sheffield, Dr Gary. "The Battle of the Atlantic: The U-boat peril." *BBC*, 30 Mar. 2011, www.bbc.co.uk/history/worldwars/wwtwo/battle_atlantic_01.shtml#:~:text=Winston%20Churchill%20once%20wrote%20that,')%20to%20the%20Atlantic%20lifeline. Accessed 22 Feb. 2021.

This article discussed the multiple factors that played into Allied victory in the Battle of the Atlantic from the initial peril, rising tension, and eventual combat of "Wolf Pack" U-Boat attacks against US/Canadian merchant ships that threatened the economy of Britain.

It specifically provided me detailed information on how the British were able to move convoys in safe areas, away from the wolfpacks, with the advantage of "Ultra" intelligence from codebreakers.

Simkin, John. "Francis Harry Hinsley." *Spartacus Educational*, Spartacus Educational Publishers, spartacus-educational.com/Francis_Harry_Hinsley.htm. Accessed 4 Mar. 2021.

This webpage provided me more insight into the life of another significant figure at Bletchley Park, Francis Harry Hinsley, and showed how his writings in which I quote later in my exhibit were important to preserving the legacy of Bletchley. I used a photograph of Hinsley to include on my exhibit to show other prominent figures in the operation which was Bletchley Park (aside from Alan Turing).

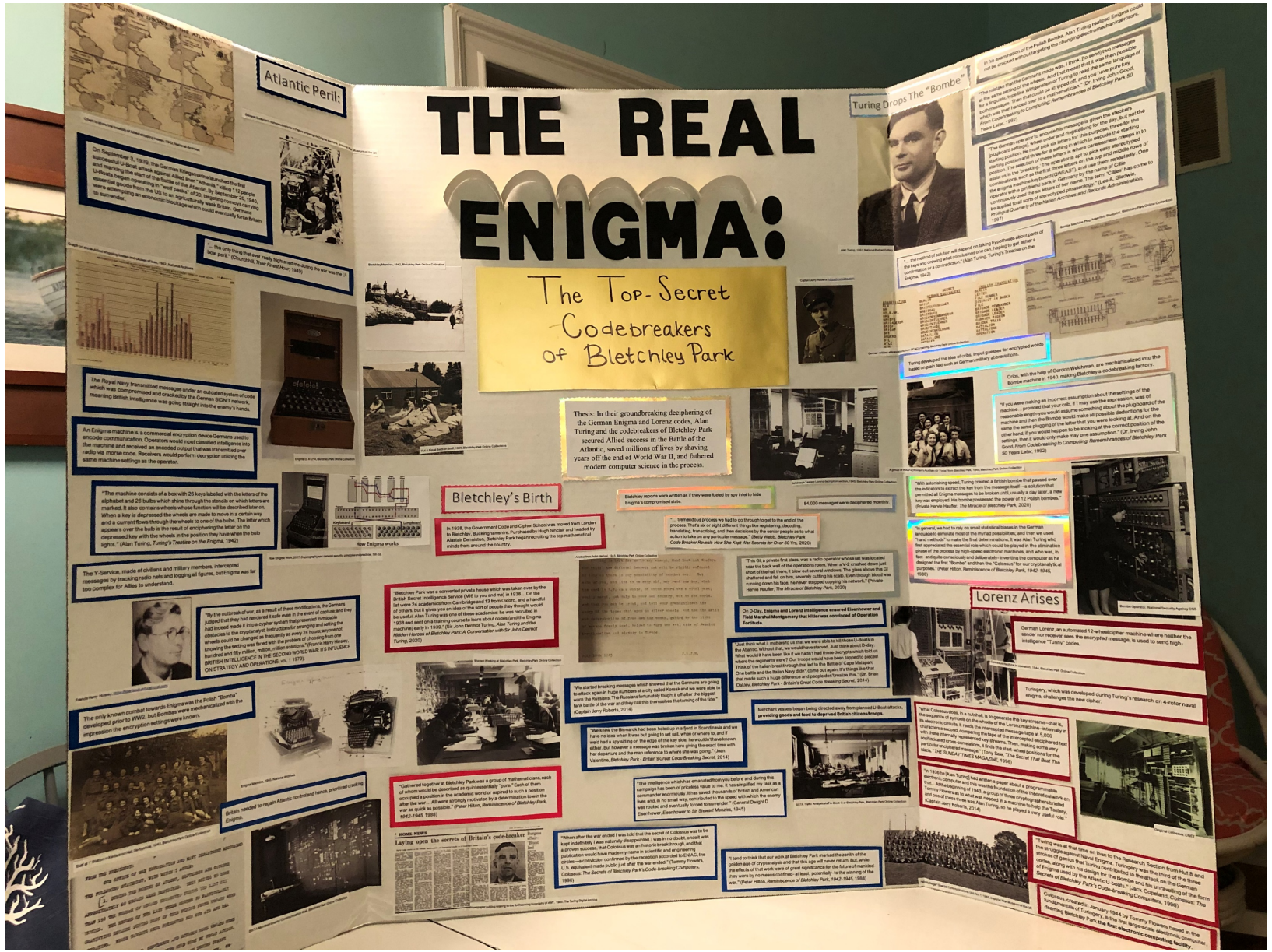
STALLINGS, W. Cryptography and network security: principles and practice, 7th Ed. Pearson Education Limited, 2017.

This diagram shows the path of an electrical current in an enigma machine, beginning from the pressing of a letter on the typewriter-like keyboard to the current's circuit through the changing rotors to produce an outcome. I included this diagram on my exhibit to help the viewer visualize the complicated workings of an enigma machine from the input to output as attempting to word said process is often difficult to understand.

"The Turing-Welchman Bombe." *The National Museum of Computing*, www.tnmoc.org/bombe. Accessed 25 Feb. 2021.

This article detailed the purpose of the Turing-Welchman Bombe machine in code deciphering and how beginning with the creation of the first bombe "Victory" in 1940, Bletchley Park grew to host 211 bombes for wartime operation. This article specifically

helped me to understand how the bombe machine did not directly decode an encrypted message but rather discovered the daily key - wheel order, wheel settings and plugboard configuration - to enable codebreakers to decipher a message.



THE REAL ENIGMA: THE TOP-SECRET CODE BREAKERS OF BLETCHLEY PARK

CENTER PANEL TOP PHOTO

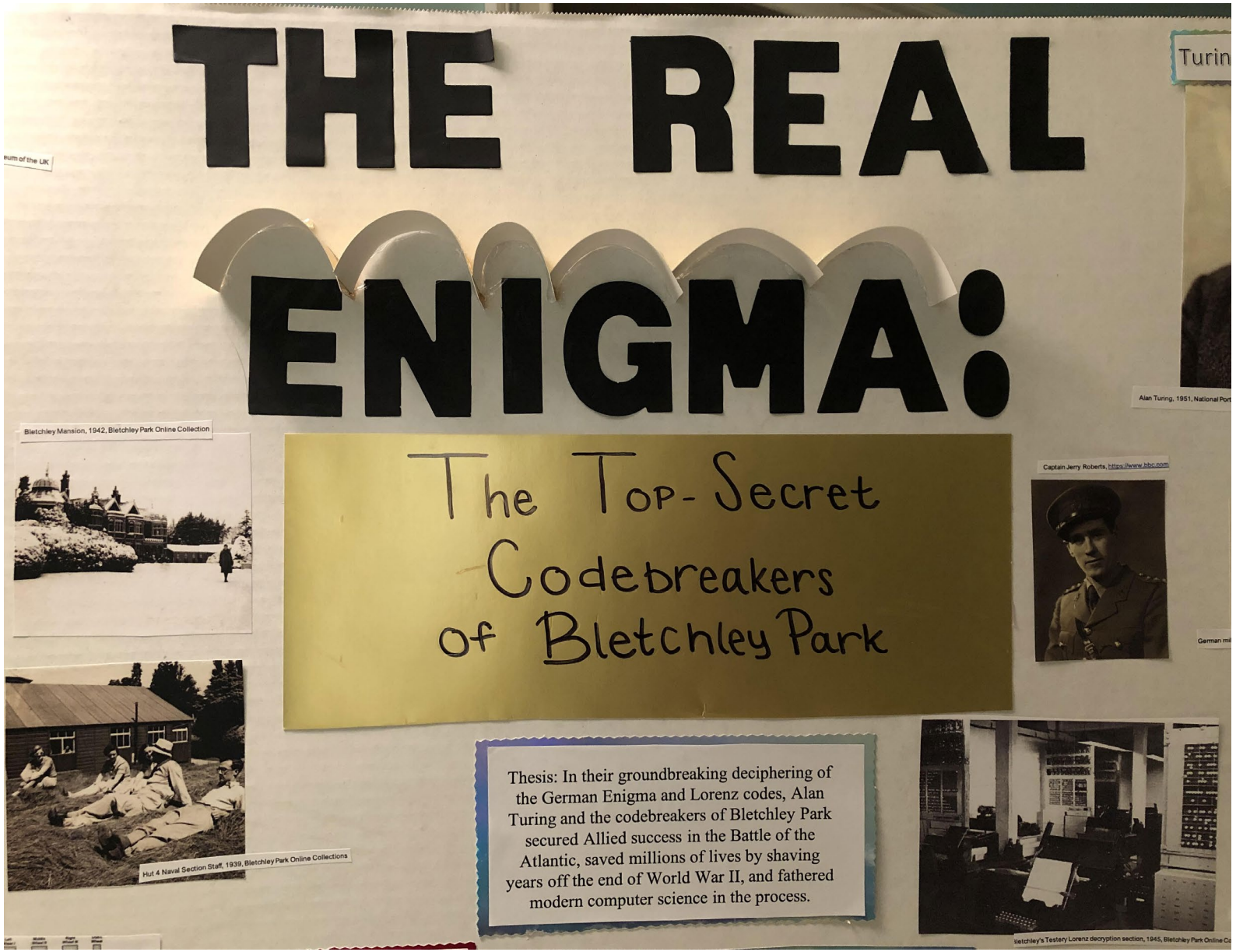
Source Credit Text:

Bletchley Mansion, 1942, Bletchley Park Online Collection

Hut 4 Naval Section Staff, 1939, Bletchley Park Online Collections

Captain Jerry Roberts, https://www.bbc.com

SIXTA Traffic Analysis staff in Block G at Bletchley Park, Bletchley Park Online Collection



CENTER PANEL TOP TEXT:

The Real Enigma: The Top-Secret Codebreakers of Bletchley Park

Thesis: In their groundbreaking deciphering of the German Enigma and Lorenz codes, Alan Turing and the codebreakers of Bletchley Park secured Allied success in the Battle of the Atlantic, saved millions of lives by shaving years off the end of World War II, and fathered modern computer science in the process.

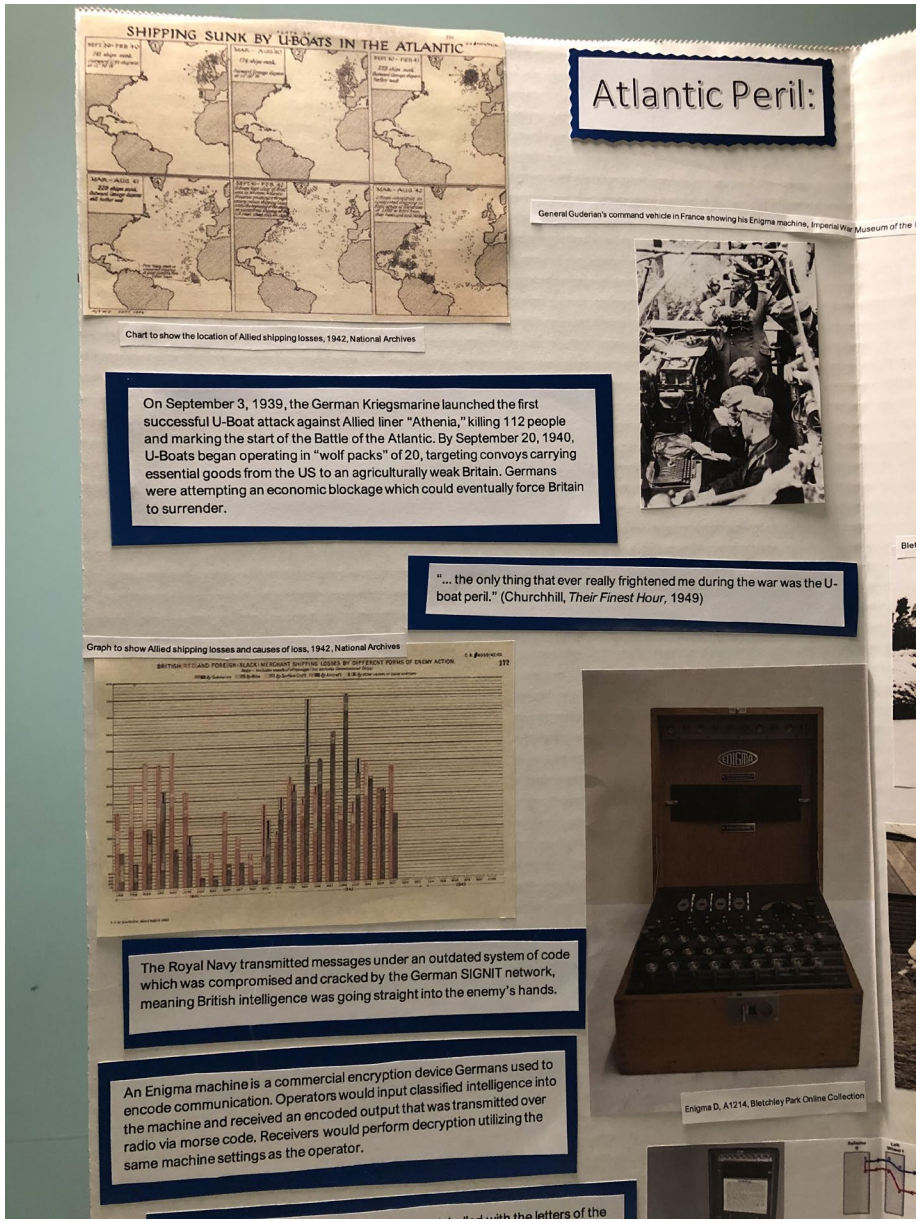
LEFT PANEL TOP PHOTO

SOURCE CREDIT TEXT:
CHART TO SHOW THE LOCATION OF ALLIED SHIPPING LOSSES, 1942, NATIONAL ARCHIVES

GENERAL GUDERIAN'S COMMAND VEHICLE IN FRANCE SHOWING HIS ENIGMA MACHINE, IMPERIAL WAR MUSEUM OF THE UK

GRAPH TO SHOW ALLIED SHIPPING LOSSES AND CAUSES OF LOSS, 1942, NATIONAL ARCHIVES

ENIGMA D, A1214, BLETCHLEY PARK ONLINE COLLECTION



LEFT PANEL TOP TEXT:

Atlantic Peril:

On September 3, 1939, the German Kriegsmarine launched the first successful U-Boat attack against Allied liner “Athenia,” killing 112 people and marking the start of the Battle of the Atlantic. By September 20, 1940, U-Boats began operating in “wolf packs” of 20, targeting convoys carrying essential goods from the US to an agriculturally weak Britain. Germans were attempting an economic blockage which could eventually force Britain to surrender.

“… the only thing that ever really frightened me during the war was the U-boat peril.” (Churchhill, Their Finest Hour, 1949)

The Royal Navy transmitted messages under an outdated system of code which was compromised and cracked by the German SIGNIT network, meaning British intelligence was going straight into the enemy’s hands.

An Enigma machine is a commercial encryption device Germans used to encode communication. Operators would input classified intelligence into the machine and received an encoded output that was transmitted over radio via morse code. Receivers would perform decryption utilizing the same machine settings as the operator.

LEFT PANEL BOTTOM PHOTO

Source Credit Text:

How Enigma Work, 2017, Cryptography and network security: principles and practice, 7th Ed.

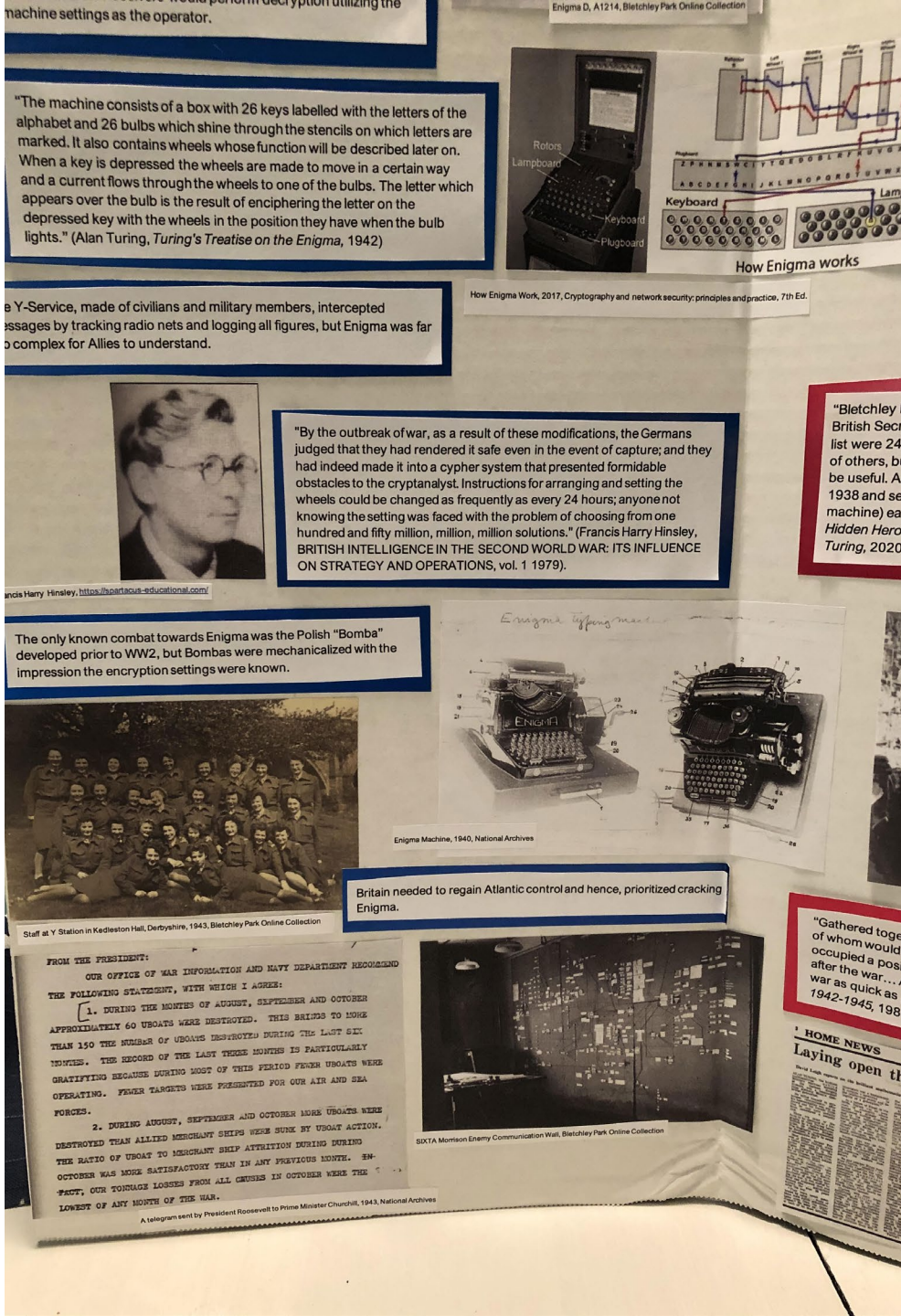
Francis Harry Hinsley, https://spartacus-educational.com/

Staff at Y Station in Kedleston Hall, Derbyshire, 1943, Bletchley Park Online Collection

A telegram sent by President Roosevelt to Prime Minister Churchill, 1943, National Archives

Enigma Machine, 1940, National Archives

SIXTA Morrison Enemy Communication Wall, Bletchley Park Online Collection



LEFT PANEL BOTTOM TEXT 1 OF 2:

- “The machine consists of a box with 26 keys labelled with the letters of the alphabet and 26 bulbs which shine through the stencils on which letters are marked. It also contains wheels whose function will be described later on. When a key is depressed the wheels are made to move in a certain way and a current flows through the wheels to one of the bulbs. The letter which appears over the bulb is the result of enciphering the letter on the depressed key with the wheels in the position they have when the bulb lights.” (Alan Turing, Turing's Treatise on the Enigma, 1942)
- **The Y-Service, made of civilians and military members, intercepted messages by tracking radio nets and logging all figures, but Enigma was far too complex for Allies to understand.**
- "By the outbreak of war, as a result of these modifications, the Germans judged that they had rendered it safe even in the event of capture; and they had indeed made it into a cypher system that presented formidable obstacles to the cryptanalyst. Instructions for arranging and setting the wheels could be changed as frequently as every 24 hours; anyone not knowing the setting was faced with the problem of choosing from one hundred and fifty million, million, million solutions." (Francis Harry Hinsley, BRITISH INTELLIGENCE IN THE SECOND WORLD WAR: ITS INFLUENCE ON STRATEGY AND OPERATIONS, vol. 1 1979).

LEFT PANEL BOTTOM TEXT 2 OF 2:

- The only known combat towards Enigma was the Polish “Bomba” developed prior to WW2, but Bombas were mechanicalized with the impression the encryption settings were known.

- Britain needed to regain Atlantic control from Germany and hence, knew they must prioritize cracking Enigma.

RIGHT PANEL TOP PHOTO

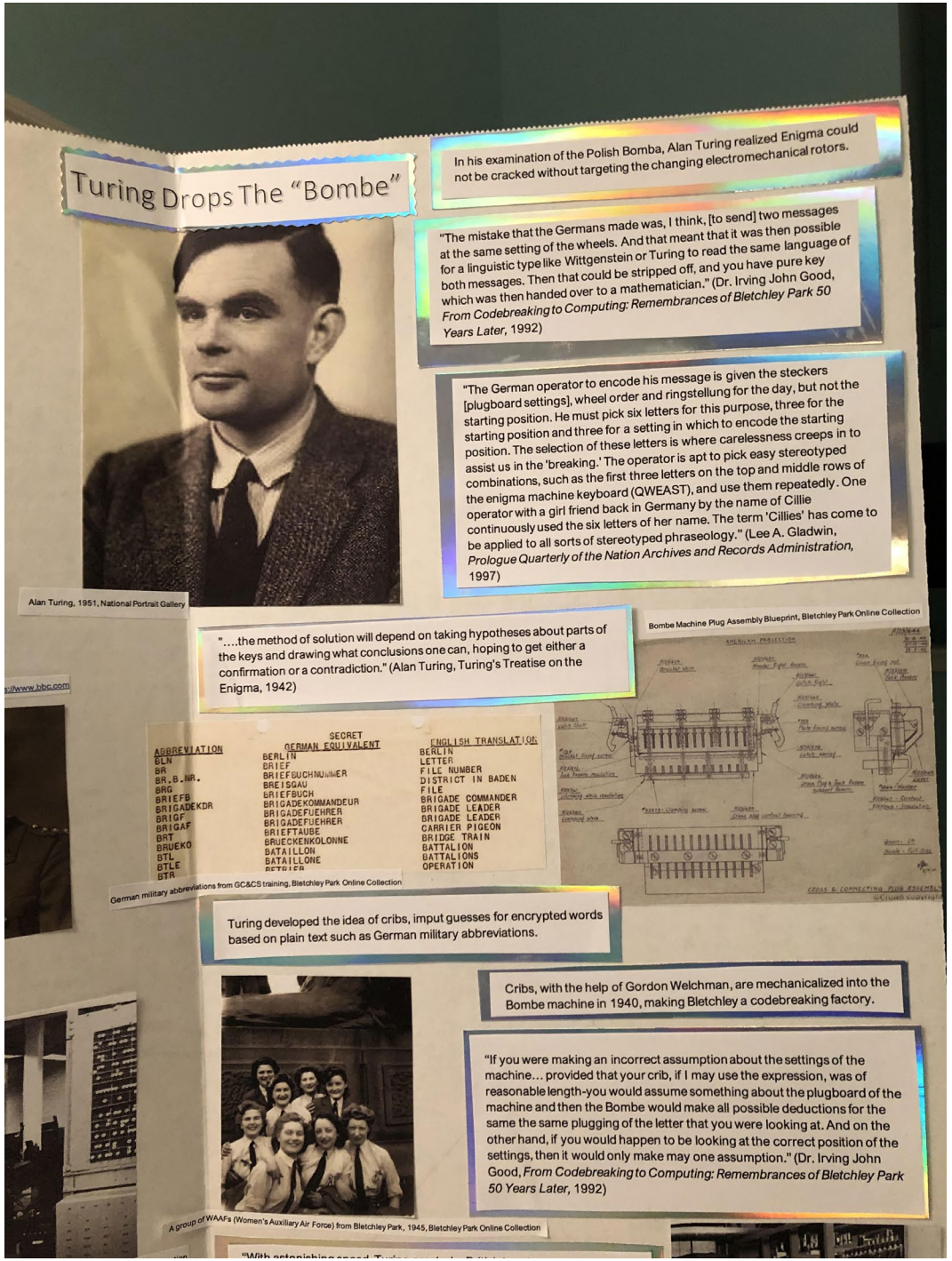
SOURCE CREDIT TEXT:

ALAN TURING, 1951, NATIONAL PORTRAIT GALLERY

GERMAN MILITARY ABBREVIATIONS FROM GC&CS TRAINING, BLETCHLEY PARK ONLINE COLLECTION

BOMBE MACHINE PLUG ASSEMBLY BLUEPRINT, BLETCHLEY PARK ONLINE COLLECTION

A GROUP OF WAAFS (WOMEN'S AUXILIARY AIR FORCE) FROM BLETCHLEY PARK, 1945, BLETCHLEY PARK ONLINE COLLECTION



RIGHT PANEL TOP TEXT 1 OF 2:

Turing Drops The “Bombe”:

In his examination of the Polish Bomba, Alan Turing realized Enigma could not be cracked without targeting the changing electromechanical rotors.

"The German operator to encode his message is given the steckers [plugboard settings], wheel order and ringstellung for the day, but not the starting position. He must pick six letters for this purpose, three for the starting position and three for a setting in which to encode the starting position. The selection of these letters is where carelessness creeps in to assist us in the 'breaking.' The operator is apt to pick easy stereotyped combinations, such as the first three letters on the top and middle rows of the enigma machine keyboard (QWEAST), and use them repeatedly. One operator with a girl friend back in Germany by the name of Cillie continuously used the six letters of her name. The term 'Cillies' has come to be applied to all sorts of stereotyped phraseology.” (Lee A. Gladwin, Prologue Quarterly of the Nation Archives and Records Administration, 1997)

“The mistake that the Germans made was, I think, [to send] two messages at the same setting of the wheels. And that meant that it was then possible for a linguistic type like Wittgenstein or Turing to read the same language of both messages. Then that could be stripped off, and you have pure key which was then handed over to a mathematician.” (Dr. Irving John Good, From Codebreaking to Computing: Remembrances of Bletchley Park 50 Years Later, 1992)

RIGHT PANEL TOP TEXT 2 OF 2:

"....the method of solution will depend on taking hypotheses about parts of the keys and drawing what conclusions one can, hoping to get either a confirmation or a contradiction." (Alan Turing, Turing's Treatise on the Enigma, 1942)

Turing developed the idea of cribs, imput guesses for encrypted words based on plain text such as German military abbreviations.

Cribs, with the help of Gordon Welchman, are mechanicalized into the Bombe machine in 1940, making Bletchley a codebreaking factory.

“If you were making an incorrect assumption about the settings of the machine... provided that your crib, if I may use the expression, was of reasonable length-you would assume something about the plugboard of the machine and then the Bombe would make all possible deductions for the same plugging of the letter that you were looking at.” (Dr. Irving John Good, From Codebreaking to Computing: Remembrances of Bletchley Park 50 Years Later, 1992)

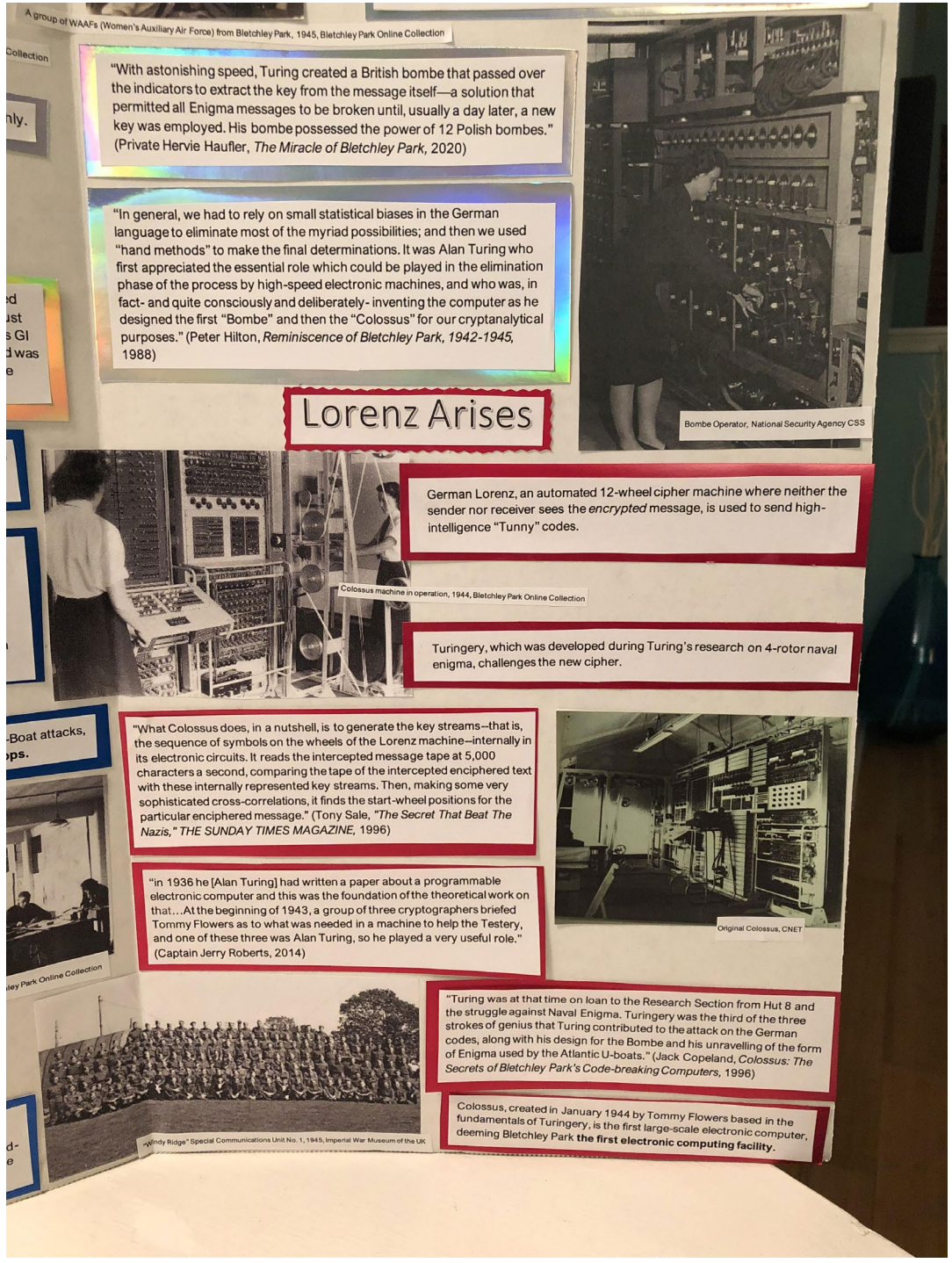
RIGHT PANEL BOTTOM PHOTO

SOURCE CREDIT TEXT:
BOMBE OPERATOR, NATIONAL SECURITY AGENCY CSS

COLOSSUS MACHINE IN OPERATION, 1944, BLETCHLEY PARK ONLINE COLLECTION

ORIGINAL COLOSSUS, CNET

“WINDY RIDGE” SPECIAL COMMUNICATIONS UNIT NO. 1, 1945, IMPERIAL WAR MUSEUM OF THE UK



RIGHT PANEL BOTTOM TEXT 1 OF 3:

“With astonishing speed, Turing created a British bombe that passed over the indicators to extract the key from the message itself—a solution that permitted all Enigma messages to be broken until, usually a day later, a new key was employed. His bombe possessed the power of 12 Polish bombes.” (Private Hervie Haufler, The Miracle of Bletchley Park, 2020)

“In general, we had to rely on small statistical biases in the German language to eliminate most of the myriad possibilities; and then we used “hand methods” to make the final determinations. It was Alan Turing who first appreciated the essential role which could be played in the elimination phase of the process by high-speed electronic machines, and who was, in fact- and quite consciously and deliberately- inventing the computer as he designed the first “Bombe” and then the “Colossus” for our cryptanalytical purposes.” (Peter Hilton, Reminiscence of Bletchley Park, 1942-1945, 1988)

RIGHT PANEL BOTTOM TEXT 2 OF 3:

Lorenz Arises

German Lorenz, an automated 12-wheel cipher machine where neither the sender nor receiver sees the encrypted message, is used to send high-intelligence “Tunny” codes.

Turingery, which was developed during Turing’s research on 4-rotor naval enigma, challenges the new cipher.

"What Colossus does, in a nutshell, is to generate the key streams--that is, the sequence of symbols on the wheels of the Lorenz machine--internally in its electronic circuits. It reads the intercepted message tape at 5,000 characters a second, comparing the tape of the intercepted enciphered text with these internally represented key streams. Then, making some very sophisticated cross-correlations, it finds the start-wheel positions for the particular enciphered message." (Tony Sale, "The Secret That Beat The Nazis," THE SUNDAY TIMES MAGAZINE, 1996)

RIGHT PANEL BOTTOM TEXT 3 OF 3:

Colossus, created in January 1944 by Tommy Flowers based in the fundamentals of Turingery, is the first large-scale electronic computer, deeming Bletchley Park the first electronic computing facility.

“in 1936 he [Alan Turing] had written a paper about a programmable electronic computer and this was the foundation of the theoretical work on that…At the beginning of 1943, a group of three cryptographers briefed Tommy Flowers as to what was needed in a machine to help the Testery, and one of these three was Alan Turing, so he played a very useful role.” (Captain Jerry Roberts, 2014)

“Turing was at that time on loan to the Research Section from Hut 8 and the struggle against Naval Enigma. Turingery was the third of the three strokes of genius that Turing contributed to the attack on the German codes, along with his design for the Bombe and his unravelling of the form of Enigma used by the Atlantic U-boats.” (Jack Copeland, Colossus: The Secrets of Bletchley Park's Code-breaking Computers, 1996)

CENTER PANEL BOTTOM PHOTO

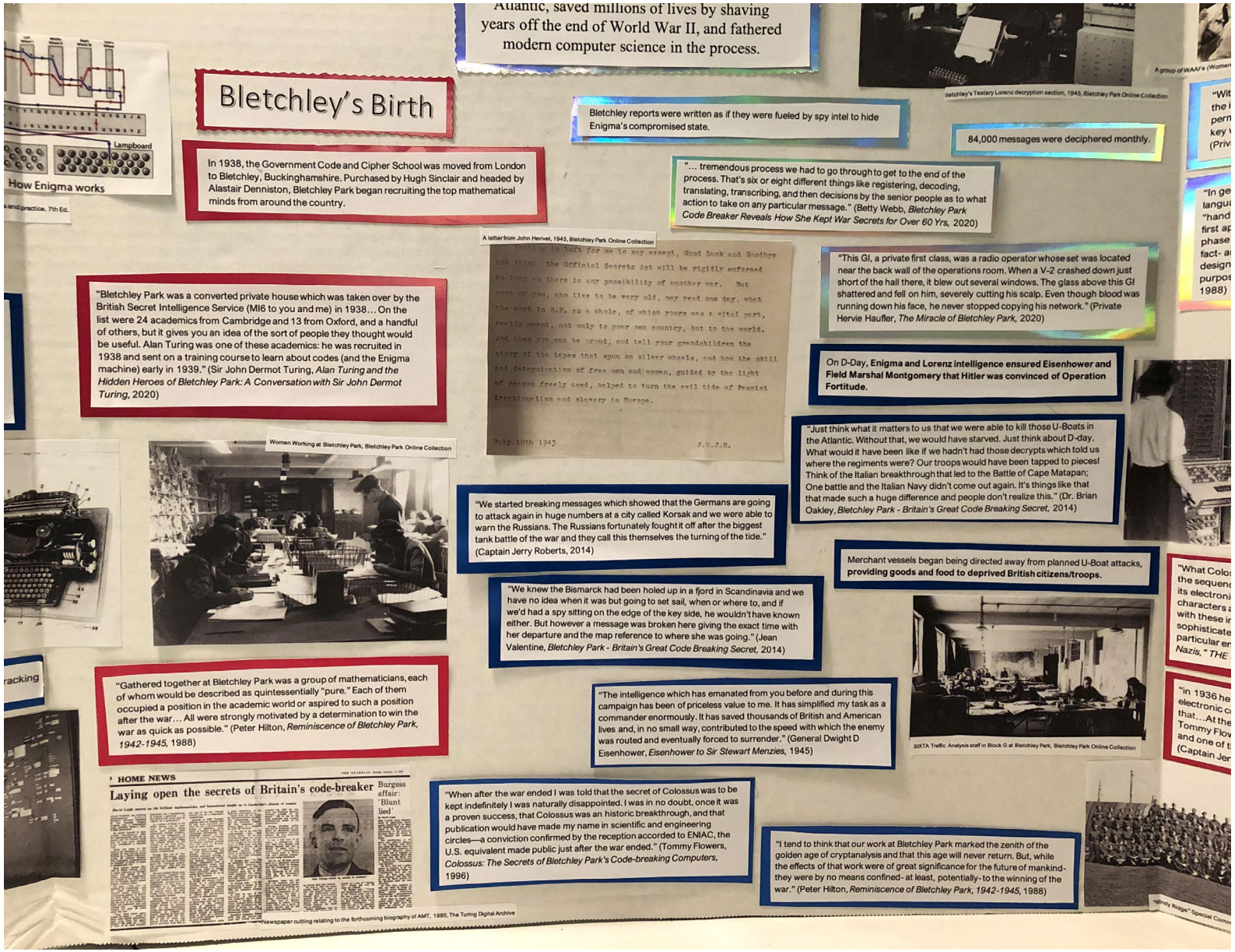
Source Credit Text:

Women Working at Bletchley Park, Bletchley Park Online Collection

Newspaper cutting relating to the forthcoming biography of AMT, 1980, The Turing Digital Archive

A letter from John Herivel, 1945, Bletchley Park Online Collection

SIXTA Traffic Analysis staff in Block G at Bletchley Park, Bletchley Park Online Collection



CENTER PANEL BOTTOM TEXT 1 OF 4:

- Bletchley's Birth:
- In 1938, the Government Code and Cipher School was moved from London to Bletchley, Buckinghamshire. Purchased by Hugh Sinclair and headed by Alastair Denniston, Bletchley Park began recruiting the top mathematical minds from around the country.
- "Bletchley Park was a converted private house which was taken over by the British Secret Intelligence Service (MI6 to you and me) in 1938… On the list were 24 academics from Cambridge and 13 from Oxford, and a handful of others, but it gives you an idea of the sort of people they thought would be useful. Alan Turing was one of these academics: he was recruited in 1938 and sent on a training course to learn about codes (and the Enigma machine) early in 1939." (Sir John Dermot Turing, Alan Turing and the Hidden Heroes of Bletchley Park: A Conversation with Sir John Dermot Turing, 2020)
- "Gathered together at Bletchley Park was a group of mathematicians, each of whom would be described as quintessentially "pure." Each of them occupied a position in the academic world or aspired to such a position after the war… All were strongly motivated by a determination to win the war as quick as possible." (Peter Hilton, Reminiscence of Bletchley Park, 1942-1945, 1988)

CENTER PANEL BOTTOM TEXT 2 OF 4:

- 84,000 messages were deciphered monthly.
- Bletchley reports were written as if they were fueled by spy intel to hide Enigma's compromised state.
- "… tremendous process we had to go through to get to the end of the process. That's six or eight different things like registering, decoding, translating, transcribing, and then decisions by the senior people as to what action to take on any particular message." (Betty Webb, Bletchley Park Code Breaker Reveals How She Kept War Secrets for Over 60 Yrs, 2020)
- "This GI, a private first class, was a radio operator whose set was located near the back wall of the operations room. When a V-2 crashed down just short of the hall there, it blew out several windows. The glass above this GI shattered and fell on him, severely cutting his scalp. Even though blood was running down his face, he never stopped copying his network." (Private Hervie Haufler, The Miracle of Bletchley Park, 2020)

CENTER PANEL BOTTOM TEXT 3 OF 4:

- **On D-Day, Enigma and Lorenz intelligence ensured Eisenhower that Hitler was convinced of Operation Fortitude. Without D-Day victory ensured by Bletchley, fascist Germany's downfall and eventual loss may have never begun.**
- "Just think what it matters to us that we were able to kill those U-Boats in the Atlantic. Without that, we would have starved. Just think about D-day. What would it have been like if we hadn't had those decrypts which told us where the regiments were? Our troops would have been tapped to pieces! Think of the Italian breakthrough that led to the Battle of Cape Matapan; One battle and the Italian Navy didn't come out again. It's things like that that made such a huge difference and people don't realize this." (Dr. Brian Oakley, Bletchley Park - Britain's Great Code Breaking Secret, 2014)
- "The intelligence which has emanated from you before and during this campaign has been of priceless value to me. It has simplified my task as a commander enormously. It has saved thousands of British and American lives and, in no small way, contributed to the speed with which the enemy was routed and eventually forced to surrender." (General Dwight D Eisenhower, Eisenhower to Sir Stewart Menzies, 1945)
- **Merchant vessels began being directed away from planned U-Boat attacks, providing goods and food to deprived British citizens/troops.**
- "We started breaking messages which showed that the Germans are going to attack again in huge numbers at a city called Korsak and we were able to warn the Russians. The Russians fortunately fought it off after the biggest tank battle of the war and they call this themselves the turning of the tide." (Captain Jerry Roberts, 2014)

CENTER PANEL BOTTOM TEXT 4 OF 4:

- “We knew the Bismarck had been holed up in a fjord in Scandinavia and we have no idea when it was but going to set sail, when or where to, and if we'd had a spy sitting on the edge of the key side, he wouldn't have known either. But however a message was broken here giving the exact time with her departure and the map reference to where she was going.” (Jean Valentine, Bletchley Park - Britain's Great Code Breaking Secret, 2014)
- “When after the war ended I was told that the secret of Colossus was to be kept indefinitely I was naturally disappointed. I was in no doubt, once it was a proven success, that Colossus was an historic breakthrough, and that publication would have made my name in scientific and engineering circles—a conviction confirmed by the reception accorded to ENIAC, the U.S. equivalent made public just after the war ended.” (Tommy Flowers, Colossus: The Secrets of Bletchley Park's Code-breaking Computers, 1996)
- “I tend to think that our work at Bletchley Park marked the zenith of the golden age of cryptanalysis and that this age will never return. But, while the effects of that work were of great significance for the future of mankind- they were by no means confined- at least, potentially- to the winning of the war.” (Peter Hilton, Reminiscence of Bletchley Park, 1942-1945, 1988)