Charles Babbage, Ada Lovelace, and the Dawn of Computing

Version 1

Charles Babbage, Ada Lovelace, and the Dawn of Computing

Version 1

Mark M. Meysenburg

Mark M. Meysenburg
Doane University
Department of Information Science and Technology
1014 Boswell Avenue
Crete, NE 68333

Contents

Part 1: Introduction

Welcome to *Charles Babbage, Ada Lovelace, and the Dawn of Computing*, a Reacting to the Past role-playing game centered on Charles Babbage and Ada Lovelace, pioneers of the modern computer who lived in Great Britain in the nineteenth century.

Brief overview of the game

Charles Babbage, Ada Lovelace, and the Dawn of Computing takes place in early nineteenth-century Britain, focusing on the calculating engines designed by Charles Babbage. The central intellectual collisions in the game concern the nature of science and scientists (are they talented, wealthy amateurs, or is science a profession?) and whether and to what degree science and engineering projects should be subsidized by the government. The main question in the game is whether or not Charles Babbage should be awarded funds from the British government for the development of his Difference Engine (an automated calculator capable of automatically creating, typesetting, and printing mathematical tables) and / or Analytical Engine (a true proto-computer), during the early to mid-1800s.

The Engines, at a minimum, would have "mechanized number," allowing rapid, automatic, error-free production of mathematical tables to be used in navigation, astronomy, and other applications. Ada Lovelace, regarded as the world's first computer programmer, could envision applications of the Analytical Engine beyond mere mathematics, however. In the notes to her English translation of Luigi Federico Menabrea's article *Sketch of the Analytical Engine Invented By Charles Babbage, Esq.* [Men43], Lovelace realized that the Engine could operate on symbols in an abstract manner, that it "might act upon other things besides number... the Engine might compose elaborate and scientific pieces of music of any degree of complexity or extent." She also foresaw applications in business, drawing graphics, and more. In addition, the precision mechanical engineering work done on the engines had profound impacts on the state of engineering in the UK and around the world. The mind boggles at the prospects had an Analytical Engine ever actually been built. What would the consequences of a steam-powered, mechanical computer have been in Victorian England? One can easily get lost in the "steam-punk" possibilities of a 100-year head start in computing technology.

Players in the game may belong to one of two factions, or may be indeterminate. The pro-Babbage faction wants the government to provide funding adequate for the construction of one or both of Babbage's Engines. The anti-Babbage faction wants the opposite -- no funding for either Engine, either because they do not feel the Engines are that important, or because they do not feel the government should provide funding for such projects. Indeterminates have no set position on this issue, and are open to persuasion by the factions.

The standard version of the game covers a broad span of time, from 1828 through 1846. There are seven game sessions and three optional labs, briefly described in Table 1 below.

Table 1: Overview of game sessions

Session (year) / location	Presiding character	Theme
GS 1 (1828) / 1 Dorset Street	Babbage	Babbage's party
Lab 1	n/a	Finite differences
GS 2 (1828) / Mechanic's Institute	Lardner	Public lectures 1
Lab 2	n/a	Difference Engine
GS 3 (1828) / Royal Society	Gilbert	RS approval for DE funding PM decision
GS 4 (1830) / Royal Society	Gilbert	Celebrating the RS
Lab 3	n/a	Analytical Engine
GS 5 (1846) / Mechanic's Institute	Brunel	Public lectures 2 PM decision
GS 6 (1846) / Royal Society	RS president	Usefulness of the AE
GS 7 (1846) / Royal Society	RS president	Final debates re. AE funding PM decision

Map

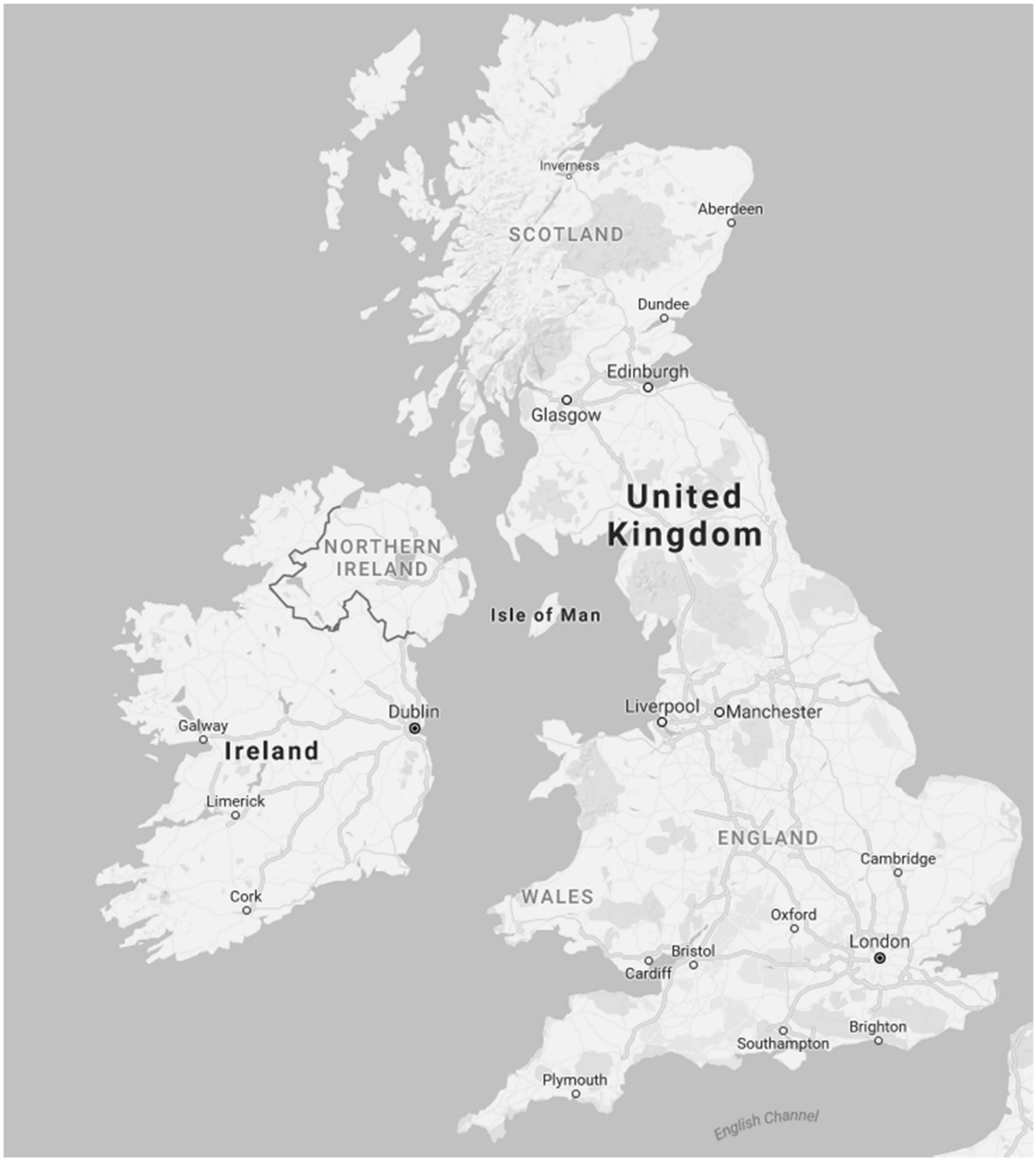

Figure 1: The United Kingdom

Prologue

You depart you lodgings at the Bull and Mouth on St. Martins le Grand in London, half a mile north of the Thames and just west of the newly-opened Guildhall Library. Your destination, Charles Babbage's house at 1 Dorset Street, is three miles to the west. The year 1828 has been unusually wet, even for

London, but on this pleasant Wednesday evening in June, the sky is clear and the sun is setting; even the stench of the Thames seems less than normal. So, you decide to walk instead of hiring a coach for the journey.

You can hardly believe that you have been invited to one of Babbage's Dorset Street parties, as they are *the* premier social events in summertime London. As Mrs. Cornelia A. H. Crosse, wife of natural philosopher Andrew Crosse, puts it, “One of three qualifications were necessary for those who sought to be invited -- intellect, beauty, or rank -- without one of these you might be rich as Croesus and yet be told you cannot enter here.” Although you do not consider yourself in the same league as Babbage -- for very, very few are -- you think that it must be your intellect that garnered your invitation. Nevertheless, you are invited, and you quicken your steps as you walk past the London Stock Exchange at Capel Court.

Saint Paul's Cathedral, the dominant fixture of the London skyline, is at your back as you make your way through the teeming streets. London is the largest city in the world, recently surpassing Peking. Disraeli has quipped that “London is a nation, not a city.” It seems like a good proportion of the population is out in the streets with you, all attending to some business on this fine evening. Many, like you, are members of the upper classes, dressed in finery and bound for a social event, although certainly none of these are attending anything of the magnitude of a Dorset Street party. You watch them as they walk along or depart from their carriages, making a show of their elegance, knowing that they would be envious if they knew where you were headed, and all seems sunny and bright with Britain and the world.

Then you walk past a blacking factory and the world dims slightly. The building is a ramshackle contrivance, seemly ready to tumble down or burst into a smoky inferno at a moment's notice. You can see children crowded into the factory's few windows, desperately clinging to the fading sunlight so they can see their work: pasting labels on cans of bootblack. You know a little about what these children -- some as young as five -- go through, working ten to twelve hours a day, six days a week, for a wage of only five or six shillings a week. Only the most callous could fail to notice the poverty and overcrowding in London's slums, where the working people live. As if to complete the vision, the breeze shifts and suddenly you can smell the Thames; the stench of the city’s raw sewage nearly causes your knees to buckle. Passing by the Soho Square Gardens on the south of the street does nothing to lighten your mood, as you can see the decrepit state of the statue of King Charles II; the inscription at the base is now all but illegible. The less said about the Manor House on the square, and its now-closed but still infamous brothel, the better.

Leaving the blacking factory and Soho Square Gardens behind, you refocus your thoughts on the progress London has seen in the last few years: public amenities such as the London Zoo, the Guildhall Library, and horse-drawn omnibuses for transportation; and civil engineering projects such as the Hammersmith, Kingston, and London bridges, the St. Katherine docks, as well as the reconstruction of Buckingham Palace. Surely a culture capable of such accomplishments must be a just and blessed society. The spring returns to your step and your pace quickens as you near Dorset Street.

Nearing the huge house, you begin to imagine what the night will be like. Which luminaries of British society will be in attendance tonight, and what will be the topics of conversation? Perhaps the man of

science John Herschel, recent winner of the prestigious Copley Medal from the Royal Society of London, will be there and regale listeners about his eighteen-inch reflecting telescope and his research on double stars.

Or maybe someone emblematic of a new kind of man of science, someone who studies the wonders of creation *professionally*? Michael Faraday, the experimentalist, perhaps? Even though he is not formally considered a gentleman, you know that he has attended Babbage's parties in the past, and you would be delighted to learn more of his experiments with electricity. Another man in this category, the engineer I. K. Brunel, might be in attendance. You imagine yourself asking him about the stalled Thames Tunnel, and his narrow brush with death during a breach and flooding of the partially completed excavation in January.

Or, even further afield, you might meet Mary Somerville, the woman who published the paper “The magnetic properties of the violet rays of the solar spectrum” in the *Proceedings of the Royal Society* two years ago. A *woman* publishing work about astronomy! Mrs. Somerville is “mathematician of the very first rank with all the gentleness of a woman,” as Sir David Brewster describes her; how fascinating it would be to make her acquaintance!

You almost dare not imagine it, but the Prime Minister, Viscount Goderich, could be inside. You have heard that even the Duke of Wellington might be in attendance, mesmerizing the crowd with tales of his exploits during the Napoleonic Wars.

Of course, one certainty is that Babbage will be there, gregarious, engaging, and able to talk to anyone: educated commoner, man of science, or Prime Minister. He might talk about mathematics -- his work on the theory of functions or how his “Analytical Society” modernized mathematics in Britain, bringing the kingdom into alignment with continental Europe's calculus notation. He will certainly demonstrate his “Silver Lady,” a clockwork-mechanized metallic statue of a young woman with a bird resting on her extended finger. When set in motion, the bird's beak opens and closes, and its wings flap! Babbage restored the workings of the Silver Lady himself, and you have heard that every new attendee to one of his parties is introduced to the mechanical wonder.

The other mechanical device that you are sure to see as a first-time guest at 1 Dorset Street is the working fragment of Babbage's Difference Engine, a beautiful assemblage of brass cogs built under Babbage's instruction by the engineer Joseph Clement. A machine that mechanizes the calculation, tabulation, and printing of numbers! Babbage is immensely proud of the machine, and he clearly considers the Engine his life's work. He is known to talk voluminously about the Engine at his parties to anyone who shows interest. You hope you are able to understand the principles and operations of the machine.

Finally you arrive at the house and are ushered inside. Many of the guests are already gathered in the parlor, and you enter excitedly, ready to participate in such a momentous social occasion.

How to react

Reacting to the Past is a series of historical role-playing games. Students are given elaborate game books which place them in moments of historical controversy and intellectual ferment. The class becomes a public body of some sort; students, in role, become particular persons from the period, often as members of a faction. Their purpose is to advance a policy agenda and achieve their victory objectives. To do so, they will undertake research and write speeches and position papers; and they will also give formal speeches, participate in informal debates and negotiations, and otherwise work to win the game. After a few preparatory lectures, the game begins and the players are in charge; the instructor serves as adviser or "gamemaster." Outcomes sometimes differ from the actual history; a post-mortem session at the end of the game sets the record straight.

The following is an outline of what you will encounter in Reacting and what you will be expected to do. While these elements are typical of every Reacting game, it is important to remember that every game has its own special quirks.

Game set-up

Your instructor will spend some time before the beginning of the game helping you to understand the historical background. During the set-up period, you will read several different kinds of material:

- The game book (from which you are reading now), which includes historical information, rules and elements of the game, and essential documents; and
- Your role, which describes the historical person you will play in the game.

You may also be required to read primary and secondary sources outside the game book (perhaps including one or more accompanying books), which provide additional information and arguments for use during the game. Often you will be expected to conduct research to bolster your papers and speeches.

Read all of this contextual material and all of these documents and sources before the game begins. And just as important, go back and reread these materials throughout the game. A second reading while in role will deepen your understanding and alter your perspective: ideas take on a different aspect when seen through the eyes of a partisan actor.

Players who have carefully read the materials and who know the rules of the game will invariably do better than those who rely on general impressions and uncertain recollections.

Game play

Once the game begins, certain players preside over the class sessions. These presiding officers may be elected or appointed. Your instructor then becomes the gamemaster (GM) and takes a seat in the back of the room. While not in control, the GM may do any of the following:

- Pass notes to spur players to action;
- Announce the effects of actions taken inside the game on outside parties (e.g., neighboring countries) or the effects of outside events on game actions (e.g., a declaration of war); and

- Interrupt and redirect proceedings that have gone off track.

Presiding officers may act in a partisan fashion, speaking in support of particular interests, but they must observe basic standards of fairness. As a failsafe device, most Reacting games employ the “Podium Rule,” which allows a player who has not been recognized to approach the podium and wait for a chance to speak. Once at the podium, the player has the floor and must be heard.

In order to achieve your objectives, outlined in your role sheet, you must persuade others to support you.

You must speak with others, because never will a role contain all that you need to know, and never will one faction have the strength to prevail without allies. Collaboration and coalition-building are at the heart of every game.

Most role descriptions contain secret information which you are expected to guard. Exercise caution when discussing your role with others. You may be a member of a faction, which gives you allies who are generally safe and reliable, but even they may not always be in total agreement with you.

In games where factions are tight-knit groups with fixed objectives, finding a persuadable ally can be difficult. Fortunately, every game includes roles that are undecided (or “indeterminate”) about certain issues. Everyone is predisposed on certain issues, but most players can be persuaded to support particular positions. Cultivating these players is in your interest. (By contrast, if you are assigned an “indeterminate” role, you will likely have considerable freedom to choose one or another side in the game; but often, too, indeterminates have special interests of their own.)

Cultivate friends and supporters. Before you speak at the podium, arrange to have at least one supporter second your proposal, come to your defense, or admonish those in the body not paying attention. Feel free to ask the presiding officer to assist you, but appeal to the GM only as a last resort.

Immerse yourself in the game. Regard it as a way to escape imaginatively from your usual “self” and your customary perspective as a college student in the 21st century. At first, this may cause discomfort because you may be advocating ideas that are incompatible with your own beliefs. You may also need to take actions which you would find reprehensible in real life. Remember that a Reacting game is only a game and that you and the other players are merely playing roles. When they offer criticisms, they are not criticizing you as a person. Similarly, you must never criticize another person in the game. But you will likely be obliged to criticize their persona. (For example, never say, “Sally's argument is ridiculous.” But feel free to say, “Governor Winthrop's argument is ridiculous” – though you would do well to explain exactly why!) Always assume, when spoken to by a fellow player -- whether in class or out of class -- that that person is speaking to you in role.

Help to create this world by avoiding the colloquialisms and familiarities of today’s college life. Never should the presiding officer, for example, open a session with the salutation, “Hi guys.” Similarly, remember that it is inappropriate to trade on out-of-class relationships when asking for support within the game. (“Hey, you can't vote against me. We're both on the tennis team!”) Reacting to the Past seeks

to approximate of the complexity of the past. Because some people in history were not who they seemed to be, so, too, some roles in Reacting may include elements of conspiracy or deceit. (For example, Brutus did not announce to the Roman Senate his plans to assassinate Caesar.) If you are assigned such a role, you must make it clear to everyone that you are merely playing a role. If, however, you find yourself in a situation where you find your role and actions to be stressful or uncomfortable, tell the GM.

Game requirements

Your instructor will explain the specific requirements for your class. In general, a Reacting game will require you to perform several distinct but interrelated activities:

- Reading: This standard academic work is carried on more purposefully in a Reacting course, since what you read is put to immediate use.
- Research and Writing: The exact writing requirements depend on your instructor, but in most cases you will be writing to persuade others. Most of your writing will take the form of policy statements, but you might also write autobiographies, clandestine messages, newspapers, or aftergame reflections. In most cases papers are posted on the class website for examination by others. Basic rules: Do not use big fonts or large margins. Do not simply repeat your position as outlined in your role sheets: You must base your arguments on historical facts as well as ideas drawn from assigned texts -- and from independent research. (Your instructor will outline the requirements for footnoting and attribution.) Be sure to consider the weaknesses in your argument and address them; if you do not your opponents will.
- Public Speaking and Debate: Most players are expected to deliver at least one formal speech from the podium (the length of the game and the size of the class will affect the number of speeches). Reading papers aloud is seldom effective. Some instructors may insist that students instead speak freely from notes. After a speech, a lively and even raucous debate will likely ensue. Often the debates will culminate in a vote.
- Strategizing: Communication among students is a pervasive feature of Reacting games. You should find yourself writing emails, texting, and attending meetings on a fairly regular basis. If you do not, you are being outmaneuvered by your opponents.

Skill development

A recent Associated Press article on education and employment made the following observations:

> "The world's top employers are pickier than ever. And they want to see more than high marks and the right degree. They want graduates with so-called soft skills -- those who can work well in teams, write and speak with clarity, adapt quickly to changes in technology and business conditions, and interact with colleagues from different countries and cultures.... And companies are going to ever-greater lengths to identify the students who have the right mix of skills, by observing them in role-playing exercises to see how they handle pressure and get along with others ... and [by] organizing contests that reveal how students solve problems and handle deadline pressure."

Reacting to the Past, probably better than most elements of the curriculum, provides the opportunity for developing these “soft skills.” This is because you will be practicing persuasive writing, public speaking, critical thinking, problem-solving, and collaboration. You will also need to adapt to changing circumstances and work under pressure.

Part 2: Historical background

This section serves as an introduction to the history explored in the *Charles Babbage, Ada Lovelace, and the Dawn of Computing* game. This is just an introduction! You should also read the works in the Core Texts section thoroughly. Your individual role sheet may refer you to other sources as well.

Chronology

The following shows a chronology of events from the dawn of civilization through the early nineteenth century, pertaining to technology used for computing, and a few other dates relevant to our game.

Circa 2700 BCE An early form of abacus is used for calculations in Mesopotamia.

Circa 200 BCE The Chinese abacus comes into use.

Circa 150 BCE Devices such as the Antikythera mechanism, a bronze clockwork device, are used to predict eclipses and to perform other astronomical or astrological tasks.

1632 William Oughtred at the University of Oxford, England, invents the modern slide rule, allowing skilled operators to quickly perform multiplication and division operations.

1642 Blaise Pascal designs and builds his first mechanical calculator (called a *Pascaline*), capable of performing addition or subtraction of two numbers. Pascal's calculator, and others that followed, required human intervention during their calculations, thus allowing human error that could cause errors.

December 26, 1791 Charles Babbage is born in Walworth, Surrey, England.

1793 - 1815 The French wars. The French Empire, led by Napoleon Bonaparte, expands to rule most of continental Europe. Rival nations, including the Austrian Empire, Prussia, and Spain, but primarily led and financed by Great Britain, finally defeat Napoleon at the Battle of Waterloo on June 18, 1815.

1801 Joseph-Marie Jacquard invents a programmable weaving loom, controlled by punched holes in a paper tape. The pattern of holes in the tape controlled the pattern of cloth produced by the loom.

October 1810 Babbage starts at Trinity College, Cambridge.

1812 Along with fellow undergraduates John Hershcel, Alexander D'Arby, Edward Ryan, Sir Edward Thomas Ffrench Bromhead, 2nd Baronet, and George Peacock, Babbage forms the Analytical Society. The Society aims to force Britain to adopt the calculus notation used in continental Europe instead of the Newtonian notation still used in the kingdom.

December 10, 1815 Augusta Ada Byron born in London, England.

1819 On a trip to Paris with John Herschel, Babbage meets Gaspard de Prony, who had been commissioned by the French government to produce a table of logarithms and trigonometric functions in celebration of the creation of the metric system. De Prony's scheme to partition the work involved into three sections inspires the architecture of Babbage's Difference Engine.

1820 or 1821 Upon encountering many errors in the printed mathematical tables used by navigators, astronomers, and other men of science, Babbage first conceives of the Difference Engine. “I wish to God the calculations had been executed by steam” is the associated, and possibly apocryphal, quotation.

July 3, 1822 A six-figure-wheel working model of the Difference Engine is completed, demonstrating that the design and technology is sound. Babbage announces the project in a letter to Sir Humphrey Davy, 1st Baronet, the president of the Royal Society of London. Davies Gilbert sends a copy of the letter to Sir Robert Peel, 2nd Baronet, then serving as Home Secretary.

April 1, 1823 The Lords of the Treasury ask the Royal Society for their opinion on the merits and utility of the proposed Difference Engine.

May 1, 1823 The Royal Society replies, “Mr. Babbage has displayed great talent and ingenuity in the construction of his Machine for Computation, which the Committee think fully adequate to the attainment of the objects proposed by the inventor; and they consider Mr. Babbage as highly deserving of public encouragement in the prosecution of his arduous undertaking.”

June 1823 Babbage meets with Lord Frederick John Robinson, 1st Earl of Ripon, the Chancellor of the Exchequer. Robinson promises £1,000 of government funds to begin the creation of the Difference Engine. Babbage actually receives £1,500, and his understanding from the meeting is that this was only a start, and that Robinson intended the government to provide more funding. However, no minutes of the meeting were made.

1823 Babbage hires the engineer Joseph Clement to build the Difference Engine.

August 31, 1827 Lord Frederick John Robinson, 1st Earl of Ripon, Viscount Goderich, becomes Prime Minister of the United Kingdom.

Narrative

This section provides very brief introductions to the history of technology used for calculations, the changing nature of science in the Georgian era, the British society in the early 1800s, and short biographies of two of the game's principal characters, Charles Babbage and Ada Lovelace.

A brief history of calculating technology

Technologies to aid human beings with mathematical calculations are as old as civilizations themselves. Writing -- including methods to record numerical values -- was one of the technologies associated with the Urban Revolution, beginning circa 3500 BCE. All of the first “pristine” civilizations shared common elements, including higher learning. Higher learning included writing, mathematics, and the beginnings of astronomy.

Writing can be seen as the earliest of all technologies related to mathematics: “Writing and reckoning were first and foremost practical technologies with practical origins meeting the practical needs of early civilizations. ... All early civilizations developed arithmetical systems and systems of permanent record-keeping.” [ID06] For example, the ancient Babylonians had notations not only for keeping track of commerce, taxes, etc., but also could represent algebraic calculations.

For a millennium, writing remained the only technology aiding humans with mathematics. True mechanical calculators began with the simple abacuses used by Sumerians circa 2700 BCE. These were tables -- literally -- with several grooved columns, with each successive column representing the next highest power in their base-60 (sexagesimal) number system. What we most likely envision when we think about an abacus, the Chinese Suanpan ("counting tray"), originated about 200 BCE. These abacuses had two tiers of beads separated by a wooden bar, with two beads above the bar and five below. A Suanpan can be used for counting and arithmetic in either our usual decimal (base-10) or the hexadecimal (base-16) number system. And, in addition to simple counting, trained abacists can use the machines to quickly perform division, addition, subtraction, and even square or cube roots.

Shortly thereafter, circa 150 BCE, sophisticated "clockwork" computers, such as the Antikythera mechanism, were in use. Built of thirty or more inter-meshed bronze gears, this surprisingly sophisticated astronomical computer could be used to predict eclipses, among other astronomical calculations. Unfortunately, the knowledge of how to create and use such sophisticated devices was lost. When the Antikythera device was first discovered in a Greek shipwreck in 1901, archaeologists did not think it possible that the machine could be 2000 years old. Nothing as technologically precise was produced until the 1300s.

Another kind of technology that was used for calculations was the astrolabe, in use from as early as 220 BCE through the present day. By measuring the angle from the horizon to a known star or planet, someone skilled in the use of an astrolabe can determine their latitude, thus aiding in navigation.

Around the year 500 CE, the "Arabic" numeral system, with place-value representation, became complete when Hindu mathematicians added the symbol representing zero to the other nine digits. The shapes of the written digits we are familiar with did not become common for centuries after that, however.

During the dark ages, as in many scientific and technological areas, there was little progress with computational technologies, whether written or mechanical.

Circa 1600 Scottish landowner and amateur mathematician John Napier, 8th Laird of Merhiston (a.k.a. Marvellous Merchiston) discovered logarithms. A logarithm is a quantity representing the power to which a fixed number (the base) must be raised to produce a given number. Pertaining to making calculations easier to perform, he also discovered that large numbers can be multiplied or divided by adding or subtracting the logarithms of the numbers. Students that have learned basic arithmetic can attest that pencil-and-paper long multiplication or division is a laborious process, especially for large numbers. On the other hand, pencil-and-paper addition or subtraction can be performed more easily and with higher accuracy than multiplication or division. So, if one had a way to quickly calculate or look up the logarithms for large numbers, multiplication and division of such numbers could be done much more quickly via addition of the logarithms. This led to the need for tables of logarithms, which could be thus used to speed up calculations.

Napier's discovery also led to the invention of the first slide rule in the 1620s. The modern form of the slide rule was invented in 1632 by William Oughtred at the University of Oxford in England.

Ten years later in 1642, Isaac Newton was born in Woolsthorpe, England -- and God said, “Let Newton be!” according to Alexander Pope. Newton's work in science and mathematics -- not the least being co-inventor of calculus with Gottfried Leibniz -- helped to cement Great Britain as the leading nation of the world in these fields.

In 1642, the French child prodigy Blaise Pascal invented a mechanical calculator that came to be known as a *Pascaline*. Pascal intended the machine to aid his father, a tax supervisor. The machine was able to add or subtract two numbers, and do multiplication or division by repeated applications of addition or subtraction. Eventually Pascal received a patent on the machine, and produced twenty or more of the machines over several years. Pascal's machines featured automatic carry operations -- that is, the machines could add a ‘1’ to the next leftmost column when the sum of the current two digits was ten or more. Almost 200 years later, Charles Babbage spent much intellectual energy in designing the automatic carry mechanism for his first Difference Engine.

In 1671 Gottfried Leibniz, of calculus fame, tried to improve the Pascaline, so that it could perform multiplications automatically. His device was called the Stepped Reckoner, and the key feature in Leibniz's design was a stepped-drum gear which came to be known as the Leibniz wheel.

Although the Reckoner was not commercially successful, the Leibniz wheel was to become very important. In 1820, the French inventor Thomas de Colmar's created his Arithmometer, an invention using Leibniz wheels. The Arthmometer was the first calculator to be used in daily business use. Machines similar to Colmar's Arithmometer remained in use until the 1970s.

As we have seen, writing calculations down (e.g., performing “long division”) is in fact a technology for performing calculations. Many who learned to do pencil-and-paper multiplication or division in grade school will attest, this technology is fraught with the possibility of human error. In fact, the possibility of human error ruining a calculation is a problem shared by all of the calculating technologies described above. These errors could occur not only during the setup of the calculation, but during the process of the calculation itself, since human intervention was required during the process. Eliminating human error is one of the driving forces Charles Babbage felt when designing his calculating engines.

Calculating technologies began with the dawn of civilizations during the Urban Revolution, and our game takes place during the next major change in humankind's mode of being, the Industrial Revolution. The Industrial Revolution began in England around the year 1760, and was well into its transformation of the nation by the 1820s.

The changing nature of science

First, it is important to discuss terminology. The word *science* itself did not come into common use until the early nineteenth century (the time period of our game). Before that, the task of explaining of the natural world, without resorting to supernatural causes, was considered a branch of philosophy, specifically, *natural philosophy*. The term *scientist* was coined by William Whewell in 1834, in a review of one of Mary Somerville's articles, and did not come into common use until later in the century. Therefore, it is inappropriate to refer to any of the characters in our game as scientists -- certainly never while the game is underway! Instead, those that study science are called “men of science.”

A commonly held misconception is that government support of scientific research is a relatively new concept, perhaps marked most clearly by the 1940s Manhattan Project in the United States. Even the earliest civilizations performed works of science, and in these cases, the rulers or governments of the time supported the scientific activities.

In these first civilizations, in Mesopotamia, Egypt, China, the Indus valley, and Central and South America, governments supported science for practical purposes. Mathematics was required for record keeping, tax collection, and trade, and so the government required trained mathematicians. Astronomy was required for religious purposes, so that the dates of festivals and other important days could be determined. Astronomy was also useful in agriculture, as the changing seasons or flood patterns determined when to plant or harvest. Astronomy was also useful for astrological predictions: when is it a good time to hold a royal wedding? When is it the right time to go to war? The answers were in the stars, and trained astrologists could find them. Note that the *perceived* usefulness of scientific knowledge is what is important, not our current-day knowledge of the actual utility. Likewise, the proto-chemistry of alchemy was deemed useful, and so alchemists were required and trained.

In ancient Greece, the character and utility of natural philosophy changed. First, science was no longer required to be immediately practical. In fact, many of the philosophers of the time rejected any thought of practical application. Science became an abstract study of the natural world, without regard for any real-world usefulness. Secondly, science moved from the realm of government support into a discipline pursued by wealthy philosophers who were able to support themselves and their own intellectual pursuit with their own funds, or with funds earned by teaching students. Some of these philosophers -- Plato and Aristotle, say -- formed the foundations of the modern scientific traditions.

Western science faded after the fall of the Roman Empire, not to be rediscovered until the Renaissance of the 1300s. During the Dark Ages, the scientific traditions of the Greeks were kept alive and expanded by Muslim scholars. Arabic scholarship of this time had somewhat of a more practical character: much progress was made in medicine and mathematics, for example. Europeans only discovered Greek philosophy when Arabic texts were captured during the Crusades. It has been said that more ancient Greek works were found in Arabic translations than in the original language.

After the Renaissance, European science once again was a philosophical discipline mostly pursued as a hobby by the wealthy. In the time period of our game, this was just on the verge of changing. By the end of the nineteenth century, science was a discipline one could pursue as a profession instead of as a hobby; one could aspire to be a “scientist” (although that term itself was not yet in use), and one did not have to be born wealthy to pursue the subject.

It is also important to know that the discipline of engineering was until recently well divorced from natural philosophy. Engineers did not need an abstract understanding of natural phenomena to build roads, buildings, or bridges; instead, they relied on rules of thumb derived from centuries of experience. In fact, the engineering usually preceded the science. For example, engineers knew how to build bridges before philosophers understood the abstract field of materials science. Also, engineers were working men, with little formal education outside of their apprenticeships, while natural philosophers were

wealthy intellectuals who had the luxury of thinking about the natural world without regard to any practical considerations. In our time, we often think of engineering as applied science, but that has only been true since the early twentieth century, marked by the Manhattan Project to develop the first atomic bomb.

The United Kingdom in the 1820s

The United Kingdom in the early part of the nineteenth century was a nation in transition. The American Revolutionary War and the French wars were over. The industrial revolution was well underway; gathering steam, one might be inclined to say.

King George III -- familiar in the United States as the king during the American Revolution -- died in 1820, succeeded by his son King George IV. George III had been blind, deaf, and mad at the time of his death, and George IV gained a reputation for overindulgence and lax morality. The monarchy's reputation suffered in the view of the people during these years.

But, the Victorian age had yet to begin. Landed gentlemen with ties to the Church of England were still by far the dominant force in British politics. The poor, most of the growing middle class, nonconformists[1], Catholics, and women had virtually no voice on the national scale. As people left the countryside to take factory jobs in the growing cities, slums, poverty, child labor, and dismal working conditions became major problems.

In certain ways, middle-class standards of living were on the rise, however. Those in the middle class might be able to take an occasional vacation by the sea, and a culture of consumption was starting to emerge. But the actual living conditions in large cities were worsening at the same time. The average life expectancy in the biggest cities dropped from 35 in 1820 to only 29 in 1830.

This was an era where “self-improvement” was popular. Public lectures on various scientific or other intellectual topics were popular and well-attended. One such venue was the London Mechanic’s Institute, established in 1823 by Sir George Birkbeck. Mechanic’s Institutes were established during this time all over the United Kingdom to provide adult education to working men.

Britain was in the midst of the industrial revolution, but the concepts of mass production were almost a century away. Most industrial concerns were relatively small, and owned by families or small partnerships rather than by large corporations.

Women were still excluded from many parts of British society during this time. Suffrage was a century away. Poor and middle class women worked outside the home, and the changing demographics of the time saw many of them move to the cities to pursue work in the factories. By the mid-nineteenth century, the need for women and children in factory work was diminishing, but in the time of our game it was very much a fact of life.

[1] In the U.K., a *nonconformist* was a Protestant Christian who did not belong to, or disagreed with the teachings of, the Church of England.

Upper-class women, while they did not have to work in the factories, were still excluded from the boardroom. They did have important social roles, though; "...the talk of the town was almost as important as the smoke of the factory chimneys in creating a prosperous industrial economy." [Mat00] Many men saw no need for suffrage, as they felt were already fully involved in the system, via the role they played as homemakers and society organizers.

During this time, the infrastructure of Britain was rapidly forming, with roads, railways, canals, and steamships connecting the nation as never before. The railways, starting in the early 1830s, are illustrative, since they were created by engineers and industrialists, and unplanned by the government. Nevertheless, by the end of the century the railways provided an excellent transportation system for passengers and goods.

Politically, the Tories -- the conservative party of landowners and the Church of England -- were convinced of the superiority of their approach. The fact that Britain was victorious over the French, and the rising power of the economy served as further proof that the British system of government -- the *unreformed* system of government -- was a superior system, particularly when compared to the more liberal traditions that had appeared in France after its revolution. A related effect on society was the rise of a large and powerful class of businessmen, who had helped finance the wars and supply the armies.

Not everyone was so satisfied with the British system of government, however. The Whigs wished to expand franchises[2], to allow underrepresented classes more political power. Radicals stirred up trouble in the cities, leading to riots, which in turn led to more repressive measures by the government. Many dissidents and criminals -- hundreds of thousands by the middle of the century -- were shipped to Australia.

This was an era of free trade and limited government spending. A large amount of money -- nearly half of the total budget each year in the early part of the century -- was spent on paying off French war debt. One-third of the government's remaining spending was defense-related. Despite this, the income tax was abolished in 1816, increasing the amount of money that had to be raised from indirect taxation, such as taxes on food.

The British government did support a limited amount of scientific work, as long as the science was clearly practical. Such projects usually had to do with the maintenance of the British Empire, "...to map the earth and its geological and botanical resources, or to produce charts of the stars and of the earth's magnetic field to aid safe navigation of oceans." [Mat00]

Charles Babbage

Charles Babbage was born on December 26, 1791, in Walworth, Surrey. In the present day, Walworth is part of London. He was, as biographer Anthony Hyman puts it, "...the child of two revolutions: industrial revolution in Britain and political and social revolution in France." [Hym85] The industrial revolution was changing the way of living in Britain, Europe, and the eventually the rest of the world, while the

[2] In the United Kingdom, *franchise* is the right to vote in public political elections. At the turn of the nineteenth century, less than five percent of the population -- mostly wealthy landowners -- could vote.

thoughts and ideals from the French Revolution were starting to change the political structure of Britain as well.

Babbage's father, Benjamin, was a banker. His family was wealthy, although not exceptionally rich. Both Babbage and his father were proud that their wealth was largely earned, rather than inherited.

Even as a schoolboy, Babbage was very curious, and also creative in the ways in which he tried to satisfy his curiosities. For example, when he wanted to prove or disprove the existence of ghosts and demons, he tried to summon the Devil, so he could interview him and thus confirm or deny Satan's existence. Luckily, he was not successful in his attempts. Later in his life, Babbage produced a unique blending of the scientific method, his ideas about computation, and theology, when he wrote his *Ninth Bridgewater Treatise*, published in 1837.

On another occasion as a youth, and at a different boarding school, Babbage and a friend were so interested in mathematics that they clandestinely awoke early in the morning -- at three o'clock -- and went to the classroom so they could further their study of the subject. They were discovered by some of their classmates, who insisted on joining the study sessions. Willingly awaking early in the morning to clandestinely study mathematics is admittedly difficult for many readers in our time to imagine. As the number of students grew, the amount of studying declined. Eventually the group made enough noise to waken the headmaster, causing them to be found out, thus ending the practice.

In 1810, Babbage began his studies at Trinity College, Cambridge. He was very much looking forward to learning advanced mathematics from the professors there, but he was disappointed. The state of mathematics at Cambridge was terrible, far behind the progress of the field in continental Europe. In a sense, Britain was still resting on the laurels of Newton, while the world had moved forward. His mathematical salvation came from two sources: first, he had access to the library, through which he could read the mathematical journals from the continent; and second, he met several like-minded fellow undergraduates.

Along with friends and future luminaries John Herschel, Alexander D'Arby, Edward Ryan, Sir Edward Thomas Ffrench Bromhead, 2nd Baronet, and George Peacock, Babbage formed the Analytical Society, dedicated to advancing the state of mathematics in the United Kingdom. One of their main goals was to change kingdom's usage of calculus notation from the style favored by Newton to the style of Leibniz, the notation used on the continent and by other modern mathematicians. Although the Society was only in existence from 1812 until 1814, it was successful in its primary goal; the Leibniz notation was adopted in Britain, and the state of mathematics in the kingdom began to recover.

The Society also had a lasting impact on Babbage. From his early days, Babbage was a firm proponent of mathematical science, of collecting copious amounts of data and then analyzing it -- with the tools of calculus or other mathematics -- to form conclusions. The like-minded compatriots of the Analytical Society helped to firmly cement that characteristic; this Baconian scientific mindset helps explain many of Babbage's prominent activities for the rest of his life.

In 1814, Charles married Georgina Whitmore. His father did not approve of the marriage, leading to a strained relationship with his son. Charles and Georgina, however, were happy in the union.

On March 14th, 1816, Babbage was elected as a Fellow of the Royal Society of London. The Royal Society was officially established in 1663 by King Charles II, to promote the study of natural philosophy in the kingdom. "The Royal," as it is sometimes called, served as a forum for men of science, a place for them to meet and discuss the subjects of the day, and also published important papers. Everyone who was an important man of science was a member of the Society. However, the Royal's membership at the time of our game was not restricted to men of science; politicians and titled gentlemen were also members, having been elected based on their political or social importance rather than on their scientific merits. Prominent Fellows who were not men of science included Arthur Wellesley, 1st Duke of Wellington, and Lord George Gordon Byron, 6th Baron Byron, father of Ada Lovelace.

In 1823, Babbage was elected as a member of the Royal Society Dining Club. The Dining Club met once a week for a sumptuous, seven-course meal, with elaborate printed menus. The President of the Royal Society usually presided, and visitors were also invited to attend. The discussions at the weekly dinners were lively and entertaining, ranging over the gamut of the scientific topics of the day.

In the five years between 1815 and 1820, Babbage was a productive mathematician, specializing in the theory of functions[3]. Charles also pursued employment during this time, in order to be able to support his growing family without relying on his father. He sought a mathematics position at the East India Company College in Hailey, Hertfordshire, just north of London. Later, he sought the chair of mathematics at the University of Edinburgh, Scotland. Babbage did not win either post, however, likely due to his liberal political leanings and his family's nonconformist past. Benjamin Babbage missed no opportunity to remind Charles that he had not found permanent employment. Charles was dependent on monthly allowances from his father.

In 1824, Babbage was invited to take part in the founding of a new life insurance company, *The Protector*. The opportunity would have offered a significant salary: £1,500 per year, which converts to approximately $160,000 in 2017. He created the required actuarial tables, but the company never came to fruition, and so another opportunity to earn his own living was lost.

In 1819, Babbage visited Paris and observed the work of Gaspard de Prony, who had been commissioned by the French government to produce a new, comprehensive table of logarithms. The scope of the work required made it virtually impossible to produce the table via normal means, and de Prony had devised a three-stage procedure to make the project practicable. A few highly-trained mathematicians organized the work and determined how particular calculations would be carried out. A larger number of perhaps less-visionary mathematicians would figure out how these calculations could

[3] In mathematics, a *function* is a mapping from a set of inputs to a set of outputs, such that each input maps to only one output. A function transforms the input into an output. The theory of functions is an inquiry in pure mathematics, where functions and their properties are studied abstractly, without regard for practical application.

be done using only addition and subtraction, via the method of finite differences[4]. In the final stage, a much larger number of human computers -- for that was a job description rather than the name of a mechanical computing device -- who only knew how to perform addition and subtraction, would do the actual calculations. De Prony's division of labor for the calculation of mathematical tables a major influence on Babbage's design for the Difference Engine.

According to Babbage's own recollection, it was in 1820 or 1821 that he first had the idea to automate calculations with his Difference Engine. The thought struck while Babbage and Herschel were working on calculations that involved the use of tables of logarithms. As we have seen, these extensive tomes, pages upon pages of columns of numbers, were necessary for performing more efficient computations. However, the tables had a seemingly unavoidable problem: the logarithms in the table had to be originally computed by a human at some point, and therefore the tables were subject to human error. Upon encountering a plethora of errors in the tables, Babbage allegedly said to Herschel, “I wish to God the calculations had been executed by steam,” leading to the idea for the Engine.

Later, Babbage sat down and sketched out his initial ideas for the Difference Engine, convincing himself that such a device was in fact possible. Babbage later claimed that the idea made him physically ill.

In February 1827, Benjamin Babbage, Charles' father, died. Benjamin's sizable estate was divided between Charles and his mother. Charles received approximately £100,000, relieving his financial woes. He was now able to support his family in a luxurious manner, and also fund his scientific investigations.

Later in 1827, Babbage was devastated when his beloved wife Georgina became ill and died. His youngest son, Alexander, also died, aged less than one year. Babbage took a year-long tour of continental Europe, returning to Britain in 1828, the year our game begins. In 1828, while still in Rome, Babbage read in a newspaper that he had been elected as the Lucasian Professor of Mathematics at Cambridge. The Lucasian Chair is perhaps the most prestigious academic position that one can hold anywhere in the world; Isaac Newton held the chair for 33 years in the seventeenth century, and Stephen Hawking held it for 30 years in the twentieth. Babbage replaced Sir George Biddell Airy, who had bested Charles for the chair just two years prior in 1826. Babbage held the chair for more than a decade.

Babbage was charming and energetic, a prominent fixture in British society. “He was equally at ease with intelligent working men, country clergymen, men of science, at court, or at the dining tables of the aristocracy.'' [Hym85] His weekly parties at his residence at 1 Dorset Street became famous in London society, and invitations were much sought after.

[4] The method of *finite differences* is a way to produce each successive value of a polynomial $f(x) = c_k x^k + c_{k-1} x^{k-1} + ... + c_1 x^1 + c_0 x^0$, using only addition and subtraction, without having to do multiplication. Other functions, such as logarithms, can be acceptably approximated via polynomials, and thus the method of finite differences can be used, if the polynomial is carefully chosen, to produce a table of logarithms using only addition and subtraction. Lab 1, if it is a part of your game, will introduce and explore the method of finite differences.

During the time period covered by this game, Babbage was a liberal, bordering on radical, although later in life he became more conservative. In keeping with his broad social circles, he knew the liberal political reformers of the time.

Babbage was a leading man of science, well known and respected by his colleagues.

Augusta Ada King-Noel, Countess of Lovelace

Augusta Ada Byron was the only legitimate child of her “mad, bad, and dangerous to know” father, poet and immense celebrity Lord Byron, and her mother, Anne Isabella Milbanke Byron. She was born on December 10th, 1815 in London. Although named Augusta for Byron's half-sister, everyone, including Byron himself, referred to her as “Ada.” Ada's parents divorced in 1816, and she never knew her father. Due to Byron's notorious fame in Britain, Ada was something of a celebrity from the time of her birth.

Lord Byron died in April 1824 in Missolonghi, Greece, where he was fighting in the war for Greece's independence from the Ottoman Empire. Byron did not die while fighting, but rather of complications from medical care, specifically bloodletting.

Ada's mother passed care of her young daughter on to her mother, Lady Milbank. A quotation from one of Anne's letters to her mother, regarding Ada, may give us some insight into her (lack of) regard for her daughter:

> “I talk to *it* for your satisfaction, not my own, and shall be very glad when you have *it* under your own.” [Woo99] (Emphasis added.)

Anne was also controlling, and determined that Ada should not follow in her father's hedonist ways. In fact, Lady Byron considered her former husband to be insane, and so to help prevent Ada following in Byron's footsteps, Anne hired tutors to teach Ada mathematics at an early age. One of these tutors, William Frend, was a mathematician so conservative that he did not believe in negative numbers. Another tutor, and later friend, was Mary Somerville, a Scottish woman who published in the subjects of mathematics and astronomy, an almost unheard of accomplishment for woman of the time. As it turned out, Ada had a natural gift for mathematics. Despite her mother's best intentions, Ada later in life described her approach to natural philosophy and mathematics as “poetical science.”

Ada was a sickly child, often being assigned to bed rest, with one spell abed lasting for a year. She did not attend any formal schooling, but continued to work with tutors throughout her teenage years.

Lovelace met Charles Babbage at one of his Dorset Street parties on June 5th 1833 (see the Counterfactuals section below for a reconciliation of this with the game's timeline). After that, she learned more about the Difference Engine by attending one of Dionysius Lardner's lectures at the Mechanics Institute.

Part 3: The game

This section provides a general sketch of how the *Charles Babbage, Ada Lovelace, and the Dawn of Computing* game works. This information just scratches the surface, however! You will find much more specific information about your character, and what is expected of your character during the game, in your role sheet.

Major issues for debate

The central intellectual collisions in the game concern the nature of science and scientists (are they talented, wealthy amateurs, or is science a profession?) and whether and to what degree science and engineering projects should be subsidized by the government. The main question in the game is whether or not Charles Babbage should be awarded additional funds from the British government for the development of his Difference Engine (an automated calculator capable of automatically creating, typesetting, and printing mathematical tables) and / or Analytical Engine (a true proto-computer), during the early to mid-1800s. Other issues concerning politics, society, the state of mathematics in Britain, and so on, may also arise during the game.

Rules and procedures

This section briefly summarizes the rules and procedures of the game. More specifics for your character in particular may be found in your role sheets.

When and how to speak

Your role sheet will provide details on when you should make a formal speech to the class, e.g., John Herschel will make a speech briefly introducing the Difference Engine in game session (GS) 1, after the Georgian party games kick things off. The basic game outline below gives an outline showing when many of the scheduled speeches will take place.

You are also most likely -- depending on your role -- expected to arise on occasion to speak spontaneously, based on the characteristics of the debate in the game so far. Each game session will have designated opportunities for this; when you wish to speak, simply arise and make your way to the podium. The *podium rule* says that whenever someone approaches the podium, they must be allowed to speak, eventually, by the presiding official during the game session.

Basic game mechanics

In this game, your fundamental goal as an individual character, and as a member of a faction (if you happen to be part of a faction), is to accumulate *influence points*, or IPs. IPs are used to exert influence on the Prime Minister (PM) when he makes a decision regarding Babbage's machines. The PM has IPs of his own, by virtue of his office, but if you play the game well, you can accumulate enough IPs to effectively force him to make a decision favorable to you. IPs are the currency of the game: the more you can accumulate the better, and if you spend them wisely you can win the game!

The current PM makes decisions regarding Babbage's engines at three points in the game: during GS 3, during GS 5, and during GS 7. For each decision, there are two or three stacks of IPs, representing the options the PM has to choose from for that decision. At the time of the decision, individuals, factions,

and the PM "spend" their IPs by distributing them across the stacks. Individuals spend their IPs first, then factions, and finally the PM. Individuals and factions may distribute their IPs across the stacks as they see fit; the PM, however, has to place all of the IPs he intends to spend in the same stack. Each party in the spending process may spend as many or as few of the IPs they control as they choose. Once the spending is complete, the stack that has the most IPs in it is the decision the PM must make. If there is a tie, then the least favorable decision, from Babbage's point of view, is the one that is made.

The first PM decision occurs in 1828, at the end of GS 3. There will be two stacks: one to fund the Difference Engine and one that says do not fund the Difference Engine. For this decision, there are two IPs already in the "fund" stack. You can use Table 2 to track the IPs involved in this decision; place markers in boxes in the appropriate column as IPs are spent.

Table 2: GS 3 decision stacks

X	
X	
Fund DE	Do not fund DE

The second PM decision occurs in 1846, at the end of GS 5. For this decision, there will be three stacks: one to continue funding the Difference Engine, one to fund the Analytical Engine instead of the Difference Engine, and one to cancel the project entirely. For this decision, there are no pre-allocated IPs in any of the stacks. You can use Table 3 to track the IPs involved in this decision.

Table 3: GS 5 decision stacks

Fund DE	Fund AE	Cancel

The final PM decision also occurs in 1846, at the end of GS 7. For this decision, there will be only two stacks: one to fund the Analytical Engine, and another to not fund the Analytical Engine. For this decision, there are no pre-allocated IPs in either of the stacks. You can use Table 4 to track the IPs involved in this decision.

Table 4: GS 7 decision stacks

Fund AE	Do not fund AE

During the game, individuals and factions can earn IPs in various ways, including, but not limited to, the following:

- By scoring the highest on the faction quiz at the end of the game setup sessions
- By winning one of the Georgian party games that take place during Babbage's party, in GS 1
- By making the best presentation during a game session, as judged by the game-master (GM)
- Based on the outcome of the Royal Society vote in GS 3, to recommend or not recommend funding the Difference Engine
- For the anti-Babbage faction only, passing a Royal Society resolution that is unfavorable to Babbage
- If a faction defection occurs, the faction to which the character defects will earn one or more IPs. Your role sheet may prohibit you from defecting from your assigned faction. If it does not, consult the GM before your defection.
- As a result of a Persuasiveness Metric vote at the end of a game session (see below)

Forfeits

Babbage will serve as the "master of the revels," during the party game at the beginning of GS 1, that is, he will run the game. He is able to assign *forfeits* during the party game, which will ultimately determine who wins the party game. Forfeits are assigned if a player cheats, cannot correctly complete an aspect of the game, commits a social *faux pas*, and so on. For example, if in the game *I Love my Love with an A*, Dionysius Lardner cannot think of a food that begins with the letter 'K,' Babbage would assign him a forfeit. Or, if Mary Somerville addresses Lord Charles Grey as Charles, rather than Lord Grey or Earl Grey, Babbage would assign her a forfeit. The game master will help Babbage keep track of the forfeits he assigns during the party game.

The practice of assigning forfeits was a common practice at parties during the era in which our game takes place. At the end of the party, party goers in the early 1800s would have to pay a small amount of money for each forfeit they received during the party. In our game, the stakes are IPs. The player with the fewest forfeits (other than Babbage, of course) will receive an IP at the beginning of GS 2. If more than one player is tied for the fewest number of forfeits, then the game master will break the tie with a die roll or other randomized method.

Persuasiveness metric

At the end of each game session, the indeterminates (including the current PM) will be polled, via secret ballot, as to who they think made the most persuasive presentation during the game session. The GM will count the votes, and the individual who receives the most votes will receive an IP. In the case of a tie, all of the tied individuals will receive an IP.

Royal Society membership

In game sessions where the Royal Society debates, votes, and makes recommendations, only Fellows of the Royal Society (FRS) are allowed to participate. Not every character in the game is a FRS, and further, some characters do not hold FRS status early in the game. Table 5 shows the characters in the game and when they possess FRS status.

Table 5: FRS status by game year

	1828 (GS 1 – 3)	1830 (GS 4)	1846 (GS 5 – 7)
Adams			
Airy			Y
Babbage	Y	Y	Y
Brunel		Y	Y
Buckland	Y	Y	Y
Clement			
Crosse			
Faraday	Y	Y	Y
Frend			
Gilbert	Y	Y	Y
Grey			
Herschel	Y	Y	Y
Lardner	Y	Y	Y
Lovelace			
Peel	Y	Y	Y
Robinson	Y	Y	Y
Russell			
Sabine	Y	Y	Y
Somerville			
Sussex	Y	Y	Y
Swing			
Wellesley			

Objectives and victory conditions

Generally speaking, if you are a member of the pro-Babbage or anti-Babbage faction, you win the game if your faction wins. That is to say, if the British government refuses to fund Babbage's machines in two out of the three opportunities for funding, then the anti-Babbage faction wins, and so all the members of that faction win. On the other hand, if the government does fund Babbage's machines in two out of the three funding opportunities, then the pro-Babbage faction wins, and therefore all the members of that faction win.

If your character is an indeterminate -- i.e., if you are a PM -- your victory conditions are not quite so clear cut. At the end of GS 7, all the characters who have a franchise will vote for the PM who made the most eloquent and convincing PM speech; the winner of the vote will be the indeterminate that meets their victory conditions. The characters that have franchise for the GS 7 vote are shown in Table 6.

Table 6: Franchise status in 1846

Character	Franchise?
Adams	Y
Airy	Y
Babbage	Y
Brunel	Y
Buckland	Y
Clement	
Crosse	Y
Faraday	Y
Frend	Y
Gilbert	Y
Grey	Y
Herschel	Y
Lardner	
Lovelace	
Peel	Y
Robinson	Y
Russell	Y
Sabine	Y
Somerville	
Sussex	
Swing	
Wellesley	Y

It is very important for you to remember that you may have different, character-specific victory conditions, even if you are a member of a faction! Refer to your role sheet for details, and make sure to keep the specifics secret from other players in the game.

Basic outline of the game

The standard version of the game covers a broad span of time, from 1828 through 1846. There are three phases to the game: setup lecture(s), the seven game sessions and three optional labs, and then a postmortem session to set the record straight. The phases of the game are summarized in the following sections.

Phase I: Setup

During the setup phase, the instructor will spend some time introducing the relevant history (briefly summarized in the Narrative section of Part 2, above). Then the instructor will explain the game, in terms of the factions, roles, game sessions, and mechanics involved.

At the end of the setup phase, the instructor will assign the members of the class to roles, and will distribute individual role sheets. **Note:** it is likely that your role sheets will contain secret information, meant for your eyes only. You should not share your role sheet with anyone, and you should not discuss any of your secret elements with anyone else, except the gamemaster.

Also at the end of the setup phase, your instructor will also likely give you a faction quiz to assess your knowledge of the portions of the core texts that have been assigned before the game begins. The quiz will be taken in groups, by faction; the indeterminates will work together as a faction for the purposes of this quiz. The faction that scores the highest on the faction quiz will earn an IP. If the indeterminates win the faction quiz, a die roll will determine which indeterminate receives the IP.

Phase II: Game play

In the standard version of the game, the game play phase consists of seven game sessions and three labs, in the sequence described below. Your instructor may omit the labs, and / or include more or fewer game sessions than those outlined here. Your instructor will solidify the number and order of sessions in your version of the game during the setup phase.

The game sessions fall into three categories: one party session, two public lecture sessions, and four sessions at the Royal Society. The character and feel of a game session should mirror the category it falls in; festive, boisterous yet educational, and reserved and serious, respectively.

Each character in the game has at least one formal speech or presentation to make during the game. Several of the characters in the game have the added responsibility of presiding over one or more of the game sessions. The sections below show when each character is expected to make his or her primary speech, and which character presides over each game session.

The specific order of the presentations may vary from the outline below. The presiding character will visit with the GM before his or her session(s) to determine the actual order. If you have a presentation scheduled for a particular game session, it would be in your best interests to be prepared to make your presentation at the beginning of the game session, or at any time after the session starts.

GS 1: Babbage's party (1828)

Location: Babbage's residence, 1 Dorset Street, London
Presiding character: Babbage
Draft schedule:

- Georgian party game
- Robinson's PM speech
- Frend on mathematics
- Somerville on mathematics
- Herschel on Babbage's Difference Engine fragment

Lab 1: The method of finite differences

GS 2: Public lectures at the Mechanic's Institute (1828)
Location: The London Mechanic's Institute
Presiding character: Lardner
Draft schedule:

- Wellesley's PM speech
- Sussex on *laissez-faire* economics
- Swing on the plight of famers and the dangers of automation
- Lardner on the Difference Engine
- Crosse on ???
- Open floor for debate

Lab 2: The Difference Engine

GS 3: Royal Society recommendation on the Difference Engine (1828)
Location: The Royal Society of London
Presiding character: Gilbert
Draft schedule:

- Faraday introduces a resolution supporting funding the Difference Engine
- Buckland introduces a resolution against funding the Difference Engine
- Open debate about which resolution to pass
- FRS voting on the resolutions
- IP spending
- PM decision

GS 4: Celebrating the Royal Society (1830)
Location: The Royal Society of London

Presiding character: Gilbert
Draft schedule:

- Grey's PM speech
- Gilbert on the Royal Society
- Babbage on the Royal Society
- Open floor for debate

Lab 3: The Analytical Engine

GS 5: Public lectures at the Mechanic's Institute (1846)

Location: The London Mechanic's Institute
Presiding character: Brunel
Draft schedule:

- Peel's PM speech
- Clement on the Difference Engine
- Brunel on the Thames Tunnel
- Lovelace on the Analytical Engine
- IP spending
- PM decision

GS 6: Royal Society discussions on usefulness of the calculating Engines (1846)

Location: The Royal Society of London
Presiding character: RS President
Draft schedule:

- Sabine on ???
- Adams on the discovery of Neptune
- Airy on the discovery of Neptune
- Open floor for debate

GS 7: Final debates at the Royal Society (1846)

Location: The Royal Society of London
Presiding character: RS President
Draft schedule:

- Russell's PM speech
- Open floor for debate
- IP spending
- Franchise voting for best PM speech
- PM decision

Phase III: Postmortem

The class session(s) schedule for the postmortem discussion take place after the final game session is complete. During the postmortem session(s), the instructor will lead discussions about the game, to reveal the winners of the game, and to uncover secrets that characters had during the game. After this, the instructor will discuss what really happened regarding Charles Babbage and his computing engines, and highlight how the outcome of the game compared to the actual history. Finally, the instructor will lead a discussion where students share their views on the central concepts and intellectual collisions that were key aspects of the game.

Assignments

Generally speaking, you will have a writing assignment for each of your formal speeches, and you will write a few paragraphs summarizing your take on each PM speech. You individual role sheet will have more detail regarding your assignments, so check there for more information.

Counterfactuals

Lardner did lecture on the Difference Engine, and Lovelace did see him speak on the subject. However, his lectures on the subject did not take place as early as 1828. In the game, his lecture on the engine takes place before the second lab and before characters need to make decisions regarding the engine.

Similarly, Ada Lovelace did meet Charles Babbage at one of his Dorset Street parties, but not until June 5th, 1833. Babbage did not pick up residence at 1 Dorset Street until 1831. In our game, Babbage is already at Dorset Street in 1828, and Ada attends the GS 1 party in 1828.

The Swing Riots did not take place until 1830, but in our game they take place in 1828; this allows Captain Swing to credibly speak during GS 2, since he cannot speak during sessions held at the Royal Society.

The period of time the game covers featured a “musical chairs” of Prime Ministers of the U.K. Not all of the men who were PM during this period are included as characters in the game.

In reality, the following characters died before our game ends in 1846: Clement (1844), Frend (1841), Gilbert (1839), Grey (1845), and Sussex (1843). For our purposes, however, these characters remain alive throughout the game.

With the exception of Captain Swing, each of the characters in this game is a real person who lived during the era of the game, and the character biographies in the role sheets are historically accurate. However, in many cases, characters in the game perform actions that are “historical fiction” rather than “historic.” In these cases, the characters in the game serve the purposes of the game, so that students can more deeply understand the key issues involved.

Part 4: Roles and factions

This section briefly summarizes the two factions in *Charles Babbage, Ada Lovelace, and the Dawn of Computing* game. Each of the roles in each faction, plus the indeterminate roles, is briefly described.

Pro-Babbage faction

The pro-Babbage faction is a collection of men of science, engineers, and personal friends of Charles Babbage. This group is committed to the development of Babbage's computing engines, recognizing how important they will be. The faction members also recognize that developing the Difference Engine or the Analytical Engine will be expensive, beyond the capacity of private financing.

John Couch Adams The John Couch (pronounced "cooch") Adams is a British astronomer and mathematician, best known for his co-discovery with Urbain Le Verrier of the planet Neptune in 1846.

Charles Babbage FRS Charles Babbage is a British polymath -- a person whose expertise spans a significant number of different subject areas -- and the inventor of two types of calculating machines. First, Babbage invented the Difference Engine, a device capable of automatically calculating and printing certain types of mathematical tables, and then the Analytical Engine, a true proto-computer.

Isambard Kingdom (I. K.) Brunel FRS I. K. Brunel is perhaps the most accomplished mechanical and civil engineer in Britain during the time of our game. Brunel, a close personal friend of Charles Babbage, is responsible for completing the Thames Tunnel project, for building the Great Western Railway, and for the construction of the steamship S. S. Great Western.

Joseph Clement Joseph Clement is the extremely capable toolmaker, draftsman, engineer, and industrialist hired by Charles Babbage to build his Analytical Engine.

Andrew Crosse Andrew Crosse is an amateur man of science, best known for his experiments with electricity. Mary Shelly, the author of the novel *Frankenstein*, is an acquaintance, and her husband Percy Bysshe Shelley attended one of Crosse's lectures on atmospheric electricity in 1814; this may or may not have helped to influence the famous novel.

Michael Faraday Michael Faraday is an extremely influential English man of science; of all the characters in this game, his influence is the greatest in our 21st-century world. His work focuses on chemistry and electricity.

John Frederick William Herschel FRS John Frederick William Herschel is another British polymath, and close friend of Charles Babbage. He and Babbage, among others, formed the Analytical Society while undergraduate students at Cambridge. Herschel studied mathematics, astronomy, chemistry, botany, and more. Herschel is the leader of the pro-Babbage faction.

Dionysius Lardner FRS Dionysius Lardner is a member of the Royal Society of London and a professor at the University of London. Lardner is a scientific populist and the first scientific journalist.

Augusta Ada King-Noel, Countess of Lovelace Augusta Ada King-Noel, Countess of Lovelace, is the only legitimate daughter of the "mad, bad, and dangerous to know" romantic poet, Lord Byron. Lovelace is a

close friend of Charles Babbage, and in 1843, she translates an article on Babbage's Analytical Engine by Luigi Federico Menabrea, and adds her own voluminous notes to the translation. The notes contain what is now considered the world's first computer program.

Mary Somerville Mary Fairfax Greig Somerville is a Scottish polymath. She is very unusual for the time, having published several very influential papers and books. Somerville served as one of Ada Lovelace's tutors, and introduced her to Charles Babbage at one of his Dorset Street parties.

Anti-Babbage faction

The anti-Babbage faction is a collection of men of science, clergy, and political figures. This group is against the British government paying any more money for the development of Babbage's computing engines. Anti-Babbage faction members have different reasons for opposing the engines: some do not think the engines will be valuable or necessary for the advancement of science in Britain; some think the engines are potentially valuable, but do not think that projects such as this should be supported by the government; and some are generally against the increasing mechanization of British society, as it forces working people from their jobs.

George Biddell Airy FRS George Biddell Airy is an English mathematician and, as of 1835, the Astronomer Royal. Airy, holder of the Lucasian Professorship of Mathematics at Cambridge before Charles Babbage assumed the chair in 1828, is the leader of the anti-Babbage faction.

Reverend William Buckland DD FRS The Reverend Doctor William Buckland, DD FRS, is an English clergyman, theologian, geologist, and paleontologist. Buckland published the first full account of a fossilized dinosaur, which he termed *Megalosaurus*.

William Frend William Frend is an English unitarian clergyman, political radical, and author of the algebra textbook, *Principles of Algebra*. Frend, along with Mary Somerville, served as one of Ada Lovelace's mathematics tutors.

Davies Gilbert PRS Davies Gilbert is a British botanist, geologist, mathematician, civil servant, politician, author, and from 1827 through 1830, president of the Royal Society of London.

Edward Sabine FRS Edward Sabine, FRS, is an Irish military man, geologist, and astronomer. He served as the on-board astronomer on expeditions to attempt to discover the Northwest Passage under Sir John Ross in 1818 and again under Sir William Edward Parry in 1819 and 1820.

Prince Augustus Frederick, Duke of Sussex, KG KT GCB FRS FRSA Prince Augustus Frederick, Duke of Sussex, is the sixth son of “mad” King George III, who reigned from 1760 until 1820. Although not a man of science, Sussex does have intellectual pursuits, chiefly in biblical studies and the Hebrew language.

Captain Swing Captain Swing represents the spirit and ideas of the farmers who participated in the “Swing Riots” across England in 1830 and 1831, starting fires and breaking threshing machines, protesting for increased wages, against restrictive Poor Laws, and against the increasing use of threshing machines in agriculture. Several of the threatening letters sent by the protesters were signed with the *nom de guerre* “Captain Swing.”

Indeterminates

In this game, the characters that will serve in the role of Prime Minister are indeterminate. That means that these characters have no pre-decided position regarding Babbage's engines, although each character does have some general political leanings that may inform his opinions on the subject.

Lord Charles Grey, 2nd Earl Grey, KG PC Lord Charles Grey, 2nd Earl Grey is a Whig MP, and the namesake of Earl Grey tea. Grey will serve as PM during the game.

Sir Robert Peel, 2nd Baronet, FRS PC Sir Robert Peel, 2nd Baronet is a Tory MP. Peel will serve as PM during the game.

Lord Frederick John Robinson, 1st Earl of Ripon, FRS PC Lord Frederick John Robinson, 1st Earl of Ripon is a Tory MP. Robinson will serve as PM during the game.

Lord John Russell, 1st Earl Russell, KG GCMG PC Lord John Russell, 1st Earl Russell is a Whig MP. Russell will serve as PM during the game.

Field Marshal Arthur Wellesley, 1st Duke of Wellington, KG GCB GCH PC Field Marshal Arthur Wellesley, 1st Duke of Wellington is the biggest hero of the French Wars and Tory MP. Wellington will serve as PM during the game.

Part 5: Core texts

This section will include annotated selections from core historical texts that everyone in the game should read, including:

[Bab64] Charles Babbage. *Passages from the Life of a Philosopher*. Longman, Green, Longman, Roberts & Green, London, 1864. Available via Google Books.

[Men43] Luigi Ferico Menabrea. Sketch of the Analytical Engine Invented by Charles Babbage, Esq. *Scientific Memoirs*, iii, 1843. Available via Google Books.

For the fall 2017 semester, students will all purchase the following companion text, which includes selections from [Bab64], the entirety of [Men43], and several other works:

[MMB61] Phillip Morrison, Emily Morrison, and Charles Babbage. *Charles Babbage on the Principles and Development of the Calculator: And Other Seminal Writings*. Dover Publications, New York, NY, 1961.

Bibliography

[Alf08] Randy Alfred. June 5, 1833: Ms. Software, Meet Mr. Hardware. https://www.wired.com/2008/06/june-5-1833-ms-software-meet-mr-hardware/, June 2008.

[Alm13] Ali Almossawi. *An Illustrated Book of Bad Arguments*. The Experiment, New York, NY, 2013.

[Bab30] Charles Babbage. *Reflections on the Decline of Science in England, and on Some of its Causes*. B. Fellowes and J. Booth, London, 1830. Available via Google Books.

[Bab32] Charles Babbage. *On the Economy of Machinery and Manufactures*. Charles Knight, London, 1832. Available via Google Books.

[Bab64] Charles Babbage. *Passages from the Life of a Philosopher*. Longman, Green, Longman, Roberts, & Green, London, 1864. Available via Google Books.

[Bab15] Charles Babbage. *Table of Logarithms of the Natural Numbers from 1 to 108,000*. E. & F. N. Spon, Ltd, London, 1915. Available via Google Books.

[Bal90] Sir Robert Stawell Ball. *The Story of the Heavens*. Cassell & Company, Ltd., London, 1890. Available on Google Books.

[BK12] Aaron Birk and Robert Krulwich. Who Wants To Eat Jelly_sh Omelets? Dolphin Meatballs? Mouse-On-Toast? These Guys. http://www.npr.org/sections/krulwich/2012/09/27/161874316/who-wants-to-eat-jellyfish-omelettes-dolphin-meatballs-mouse-on-toast-these-guys, September 2012.

[Blo12] Marjorie Bloy. Frederick Robinson, Viscount Goderich (1782-1859). http://www.historyhome.co.uk/pms/goderich.htm, 2012.

[Bri36] Bridgewater, F.H.E. *The Bridgewater Treatises on the Power, Wisdom and Goodness of God, as Manifested in the Creation. Treatise I-VIII.: Geology and mineralogy considered with reference to natural theology, by William Buckland. 2d ed*. The Bridgewater Treatises on the Power, Wisdom and Goodness of God, as Manifested in the Creation. Treatise I-VIII. W. Pickering, 1836. Available via Google Books.

[Bro66] W. H. Brock. The Selection of the Authors of the Bridgewater Treatises. *Notes and Records of the Royal Society of London*, 21(2):162{179, 1966.

[Buc02] R. Angus Buchanan. *Brunel: The Life and Times of Isambard Kingdom Brunel*. Hambledon & London, London, 2002.

[Con14] Ciaran Conliffe. Dionysius Lardner, Scientific Populist - HeadStuff. http://www.headstuff.org/2014/07/dionysius-lardner-scientific-populist/, 2014.

[Cro57] Mrs. Cornelia A. H. Crosse. *Memorials, Scientific and Literary, of Andrew Crosse, the Electrician*. Longman, Brown, Green, Longmans, & Roberts, London, 1857. Available via Google Books.

[Das12] Mike Dash. The Epic Struggle to Tunnel Under the Thames. http://www.smithsonianmag.com/history/the-epic-struggle-to-tunnel-under-the-thames-14638810/, 012.

[Dow95] Douglas Downing. *Dictionary of Mathematics Terms*. Baron's, Hauppauge, NY, 2nd edition, 1995.

[Ess14] James Essinger. *Ada's Algorithm: How Lord Bryon's Daughter Ada Lovelace Launched the Digital Age*. Melville House Publishing, Brooklyn, NY, 2014.

[Fre92] William Frend. *Peace and Union recommended to the associated bodies of Republicans and Anti-Republicans*. P. C. Croft, 1792.

[Fre93] William Frend. *An account of the proceedings in the University of Cambridge, against William Frend, M.A. Fellow of Jesus College, Cambridge, for publishing a pamphlet, intitled Peace and union, &c: Containing the proceedings in Jesus College, the trial in the Vice-Chanceller's Court, and in the Court of Delegates*. Printed by B. Flower, 1793.

[Fre96] William Frend. *Principles of Algebra*. G. G. and J. Robinson, London, 1796. Available via Google Books.

[FTT17] E. Fitzgerald, A.M.K. Terhune, and A.B. Terhune. *The Letters of Edward Fitzgerald, Volume 1: 1830-1850*. Princeton Legacy Library. Princeton University Press, 2017. Available via Google Books.

[Gil25] Davies Gilbert. *On the Vibrations of Heavy Bodies*. W. Clowes, 1825. Available via Google Books.

[gov16] gov.uk. Past Prime Ministers -- GOV.UK. https://www.gov.uk/government/history/past-prime-ministers, 2016.

[Gun54] Henry Gunning. *Reminiscences of the University, Town, and County of Cambridge from the Year 1780*. George Bell, 1854. Available via Google Books.

[Her30] John Frederick William Hershcel. *Preliminary Discourse on the Study of Natural Philosophy*. Longman, Bees, Orme, Brown, & Green, London, 1830. Available via Google Books.

[HH13] John Lawrence Hammond and Barbara Bradby Hammond. *The Village Labourer, 1760-1832: A Study in the Government of England Before the Reform Bill*. Longmans, Green, and Company, 1913. Available via Google Books.

[HR14] Eric Hobsbawm and George Rudé. *Captain Swing*. Verso, 2014.

[Hym85] Anthony Hyman. *Charles Babbage, Pioneer of the Computer*. Princeton University Press, Princeton, NJ, 1985.

[ID06] James E. McClellan III and Harold Dorn. *Science and Technology in World History*. The Johns Hopkins University Press, Baltimore, Maryland, 2006.

[Kar16] Aditi Kar. Charles Babbage and the Di_erence Engine. http://people.maths.ox.ac.uk/kar/Babbage.html, 2016.

[Ken16] Maev Kennedy. Brunel's Thames Tunnel (and Accidental Brothel) Becomes New Arts Space. https://www.theguardian.com/stage/2016/apr/15/brunel-thames-tunnel-arts-space-grand-entrance-hall, 2016.

[Kle15] Christopher Klein. 10 Things You May Not Know About Ada Lovelace. http://www.history.com/news/10-things-you-may-not-know-about-ada-lovelace, 2015.

[LB86] John E. Littlewood and Béla Bollobás. *Littlewood's Miscellany*. Cambridge University Press, 1986.

[Lev82] Trevor H. Levere. SABINE, Sir EDWARD. http://www.biographi.ca/en/bio/sabine_edward_11E.html, 1982.

[Lup84] Sydney Lupton. *Numerical Tables and Constants in Elementary Science*. MacMillan and Co., London, 1884. Available via Google Books.

[Mat00] Colin Matthew. *The Nineteenth Century: The British Isles, 1815-1901*. Oxford University Press, Oxford, 2000.

[Men43] Luigi Federico Menabrea. Sketch of the Analytical Engine Invented By Charles Babbage, Esq. *Scientific Memoirs*, iii, 1843. Available via Google Books.

[Mil04] David Phillip Miller. Oxford DNB article: Gilbert, Davies. http://www.oxforddnb.com/view/article/10686, 2004.

[MMB61] Phillip Morrison, Emily Morrison, and Charles Babbage. *Charles Babbage on the Principles and Development of the Calculator: And Other Seminal Writings*. Dover Publications, New York, NY, 1961.

[Mou14] Forest Ray Moulton. *An Introduction to Celestial Mechanics*. The MacMillan Company, New York, 1914.

[Mus16] The Brunel Museum. The Thames Tunnel. http://www.brunel-museum.org.uk/history/the-thames-tunnel/ , 2016.

[OR99] J. J. O'Connor and E. F. Robertson. Somerville biography. http://www-history.mcs.st-andrews.ac.uk/Biographies/Somerville.html, November 1999.

[OR01] J. J. O'Connor and E. F. Robertson. Airy biography. http://www-groups.dcs.st-and.ac.uk/~history/Biographies/Airy.html, May 2001.

[OR05] J. J. O'Connor and E. F. Robertson. Adams biography. http://www-groups.dcs.st-and.ac.uk/~history/Biographies/Adams.html, February 2005.

[Pad15] Sydney Padua. *The Thrilling Adventures of Lovelace and Babbage: With Interesting & Curious Anecdotes of Celebrated and Distinguished Characters, Fully Illustrating a Variety of Instructive and*

Amusing Scenes; as Performed within and without the Remarkable Difference Engine, Embellished with Portraits and Scientifick Diagrams. Pantheon Books, New York, NY, 2015.

[Par16] Jonathan Parry. Lord John Russell, later Earl Russell | History of government. https://history.blog.gov.uk/2016/03/16/lord-john-russell-later-earl-russell/, 2016.

[Pat08] Elizabeth C. Patterson. Somerville, Mary Fairfax Greig. http://www.encyclopedia.com/science/dictionaries-thesauruses-pictures-and-press-releases/somerville-mary-fairfax-greig, 2008.

[Rev25] Rachel Revel. *Winter evening pastimes; or, The merry-maker's companion*. A. Mesnard, 1825. Available via Google Books.

[Roe16] Joseph Wickham Roe. *English and American Tool Builders*. Yale University Press, New Haven, CT, 1916. Available via Google Books.

[RS69] F. James Rohlf and Robert R. Sokal. *Statistical Tables*. W. H. Freeman and Company, San Francisco, CA, 1969.

[Smi64] Samuel Smiles. *Industrial Biography: Iron-Workers and Tool-Makers*. Ticknor and Fields, Boston, MA, 1864. Available via Google Books.

[Sny11] Laura J. Snyder. *The Philosophical Breakfast Club: Four Remarkable Friends Who Transformed Science and Changed the World*. Broadway Books, Portland, OR, 2011.

[Soc16] The Royal Society. Welcome. https://royalsociety.org/, 2016.

[SU96] Francis Spufford and Jennifer S. Uglow. *Cultural Babbage: Technology, Time, and Invention*. Faber and Faber, London, 1996.

[Swa16] Doron Swade. Joseph Clement | Babbage Engine | Computer History Museum. http://www.computerhistory.org/babbage/josephclement/, 2016.

[The06] The Royal Society of Edinburgh. *Former Fellows of The Royal Society of Edinburgh 1783 -- 2002, Bibliographical Index, Part One*. The Royal Society of Edinburgh, Edinburgh, 2006.

[ue16] Biography.com editors. Ada Lovelace Biography. http://www.biography.com/people/ada-lovelace-20825323, 2016.

[Wil17] L. Pearce Williams. Michael Faraday, British Physicist and Chemist. https://www.britannica.com/biography/Michael-Faraday, Jan. 2017.

[Woo99] Benjamin Woolley. *The Bride of Science: Romance, Reason and Byron's Daughter*. PAN, London, 1999.

[Zie11] Sarah Zielinski. Ten Historic Female Scientists You Should Know: Before Marie Curie, these women dedicated their lives to science and made significant advances.

http://www.smithsonianmag.com/science-nature/ten-historic-female-scientists-you-should-know-84028788/, Sept. 2011.

Appendix A: List of abbreviations and titles

Below is a list of abbreviations and honorary titles which you might encounter while reading the materials for this game.

Baronet A rank in the United Kingdom's peerage system of hereditary titles. A baronet is a member of the lowest hereditary titled British order, still a commoner, but allowed to use the prefix "Sir." A 1st Baronet would be the first commoner in a family elevated to this status. A 2nd Baronet would be the eldest son of the 1st Baronet, and so on.

Countess A rank in the United Kingdom's peerage system of hereditary titles. A countess is the female spouse of an Earl, or, less frequently, a woman who holds an earldom in her own right. A countess would properly be referred to as "Lady" So, Ada Lovelace's proper title is Lady King-Noel, Countess of Lovelace.

DD Doctor of Divinity, an advanced or honorary academic degree in divinity. In the United Kingdom, D.D. is awarded to religious scholars for distinctive works beyond the doctorate (Ph.D.) level.

Duke A rank in the United Kingdom's peerage system of hereditary titles. A duke is a member of the highest titled British order, above marquesses and earls, and is the highest rank short of the monarch him or herself.

Earl A rank in the United Kingdom's peerage system of hereditary titles. An earl is a member of the middle titled British order, above viscounts and baronets, but below dukes and marquesses. These titles would often be associated with locations, e.g., Charles Jenkinson was elevated to the title of Earl of Liverpool by the king in 1796. The titles were passed down from father to first-born son, and so to continue the example, Charles' son Robert was known as Sir Robert Jenkinson, 2nd Earl of Liverpool. It would also be proper to refer to this person as Lord Jenkinson.

FRS Fellow of the Royal Society. A post-nominal title used by members of the Royal Society of London, the academy of sciences for the United Kingdom. Fellows are elected to the society by existing fellows. In the time period of our game, election to "The Royal" had as much to do with who you were as with what scientific achievements you made. Also, during the time of our game, all fellows of the Royal Society really were in fact "fellows;" no women were allowed in the society until Kathleen Lonsdale and Marjory Stephenson were elected in 1945.

FRSA Fellow of the Royal Society of Arts. A post-nominal title awarded to individuals who have made outstanding achievements in the arts, manufacturing, and / or commerce. The Royal Society for the Encouragement of Arts, Manufactures and Commerce (RSA) is a London-based, British organization committed to finding practical solutions to social challenges.

GCB Knight Grand Cross of the Most Honourable Order of the Bath. This order was expanded in 1815 by Prince George Augustus Frederick, five years before he became King George IV in 1820. The restructured order was to honor those high-ranking officers who served in the Napoleonic Wars, and "Knight Grand Cross" is the highest rank in this order.

GCH Knight Grand Cross of the Royal Guelphic Order, a.k.a. the Hanoverian Guelphic Order, a chivalric order of the Kingdom of Hanover. Hanover was a Germanic kingdom created after the Napoleonic Wars, which was jointly ruled by its own royalty, Great Britain, and Ireland. The order was established in 1815 by Prince George Augustus Frederick, five years before he became King George IV in 1820. Since this was a "foreign" order, holders of this honorific title were not entitled to be called "sir." "Knight Grand Cross" is the highest rank in this order.

GCMG Knight Grand Cross of the Most Distinguished Order of Saint Michael and Saint George. This order was created in 1818 by Prince George Augustus Frederick, two years before he became King George IV in 1820. The order was intended to honor those with high positions in the Mediterranean territories acquired during the Napoleonic Wars. "Knight Grand Cross" is the highest rank in this order.

GS Game Session. One of the class sessions for the game. In the standard version of the game, there are eight game sessions, GS 1, GS 2, …, GS 8, and three optional lab sessions.

IP Influence Point. IPs are used to exert influence on the PM when he makes a decision regarding Babbage's machines. IPs can be earned in a variety of ways as the game progresses.

KCB Knight Commander of the Most Honorable Order of the Bath. Knight Commander is the mid-level rank (between Knight Grand Cross and Companion) of the chivalric Order of Bath. The Order of Bath is used to honor senior civil servants.

KG Knight of the Most Noble Order of the Garter, the highest order of chivalry in the United Kingdom. This title is given by the king or queen to subjects at his or her pleasure, but there are only allowed to be 24 members of the order (other than members of the royal family) at any one time.

KH Knight of the Royal Guelphic Order, a.k.a. the Hanoverian Guelphic Order, a chivalric order of the Kingdom of Hanover. Hanover was a Germanic kingdom created after the Napoleonic Wars, which was jointly ruled by its own royalty, Great Britain, and Ireland. The order was established in 1815 by Prince George Augustus Frederick, five years before he became King George IV in 1820. Since this was a "foreign" order, holders of this honorific title were not entitled to be called "sir." "Knight" is the lowest rank in this order.

KT Knight Companion of the Order of the Thistle. A chivalric order of Scotland, established in 1687 by King James II. This order is limited to the sovereign and sixteen Knights and Ladies, who are selected for the order by the sovereign.

MOS Men of Science. This abbreviation stands for the collection of men (and some women) game characters who are engineers, mathematicians and / or men of science (a.k.a. natural philosophers). During our game, it is inappropriate to call men of science "scientists," as that term was not coined until 1833 by William Whewell, and did not come into full use until late in the nineteenth century.

MP Member of Parliament. A person elected by the general public to represent their interests in the House of Commons, one of the two houses of the British Parliament. At the time of our game, all MPs are male; the first woman elected to the House of Commons was Constance Markievicz, who won her

seat in 1918. However, Markievicz was a member of Sinn Féin, the Irish political party advocating for Irish independence, and so she did not take her seat. A year later, Nancy Astor was elected and took her seat in 1919.

PC Member of the Privy Council. The Privy Council is an advisory group serving the monarch (first King William IV and then Queen Victoria in our game). PC is a post-nominal title used by current or past members of the Privy Council.

PM Prime Minister. The head of the UK government and is ultimately responsible for the policy and decisions of the government. The PM oversees the operation of the Civil Service and government agencies, appoints members of the government, and is the principal government figure in the House of Commons.

PRS President of the Royal Society. A post-nominal title used by fellows of the Royal Society of London who have served as president of the society. The governing council and president of the RS are elected by the fellows of the society.

Acknowledgements

Sincere and profound thanks to the Association for Computing Machinery (ACM), whose Special Interest Group on Computer Science Education (SIGCSE) Special Projects grant allowed me to begin writing this game in the fall of 2016.

Thanks are also due to my institution, Doane University, who named me Ardis Butler James Endowed Chair for Advancement of the Liberal and Fine Arts for the 2017-2018 academic year. This generous endowment allowed me to further develop and refine the game.

I also wish to thank my first group of playtesters, the students in my Fall 2017 first-year Liberal Arts Seminar (LAR 101) course entitled *The Dawn of Computing*.

Finally, I would be nothing without the support of my wife Vicki and daughter Kay. Thank you so much!