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Teacher: Pim Huijnen

Student: Thierry Orth

Student number: 6176178

E-mail: t.orth@students.uu.nl

Computing creativity. A historical analysis of Charles Babbage's and Ada Lovelace's views on the Analytical Engine

'Sketch based on portraits of Ada Augusta Lovelace and Charles Babbage'.[1]

[1] For reference, Alfred Edward Chalon is the author of the original portrait of Lovelace (1840). Charles Babbage's photograph is from an unknown author (1860).

ABSTRACT In this paper I argue against the persistent view that Charles Babbage's Analytical Engine was the ''pre-anticipation'' or the ''birth'' of the modern-day computer. Instead, I argue that the Analytical Engine is only a precursor of the modern-day computer in hindsight. I do so by examining the views of its inventor Charles Babbage and its most important commentator Ada Lovelace, and relating these to the scientific context of 1830s and 1840s Britain. Although Babbage and Lovelace described the same machine, their views substantially differed. Whereas Babbage cherished a more ''optimistic'' view on its mathematical capacities, Lovelace believed that the machine would structurally lack creativity, a capacity essential for mathematical exertion.

Nonetheless, Babbage and Lovelace did agree in their view that, ultimately, the Analytical Engine was meant for mathematical calculation. To say that Babbage and Lovelace ''pre-anticipated'' the modern-day computer, in some way or the other, would be to claim that they had this modern machine in mind. But this would merely be a projection of the developments of our own age upon Babbage's and Lovelace's day, thereby leaving us blind for what they actually had in mind. For them, the Analytical Engine was not akin to modern-day computers, but primarily meant for the purpose of mathematical calculation.

Nevertheless, this is not to say that Babbage's and Lovelace's views are too much removed from ours, and therefore of no interest to modern debates on the capacities and limitations of modern-day computers. Indeed, their views at least teach us something about the need to critically reflect on the bearing of our historically situated presuppositions concerning the answers we tend to give on questions about the capacities of machinery.

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Introduction

Computer science seems to be thriving more than ever. As a result, human life is becoming increasingly 'computerized': ordinary as well as professional routines rely more and more on digital computers in one way or another. In a deeper sense, an ongoing transfer occurs of human capacities to machines. Historically, this process started with the transmission of physical labor to machinery. Today, mental labor has become subject to computerization, too. Parallel to the developments in computer science, the idea of reproducible intelligence has steadily increased in popularity. According to this view, human intelligence will eventually become 'programmable' in computers.

Unquestionably, the project of computer science has come a long way since the innovations of one of its most important innovators, Alan Turing. But as he readily admits, he was not the first. In his influential article 'Computing Machinery and Intelligence', Turing mentions one of the most important precursors to the modern computer: Charles Babbage's Analytical Engine. Between 1837 and 1871, Babbage devised an extensive draft for an automatic mechanical calculator. Although it did not possess the extensive functionalities of modern-day computers, it did possess one unprecedented ability: the calculation of any arbitrary mathematical function.[2]

In Babbage's age, the Analytical Engine captured the imagination of many. Few however described its philosophical implication so aptly as Babbage's fellow mathematician Ada Lovelace. In computer science, Lovelace is reputed for being the inventor of the computer algorithm: the notion of a finite set of instructions to compute any mathematical function. She described this idea in her translation of Luigi Menabrea's article on the Analytical Engine.[3] Philosophically, this article is equally interesting for Lovelace's view on the capabilities of the Analytical Engine. In Note G, the last annotation of that article, she writes:

> The Analytical Engine has no pretensions whatever to *originate* any thing. It can do whatever we *know how to order it* to perform [...] but it has no power of *anticipating* any analytical relations or truths.

Here, one finds the following view: the Analytical Engine is a mechanism that, as such, requires a given set of instructions and rules. Therefore, it cannot '*originate* any thing' by itself, nor is it capable of '*anticipating* any analytical relations or truths'. In the end, its powers are restricted to 'making *available* what we are already acquainted with'.[4]

In the age of the modern computer, one is deeply familiarized with calculators capable of calculating all mathematical functions. But this brute fact should not be projected upon Babbage's and Lovelace's day, in which such calculators did not exist.

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[2] Betty Alexandra Toole, *Ada, The Enchantress of Numbers* (Sausalito: Critical Connection, 1992), 128.

[3] Herbert Sussman, *Victorian Technology. Invention, Innovation, and the Rise of the Machine* (California: ABC-CLIO, LLC, 2009), 46.

[4] Luigi Menabrea, "Sketch of the Analytical Engine invented by Charles Babbage," in *Scientific Memoirs*, trans. Ada Lovelace and ed. Richard Taylor (London: Richard and John E. Taylor, 1843), 725-726.

Neither should one abstract their historically situated statements to more substantial claims about digital computers. With that, I distantiate myself from Turing, who generalized Lovelace's claims to the assertion 'that a machine can ''never do anything really new'''.[5] Such an abstraction might be interesting for a philosophical argument, but not for a historical examination.[6]

Remarkably, Lovelace's words are closely related to modern debates on artificial intelligence. Especially the debate on whether artificial intelligent automata are capable of originality comes to mind. I will not enter into this debate, but it forms the main incentive for writing this paper. By examining the historical context of the Analytical Engine, I intend to uncover the meaning of this machine in that time, instead of reducing its meaning to later-day developments. Simultaneously, I hope to show that historical contextualization can contribute to orientating ourselves in the present-day debates on artificial intelligence.

Regrettably, a significant part of the historiographical literature on Babbage and Lovelace is written through the lens of the modern-day computers. It is therefore both affected and infected by one major historical deficiency: the projection of the present upon the past.

Computer programmer Dorothy K. Stein does insist on the historical context of Lovelace's comments. Unfortunately, these are words rather than deeds. First, Stein states that Lovelace's writing 'was essentially intuitive and mystical'.[7] Thus, she presupposes that intuition was a bad thing in Lovelace's time. This was not the case, as I shall argue. Second, Stein claims that Babbage's views were 'truly prophetic of the computer's position and prestige in our own society'.[8] But it is rather anachronistic to suggest that Babbage consciously outlined the ideas behind the modern-day computer.

Historian Betty A. Toole refers to the Analytical Engine as the 'conceptual birth of the computer revolution'.[9] But to state that the Analytical Engine ''gave birth'' to this revolution would be to state that this development was, in some way, teleologically determined.[10] Obviously it was not the case that Babbage intentionally initiated the computer revolution. Toole's observation therefore holds only in hindsight, but not in ''foresight''.

Historian Anthony Hyman writes that it must 'remain an open question' to what extent Babbage's Analytical Engine resembles the modern-day general stored-program

[5] Alan Turing, ''Computing Machinery and Intelligence,'' *Mind* 59, 236 (1950): 450.

[6] Remark that Turing has no pretensions to treat his generalization as if it were a historically correct claim. For a detailed argument, see for instance: Selmer Bringsjord, Clarke Caporale and Ron Noel. ''Animals, Zombanimals and the Total Turing Test: the Essence of Artificial Intelligence.'' *Journal of Logic, Language and Information* 9, 4 (2000): 415.

[7] Dorothy K. Stein, ''Lady Lovelace's Notes: Technical Text and Cultural Context,'' *Victorian Studies* 28, 1 (1984): 63.

[8] Stein, ''Lady Lovelace's Notes,'' 67.

[9] Toole, *Ada, The Enchantress of Numbers*, 128.

[10] Sussman, *Victorian Technology*, 7.

computer.[11] Similarly, I think that it must remain a closed question whether Babbage and Lovelace had the modern computer in mind in their occupations with the Analytical Engine. I shall argue for a negative answer.

In their seminal work 'Leviathan and the Air-Pump', historians of science Steven Shapin and Simon Shaffer show why the Boylean 'experiment as a systematic means of generating natural knowledge' triumphed over the Hobbesian approach of science. In their book, Shapin and Shaffer argue that one should refrain from projecting the outcomes of the past upon the past as if the subsequent developments that led to the present were, in some way, necessitated by and through some inherent superiority of these developments.[12]

The purpose of this paper is, in essence, to show that Babbage's and Lovelace's conceptions of the Analytical Engine did not foreshadow the modern-day computer. I intend to place their conceptions back in the scientific context of 1830s and 1840s Britain and, with that, to disconnect Babbage's Analytical Engine from its later-day connotations with the modern-day computer.

As in mathematics, the method of arriving at the result is equally important as the result itself, if not more important. My method follows a couple of hermeneutic intuitions. I particularly think that a good understanding of Babbage's and Lovelace's ideas requires a well-balanced contextualization; one that appropriately grounds them in the context in which these ideas inhered. My explanation primarily draws on Babbage's and Lovelace's theoretical views and the scientific context of 1830s and 1840s Britain, but also gives some attention to their personal motives.

My paper is subdivided into three subtopics. First, an outline of Babbage's concept of the Analytical Engine in its historical context. With this, I intend to ensure that my reader is capable of adequately understanding Babbage's and Lovelace's ideas. Second, an examination of Babbage's conception of this machine in the context of British science and mechanicism. I will here rely on two chapters from Babbage's autobiography *Passages from the Life of a Philosopher*.[13] Third and last, an analysis of Lovelace's conception of the Analytical Engine in the context of British science and Romanticism remains. This chapter leans upon Lovelace's article 'Sketch of the Analytical Engine invented by Charles Babbage', as well as a selection of Lovelace's letters between 1841-1843.[14]

Source criticism is the core attribute of historical research. One should remain aware of the brute fact that sources are never complete representations of the past, but

[11] Anthony Hyman, "Charles Babbage: Science and Reform," in *Cambridge scientific minds*, ed. Peter Harman and Simon Mitton (New York: Cambridge University Press, 2002), 88.
[12] Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump. Hobbes, Boyle, and the experimental life* (Princeton, New Jersey: Princeton University Press, 1985), 4-5.
[13] Following the paper topic, the emphasis lies on the fifth chapter, 'Difference Engine No.1', and the eighth chapter, 'Of the Analytical Engine'.
[14] From Lovelace's article, I will primarily use Note A and Note G for the sake of their relevance for my topic.

instead incomplete selections, created and contained by intentional human actors. In this light, some caveats are in place concerning the historical equipment of this paper.

First of all, my paper relies on Babbage's and Lovelace's representations of their views. But can one trust that these are, in fact, truthful representations? This is rather questionable in the case of Babbage's autobiographical views and Lovelace's letters: these are, after all, their views on the matters at hand. However, this problem is solved as long as one remains careful which conclusions can or may validly be drawn from their testimonies. Their testimonies are not necessarily truthful representations of the facts, but they can in general be taken as truthful representations of what Babbage's and Lovelace's themselves believed.

Further, one might question if general conclusions about British science are always representative for the writings of Babbage and Lovelace. I admit that this is not the case. For if Babbage and Lovelace did not follow the general trend, then these general characterizations fail to capture their individual tendencies. Nevertheless, this problem exists only if one uncritically imposes the trends of British science upon Babbage's and Lovelace's writings. To dodge logical fallacies, I will instead depart from their individual writings to ensure that my conclusions hold.

Finally, the issue of source incompleteness remains in the case of Toole's bundle of Lovelace's letters. This bundle does not contain all of Lovelace's letters. However, it is not the purpose of this paper to provide a complete representation of Lovelace's ideas. Rather, I mean to provide a sound representation that complies with the common thread in Lovelace's ideas. For this purpose, one does not require a complete overview of all source material. Admittedly, it could be the case that this selection does not provide a completely sound picture of Lovelace's ideas. To reduce such problems, I will make sure to stay in tune with the secondary literature.

1. Self-regulation, inerrancy, efficiency. Babbage's project of the Analytical Engine

In this chapter, I provide an outline of the theoretical concepts and the historical context behind Babbage's Analytical Engine. Before discussing Babbage's and Lovelace's views, it is namely important to first get a grasp on the Analytical Engine. By far, this will be the most technical topic of the paper. At the same time, it constitutes one of its core foundations, if not *the* core foundation. I will not articulate the workings of Babbage's machine in all its subtleties, but only mean to provide a means for understanding Babbage's and Lovelace's ideas. For this purpose, I shall treat the theoretical principles, the practical implementation and the historical background of the Analytical Engine.

Rather than instantly delving into the technicalities of the Analytical Engine, it is helpful to examine Babbage's prior calculating machine: the Difference Engine. This machine was meant for mechanically adding differences to starting values. Take for instance the number sequence '0', '5', '10', '15', '20' as input values. Suppose we write these in a vertical column. Next to this column, we add another column consisting of difference values: '5', '5', '5', '5', '5'.[15] If we now add these difference values to the input values, the following results follow: '0+5=5', '5+5=10', '10+5=15', '15+5=20', '20+5=25' (see figure 1 in 'Appendix').[16] Roughly, these two columns illustrate the core purpose behind the Difference Engine: the mechanical addition of 'constant differences' to 'specified starting values'.[17]

In the practical implementation of the Difference Engine, numbers would be represented by gear wheels. Each 'digit of a number [has] its own wheel', ranging from '0' to '9' (see figure 3 in 'Appendix'). Digits are, in turn, 'represented by the amount by which the wheels rotate[s]'. Initially, a human operator moves the gear wheels to a preferable sequence of numbers, thereby creating a starting value. After initiation, the machine would follow the method of difference sketched in the previous paragraph. After each cycle, the machine would print the result of the differential calculation.[18]

Babbage's Difference Engine thus had one particular aim: mechanizing the calculations that had traditionally been processed through mathematical tables. For centuries, polymaths had sought to eliminate the drawbacks of mathematical tables. Notably, Gottfried Leibniz and Blaise Pascal had tried to construct calculating machines in order to expel the pervasive risk of errors inherent to the often arduous process of analogue calculation.[19] Perhaps this struggle is less conceivable with the

[15] Charles Babbage, *Passages from the Life of a Philosopher* (London: Longman, Green, Longman, Roberts & Green, 1864), 50.
[16] Bruce Collier and James MacLachlan, *Charles Babbage and the Engines of Perfection* (Oxford: Oxford University Press, 1998), 39.
[17] Ibidem, 37.
[18] Doron Swade, *The Difference Engine. Charles Babbage and the Quest to Build the First Computer* (New York: Viking Penguin, 2001), 29-30.
[19] Louise Purbrick, "The Dream Machine: Charles Babbage and his Imaginary Computers," *Journal of Design History* 6, 1 (1993): 20.

straightforward calculations stated above, but Babbage's objective was to automatize polynomial functions.[20] Calculation of these complex functions demanded a large number of calculating steps, thus enlarging the risk of miscalculation.[21]

Following theoretical motivations, Pascal and Leibniz had 'cast the quest for monetary gain as complementary to natural philosophical and technical achievement'.[22] In Babbage's time, the need for correct mathematical calculation was however not merely a theoretical problem. Britain's key industries frequently relied on mathematical calculation - this was particularly the case for maritime navigation.[23] For a significant part, Babbage's calculator projects were in fact aimed to support sea navigation in 'the world's leading seafaring country'.[24]

Allurements of monetary gain were thus just around the corner.[25] Babbage did not have a high opinion of science for the sake of science either; he himself had actively engaged for a 'systematic development of science' and explicit 'application [of science] to commerce and industry'.[26] Nevertheless, it is not always entirely clear whether philosophical and technical achievements or monetary gain came first for Babbage. This must remain an open question.

In Britain, technological achievements were typically propelled by steam. Steam was regarded by British society to be the 'agent of change', and it 'held the promise of prosperity'. If steam implied change, then engines constituted the vehicles of progress. For Babbage in particular, steam meant a way out of 'the curse of human fallibility': ultimately, steam-driven calculating engines could yield error-free calculations.[27] One should here be careful with the word 'engine': in Babbage's age, this word specifically referred to steam engines in the tradition of James Watt.

Babbage was especially impressed by Watt's governor-inspired steam engine. This machine possessed the capacity for self-regulation: it could 'run consistently and efficiently by adjusting [itself] to varying conditions without human intervention'.[28] For Babbage, this mechanical 'repetition of one simple task' meant the escape of the 'inattention, the idleness or the dishonesty of human agents'.[29] Unfortunately,

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[20] An example of a polynomial function is the function 'x2 + x + 41'. Because these functions contain powers and variables, calculating them is more complex and thus requires more calculation steps. Figure 4 in 'Appendix' illustrates the incremental complexity of differential functions.
[21] Swade, *The Difference Engine*, 29.
[22] Matthew L. Jones, "Improvement for Profit: Calculating Machines and the Prehistory of Intellectual Property," in *Nature Engaged. Science in Practice from the Renaissance to the Present*, ed. Mario Biagioli and Jessica Riskin (New York: Palgrave Macmillan, 2012), 126.
[23] Sophie Waring, "The *Nautical Almanac*: Instrument of Controversy," in *The Material Cultures of Enlightenment Arts and Sciences*, ed. Adriana Craciun and Simon Schaffer (London: Springer Nature, 2016), 105.
[24] Hyman, "Charles Babbage," 81.
[25] Sussman, *Victorian Technology*, 40.
[26] Hyman, "Charles Babbage," 79.
[27] Swade, *The Difference Engine*, 17.
[28] Sussman, *Victorian technology*, 12.
[29] Iwan Rhys Morus, "Manufacturing Nature: Science, Technology and Victorian Consumer Culture," *The British Journal for the History of Science* 29, 4 (1996): 407.

self-regulation was missing in the Difference Engine - this machine needed to be manually operated 'for each new run of calculations'.[30]

Babbage thus desired a self-regulating calculator. Furthermore, he wanted one that could do 'more than simply calculate mathematical tables'.[31] Therefore, he discontinued his project and replaced it with another project: the Analytical Engine. One should bear in mind that the term 'analytical' did not denote human intelligence. Instead, it referred to mathematical analysis in the tradition of the so-called 'analytical' or 'Leibnizian' calculus.[32]

Principally, the difference between the Difference Engine and the Analytical Engine consisted in their system of input. Whereas the Difference Engine demanded an operator moving gear wheels, the Analytical Engine, instead, retrieved its starting values from so-called 'punched cards'. Punched cards were each provided with distinct hole patterns. Depending on the unique pattern, card readers in the Engine would determine the input values and the type of arithmetic operation to perform (see figure 4 in 'Appendix'). Values and instructions would only be provided at the commencement of calculation. Constant human intervention thus made place for self-regulation in Babbage new project.[33]

At this point, the technical material has been addressed. It is therefore time to make some general remarks concerning the nature of the Analytical Engine. Whereas the Difference Engine processed numbers using the method of differences, the Analytical Engine was gifted with the capability of performing other operations 'than [those] dictated by its wheelwork'.[34]

This fact stemmed from the theoretically unlimited configurations of hole patterns in punched cards, which in turn implied that the storage capacity and the number of possible instructions were 'in theory limitless'.[35] One might thus call the Analytical Engine a general-purpose machine, a machine 'capable of being programmed by the user' for all sorts of calculations.[36]

In theory, the Analytical Engine could calculate all mathematical functions without thereby requiring the step-by-step control of human heads and hands.[37] In practical terms, Babbage's project did not run that smoothly. In the beginning, Babbage had financed his project through governmental fundings. But eventually, he lost the

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[30] Note that by 'self-regulation' or 'self-action', Babbage does not understand full autonomy. As he writes on page 41 of his autobiography *Passages from the Life of a Philosopher*, self-action refers to the notion that 'when the numbers on which [the machine] is to operate are placed in the instrument, it is capable of arriving at its result by the mere motion of a spring, a descending weight, or any constant force'.

[31] James Essinger, *A Female Genius. How Ada Lovelace, Lord Byron's daughter, started the Computer Age* (London: Gibson Square, 2014), 126.

[32] Essinger, *A Female Genius*, 170.

[33] Swade, *The Difference Engine*, 109.

[34] Sussman, *Victorian Technology*, 45.

[35] Sussman, *Victorian Technology*, 45.

[36] Swade, *The Difference Engine*, 113.

[37] Ibidem, 113.

confidence of the English government.[38] From the perspective of the government, Babbage was quite the controversial figure. During a parliamentary debate in 1835, the governmental sponsorship of Babbage's project was criticized as 'unprincipled waste' and a 'squandering [of] public money'. A year earlier, Babbage sent an aggrieved letter to Foreign Secretary Duke of Wellington, accusing the English government of begrudging his activities.[39] The abundant amount of changes of government between 1834 and 1835 also did not help in heightening Babbage's credibility.[40]

In fact, the English government was scarcely involved in scientific projects. In fact, it 'would only patronize [science] where a national need could be palpably demonstrated'.[41] In Babbage's project, there clearly existed neither trust nor interest.[42] But Babbage did not abandon his aspirations so easily. In 1840, Babbage tried to approach the English government anew. Simultaneously, he was also trying to gain support on the Continent to acquire his required fundings. At the invitation of Giovanni Plana, Babbage visited Turin.[43] In Turin, he explained his concept of the Analytical Engine in front of a group of Italian philosophers. Of the philosophers, Luigi Menabrea especially became interested in Babbage's ideas.[44]

Babbage desired a written account of the Analytical Engine that would justify his purposes, 'a report' that 'would serve as an independent ratification of its merits and help his case in the new negotiations' with the British government. Two years after his visit to Turin, Menabrea answered Babbage's wish by publishing an article on the Analytical Engine.[45] Unfortunately, Menabrea's article was written in French and therefore inaccessible for a significant part of English entrepreneurs, investors and scientists. At the suggestion of Babbage and Charles Wheatstone, Ada Lovelace translated Menabrea's article to English in order to help 'the cause of advancing Babbage work in England'.[46]

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[38] John Fuegi and Jo Francis, "Lovelace & Babbage and the Creation of the 1843 'Notes'," *IEEE Annals of the History of Computing* 25, 4 (2003): 18.
[39] Swade, *The Difference Engine*, 122-123.
[40] Ibidem, 124.
[41] W.H. Brock, "British Science Periodicals and Culture: 1820-1850," *Victorian Periodicals Review* 21, 2 (1988): 51.
[42] Hyman, "Charles Babbage," 84.
[43] Swade, *The Difference Engine*, 130-131.
[44] Toole, *Ada, The Enchantress of Numbers*, 77.
[45] Swade, *The Difference Engine*, 132-133.
[46] Fuegi and Francis, "Lovelace & Babbage and the Creation of the 1843 'Notes'," 18.

2. Mechanizing mathematics. Babbage's "positive" conception of the Analytical Engine

In this chapter, I examine Babbage's concept of the Analytical Engine in the context of British science. I argue that Babbage's conception of the machine should be understood against the background of industrial productivity on the one hand, and mechanicism on the other hand. Roughly, I follow Stein's view that Babbage differed from Lovelace in his 'scientific approach'. Whereas Lovelace propagated the use of imagination, Babbage 'fitfully fought hard' against these tendencies.[47] Instead, he was concerned with 'computational necessity'.[48] I will first depict Babbage's views on the Analytical Engine. Afterwards, these views will be related to the context of 1830s and 1840s British science.

Before delving into the nature of British science, it is sensible to depart from Babbage's own thought-world. In his autobiography *Passages from the Life of a Philosopher*, Babbage describes a dream that supposedly sparked his calculator projects:

> One evening I was sitting in the rooms of the Analytical Society, at Cambridge, my head leaning forward on the Table in a kind of dreamy mood, with a Table of logarithms lying open before me. Another member [...] called out, "Well, Babbage, what are you dreaming about?" to which I replied, "I am thinking that all these Tables [...] might be calculated by machinery."[49]

Babbage's dream revealed to him that mathematical calculation, traditionally a human undertaking, could be executed 'by machinery'. Elsewhere, he remarks that the project of the Difference Engine made him realize that '[t]he whole of arithmetic [...] appeared within the grasp of mechanism'.[50]

Babbage's ideas emerged at a moment when the authority of science was thriving.[51] Arguably, science had produced extensive economic prosperity in Britain. For many Britons, Watt's innovation of machinal self-regulation had signified 'progress towards large-scale, rapid, and continuous production in the factory'. Without the need for constant human intervention, industries would certainly flourish.[52]

Following the trend of his age, Babbage's Analytical Engine was deeply inspired by industrial developments. For instance, he called his machine a 'miniature factory'.[53] Similarly, the names of the two main sections of the Engine are derived from the textile industry.[54] But in a sense, Babbage distantiated himself from the industrial projects

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[47] Stein, "Lady Lovelace's Notes," 63.
[48] Ibidem, 52.
[49] Babbage, *Passages from the Life of a Philosopher*, 42.
[50] Ibidem, 112.
[51] Bernard Lightman, "Introduction," in *Victorian Science in Context*, ed. Bernard Lightman (Chicago: The University of Chicago Press, 1997), 10.
[52] Sussman, *Victorian Technology*, 13.
[53] Ibidem, 45.
[54] Swade, *The Difference Engine*, 105.

before him. Whereas Watt's steam engines, for instance, responded to the increasing demand for physical labor, Babbage's project had a non-physical capacity in mind: mathematical calculation.[55] Consequently, Babbage's projects 'gave new impetus to the notion of a "thinking machine" and stimulated the debate about the relationship between mind and physical mechanism'.[56] Could a machine, perhaps, think?

According to his contemporary polymath Harry Wilmot Buxton, Babbage indeed 'had taught wheelwork to *think*'.[57] Lady Byron, mathematician and mother of Ada Lovelace, likewise referred to the Difference Engine as a 'thinking machine'. But one should not take the word "thinking" too literally here. Instead, one should understand the word in a metaphorical sense.[58]

For Babbage, the word "thinking" did not refer to human thinking in all its complicated dimensions. Rather, it denoted the complex mathematical analysis that the Analytical Engine could perform. "Thinking" thus only referred to a specific faculty of thinking, not to the whole compound of thinking.[59] The Analytical Engine was therefore not in a literal sense a "thinking machine".

Be that as it may, Babbage still profoundly altered how the relationship between mind and mechanism was perceived, even if one takes "thinking" in this narrow sense of the word. Babbage's belief that the capacity for mathematical thought could be reproduced in a machine promised an unprecedented innovation. To understand why he believed this, one first has to consider Babbage's views on mathematics.

As a mathematician, Babbage criticized the prevalent notion that 'higher forms of math were dangerous because they mechanized the mind of the student'.[60] Polymath William Whewell for instance thought that algebra deadened 'the mind's receptivity to culture and moral cultivation'. Similarly, Babbage's fellow mathematician Thomas Carlyle accused mathematics of perverting the mind into a 'cunningly-constructed arithmetical mill'.[61]

Even if Babbage's mechanistic approach of mathematics was unorthodox, the overall idea of "mechanicism" was not. From 1800 onwards, a sharp contrast arose between mechanistic scientists who thought that knowledge should be defined through 'empirical and experimental methods', and Romanticists who saw 'intuition' or 'imagination' as 'the supreme tool for cognition'.[62]

By "mechanicism", I mean the view that the world can be exhaustively explained through empirical observations of 'undifferentiable, homogeneous' particles following

[55] Sussman, *Victorian Technology*, 40.
[56] Swade, *The Difference Engine*, 85.
[57] Swade, *The Difference Engine*, 85.
[58] Toole, *Ada, The Enchantress of Numbers*, 40.
[59] Simon Schaffer, "Babbage's Intelligence: Calculating Engines and the Factory System," *Critical Inquiry* 21, 1 (1994): 224.
[60] Jessica Kuskey, "Math and the Mechanical Mind: Charles Babbage, Charles Dickens, and Mental Labor in 'Little Dorrit'," *Dickens Studies Annual* 45, 1 (2014): 255.
[61] Kuskey, "Math and the Mechanical Mind," 248.
[62] Christine Lehleiter, ed., *Fact and Fiction. Literary and Scientific Cultures in Germany and Britain* (Toronto: University of Toronto Press, 2016), 8.

'forces of attraction and repulsion'.[63] Mechanicists often compare the world to a clock, a mechanically coherent system following only principles of deterministic causation.[64]

Babbage's views were particularly akin to the British empiricists' mechanistic conception of the mind. According to the empiricists, the human mind was nothing but a mechanism, constructing 'complex ideas out of [...] simple sense perceptions through the principle of association'. Therefore, every process of thought was a non-original, mechanical process.[65] Babbage thought that, in general, 'a machine could imitate the full range of human mental life, particularly in the realm of logical analysis'.[66] Specifically, he applied this idea to mathematical thought.

Take for instance Babbage's characterization of algebra, the ''language of higher mathematics''. According to Babbage, algebra rationalized the mind 'like a factory', thereby increasing its productivity. Hereby, algebra guided mathematical thought and made the mind able to 'comprehend in a single formula the whole of a problem'. Without algebra, however, mathematical thought 'would be forced to continually move from component to component'. It would then 'never be able to grasp' the problem 'as a whole'.[67] Therefore, mathematics was better off a strict ''rational'' or ''mechanistic'' organization of underlying ''units of labor''.

Instead of considering it a vice, Babbage considered the mechanistic tendency of mathematics to be a virtue. From his mechanistic characterization of mathematics it was but a small step towards real-world mechanization of mathematics itself. In hindsight, Babbage's Analytical Engine merely followed the trend of his age in 'replacing human operations by mechanical in a complex self-regulating device'.[68] However, his machine substantially differed in the sense that it incorporated the mental capacity for mathematical analysis.[69] The Analytical Engine was 'the first ingression of machinery into psychology': it externalized a 'faculty of thought' into an inanimate machine. Thus, Babbage attempted to mechanize a capability that could previously 'only have been arrived at by *mental* effort'.[70]

To some extent, Babbage's project to transfer the human capacity for mathematics into 'material forms of iron and wood' faded the boundaries between human and machine. With that, it shook the foundations of the prevailing view that human and machine were strictly opposed.[71] In Babbage's eyes, this was a false dichotomy. He believed that the displacement of mathematics unto mechanical machinery was, in fact, a highly reasonable undertaking. For this belief, the following

[63] Carmen Casaliggi and Porscha Fermanis, *Romanticism. A Literary and Cultural History* (London: Routledge, 2016), 4.
[64] Shapin and Schaffer, *Leviathan and the Air-Pump*, 24.
[65] Casaliggi and Fermanis, *Romanticism*, 31.
[66] Sussman, *Victorian Technology*, 43.
[67] Kuskey, ''Math and the Mechanical Mind,'' 255-256.
[68] Sussman, *Victorian Technology*, 40.
[69] Ibidem, 43.
[70] Swade, *The Difference Engine*, 84.
[71] Sussman, *Victorian Technology*, 38.

two reasons are insightful. More importantly, these reasons go to the heart of Babbage's conception of the Analytical Engine.

In the first place, the Analytical Engine would alleviate humans from 'the intolerable labour and fatiguing monotony of a continued repetition of similar arithmetical calculations'. Simultaneously, it would increase mathematical labor productivity.[72] In the same manner in which 'algebra modeled a hierarchical division of labor', the Analytical Engine would process given mathematical functions through error-free, economical operations.[73]

Furthermore, Babbage's conception rested on the idea that mathematics could, in fact, become mechanized. According to his view, there existed no real opposition between human and machine to begin with. Mathematics merely demanded that the mathematician in question followed the correct mathematical rules. But for this purpose, it was of secondary importance whether the mathematician was human or machine. Babbage thus saw no impossibility in his desire to create 'a machine, which [...] should become a substitute for one of the lowest operations of human intellect'.[74]

For Babbage, mathematics was therefore not exclusively a function of the human mind. Instead, it could conceivably be undertaken by a purely mechanical system. In essence, Babbage's project was based on practical industrial motives and theoretical mechanistic views. But as a result of these views, little space was left for creativity or imagination. The Analytical Engine was namely supposed to be a full-blown ''mechanistic'' and ''rational'' system, deterministically executing whatever instructions it was given.[75]

[72] Kuskey, ''Math and the Mechanical Mind,'' 256.
[73] Ibidem, 249.
[74] Ibidem, 256.
[75] Casaliggi and Fermanis, *Romanticism*, 31.

3. Imagining science. Lovelace's "negative" conception of the Analytical Engine

In this chapter, I place Lovelace's ideas about the Analytical Engine in the context of British science. Essentially, I argue that her ideas were an expression of Romantic tendencies in science, specifically of the notion of imagination.[76] Therefore, this chapter will append some subtle distinctions to the remarks on British science from the previous chapter: Romanticism and science were not opposed, but instead entangled endeavours. I start with an exposition of Lovelace's views, and will thereafter reconsider the nature of British science in order to place Lovelace's comments in this context.

First, I will provide some historical context behind Lovelace's annotations of Menebrea's article. Lovelace did not create her Notes by herself, but in collaboration with her friend Charles Babbage. Historians such as Stein thereby question the authenticity of the Notes and, instead, claim that Babbage did all the work. But this was not the case.[77] On the contrary: Babbage himself writes that the Notes were Lovelace's work and, moreover, that Ada pointed out at least one mathematical error in his work.[78] Yet, even if Lovelace's exposition of the theoretical principles behind the Analytical Engine was not authentic, one might still say that her views differed from Babbage in her original thoughts about the nature and capabilities of the machine.[79]

Most material discussed in the Notes is highly mathematical, and thus of little interest here. Instead, the focus lies on Lovelace's more philosophical observations. In the light of the discussion about the Analytical Engine in the first chapter, it is interesting to consider Lovelace's remarks in Note A:

> If we compare together the powers and the principles of construction of the Difference and of the Analytical Engines, we shall perceive that the capabilities of the latter are immeasurably more extensive than those of the former, and that they in fact hold to each other the same relationship as that of analysis to arithmetic.[80]

Lovelace's distinction between the Difference Engine and the Analytical Engine consists in that the former is primarily arithmetical, whereas the latter is essentially analytical. As I argued in the first chapter, the Difference Engine solely follows the method of differences, whereas the Analytical Engine is, in principle, capable of calculating any mathematical function. As Lovelace proceeds, '[t]he Difference Engine can [...] do nothing but *add*'. In contrast, 'the Analytical Engine is equally capable of analysis or of

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[76] Gowan Dawson and Sally Shuttleworth, ''Introduction: Science and Victorian Poetry,'' *Victorian Poetry* 41, 1 (2003): 3.
[77] On page 136 of his autobiography, Babbage even remarks that Lovelace 'entered fully into almost all the very difficult and abstract question connected with the subject [i.e., the Analytical Engine]'.
[78] Betty Alexandra Toole, ''Ada, an Analyst and a Metaphysician,'' *Ada Letters* 11, 2 (1991): 65-66.
[79] Fuegi and Francis, ''Lovelace & Babbage and the Creation of the 1843 'Notes',' '' 24.
[80] Menabrea, ''Sketch of the Analytical Engine invented by Charles Babbage,'' 695.

synthesis'.[81] For her, this not only implied 'practical advantage', but 'a deeper understanding of mathematics and science' as well.[82]

But in what sense could the Analytical Engine possibly grant deeper understanding of mathematics and science? Would it not merely implement what is already understood by its operator? Here, I must remark that for Lovelace "understanding" means more than merely arriving at the result of a problem. Indeed, she believed that 'the process of scientific discovery' was more significant than the 'result of the discovery'. True understanding did not start with practicing mathematics, but with reflecting on the core "axioms" or "first principles" of mathematics.[83] As her mathematics teacher Augustus de Morgan remarked, Lovelace more than often questioned "basic assumptions" rather than working out concrete mathematical solutions.[84]

Lovelace's prioritization of the process of science above the result of science should be understood from her propagation of intermingling the "poetical faculty" of imagination with the more "matter-of-fact" scientific approach. As she writes, '[i]magination is the Discovering Faculty [...]. It is that which penetrates into the unseen worlds around us, the world of Science'.[85]

This view was not solely theoretically grounded, however. In an undated fragment to her mother Lady Byron, Lovelace writes:

> You will not concede me philosophical poetry. Invert the order! Will you give me poetical philosophy, poetical science?

In a sense, Lovelace's reconciliation of poetry and science could be seen as a contentious dissention from Lady Byron's strict views.[86] Her mother had educated and nurtured Ada to become a mathematician and scientist, whilst firmly prohibiting more imaginative disciplines such as poetry and philosophy. Lady Byron namely believed that these fields had deranged her husband and Ada's father, Lord Byron.[87]

With the mechanistic conception of science in mind, one might question whether Lovelace's conception matched the prevalent standards of science. Remember that according to mechanicists, the human mind was a mechanical system, combining thoughts out of simple ideas. These were, in turn, caused by 'simple sense perceptions through the principle of association'. Following this conception, no room is left for originality, nor for the faculty of imagination 'to create, invent or frame entirely new ideas'.[88]

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[81] Ibidem, 697.
[82] Toole, *Ada, The Enchantress of Numbers*, 38.
[83] Ibidem, 78.
[84] Ibidem, 56.
[85] Ibidem, 79.
[86] Ibidem, 24.
[87] Ibidem, 26.
[88] Casaliggi and Fermanis, *Romanticism*, 31.

Nevertheless, that line of thought is mistaken. On the contrary, Lovelace's conception fitted right into the scientific context. To understand this point, it is important to revise our historical conception of 1830s and 1840s British science. In these decades, a major debate emerged concerning the definition of science, brought about by its thriving authority.[89] What deserved the name 'science', and what did not? During this period, no 'clear orthodoxy' existed to define or delineate the "borders" of science.[90]

Remarkably, the word 'science' did not denote some mechanistic idea of science. Instead, it referred to 'any systematic study' in general. One might, then, imagine the difficulty of divorcing science from more imaginative yet equally systematic disciplines as poetry. Besides this more theoretical problem, British scientists often rejected full-blown mechanicism because of its connotation with 'the potential violence that [had] led to the French Revolution'.[91]

In the 1830s and 1840s, Romanticism and mechanicism were not opposed. Indeed, boundaries between these movements were often rather vague.[92] Romantic thinkers rarely thought that 'an inherent conflict' existed between poetical and scientific approaches.[93] In fact, Romanticists often made 'decisive contributions' to 'fields indebted to empiricism'.[94] Similarly, scientists working in "empiricist" or "mechanicist" fields often incorporated the Romantic faculty of imagination in their works.[95]

Romanticism was, then, not an endeavour to counter mechanistic science and provide what that approach could not. Rather, Romanticism epitomized the idea that science and intuition, in essence, approached the same issues.[96] In the 1830s and 1840s, British science was thus caught in a creative interplay with other cultural expressions, in particular with Romanticism.[97]

Lovelace's integration of 'scientific skills of reason and analysis' and 'poetical skills of imagination' was, then, not an idiosyncratic one.[98] Rather, she proved herself to be highly indebted to the then prevalent idea that science and intuition, essentially, approached the same issue:

> I do not believe that my father was (or ever could have been) such a Poet as I shall be an Analyst; (& Metaphysician); for with me the two go together indissolubly.[99]

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[89] Lightman, "Introduction," 10.
[90] Alison Winter, "The Construction of Orthodoxies and Heterodoxies in the Early Victorian Life Sciences," in *Victorian Science in Context*, ed. Bernard Lightman (Chicago: The University of Chicago Press, 1997), 24-26.
[91] George Levine, "Defining Knowledge: An Introduction," in *Victorian Science in Context*, ed. Bernard Lightman (Chicago: The University of Chicago Press, 1997), 21.
[92] Casaliggi and Fermanis, *Romanticism*, 7.
[93] Ibidem, 29-30.
[94] Lehleiter, *Fact and Fiction*, 9.
[95] Casaliggi and Fermanis, *Romanticism*, 29-30.
[96] Lehleiter, *Fact and fiction*, 10.
[97] Lightman, "Introduction," 3.
[98] Toole, *Ada, The Enchantress of Numbers*, 129.
[99] Ibidem, 114.

Lovelace's approach should thus be seen as an expression of the intimate intermingling of science and Romanticism in Britain.[100]

In another sense, however, Lovelace took her own stance. Admittedly, she thought that 'Mathematical Science shows what [the worlds of Science] is'. However, she also writes that 'to use & apply that language we must be able fully to appreciate, to feel, to seize, the unseen, the unconscious. Imagination too shows what *is*, the *is* that is beyond the senses'.[101]

Understanding mathematics could therefore not be achieved without invoking the faculty of imagination. Rather, imagination should precede mathematics - without imagination, true understanding of mathematics could not be achieved.[102] In this, she proved herself to be an explicit exponent of the Romantic view that imagination was not only beneficial, but indeed vital in understanding the world.[103]

Admittedly, terms such as ''imagination'' or ''intuition'' are highly ambiguous and hard to grasp. But it is not the purpose of this chapter to arrive at a clear definition of these terms. Instead, the purpose is to show that Lovelace's propagation of imagination results in a particular stance towards the Analytical Engine.

In the first sentence of Note G, Lovelace indicates that '[i]t is desirable to guard against the possibility of exaggerated ideas that might arise as to the powers of the Analytical Engine'. First, there is the tendency 'to *overrate* what we find to be already interesting or remarkable'. Second, one might '*undervalue* the true state of the case, when we do discover that our notions have surpassed those that were really tenable'.[104] Against the background of these tendencies, Lovelace warns against a particular overestimation:

> The Analytical Engine has no pretensions whatever to *originate* any thing. It can do whatever *we know how to order it* to perform. It can *follow* analysis; but it has no power of *anticipating* any analytical relations or truths. Its province is to assist us in making *available* what we are already acquainted with.

In short, this overestimation consists in the view that the Analytical Engine possesses the capacity to ''originate'' or ''create'' new 'relation or truths'. Lovelace however refutes this view: the Analytical Engine performs only according to 'whatever *we know how to order it* to perform', but it cannot ''create'' or ''originate'' by itself.[105]

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[100] By this, I do not mean that no strict, anti-Romantic mechanistic thinkers existed. The point is that imagination, poetry and Romanticism were not prima facie rejected by science. For more information on this revisionist view, see the chapter 'Contexts of Romanticism' in Carmen Casaliggi and Porscha Fermanis, *Romanticism. A literary and cultural history* (London: Routledge, 2016).
[101] Toole, *Ada, The Enchantress of Numbers*, 79-80.
[102] Ibidem, 132.
[103] Casaliggi and Fermanis, *Romanticism*, 4.
[104] Menabrea, ''Sketch of the Analytical Engine invented by Charles Babbage,'' 725.
[105] Ibidem, 725-726.

Perhaps it is sensible to dwell on this idea for a moment. John Searle's Chinese Room Argument provides a clear illustration of Lovelace's comments.[106] Imagine a man in a locked room, surrounded by 'several baskets full of Chinese symbols'. Suppose, further, that this man does not understand a word of Chinese. Instead, he is 'given a rule book in English for manipulating [...] Chinese symbols'. Can one, then, claim that this man understands Chinese? Surely not: the man only knows how to manipulate the formal structure of Chinese; he is in no sense aware of the meaning behind this structure.[107]

In a similar manner, Lovelace argues that the Analytical Engine only follows the track laid down by its human operator, since it only manipulates functions through given input and instructions. Even if it can actually be programmed to calculate all mathematical functions and even if it appears to perform original activities, it still does not factually possess ''originality''.

As I mentioned, Lovelace's conception of the Analytical Engine emerged from her prioritization of imagination. This idea was, in turn, imbued with the notion of 'creative processes in poetry and discovery'.[108] To understand this, consider the following citation:

> [...] I look on through a very immeasurable vista, and though I see nothing but vague & cloudy uncertainty in the foreground of our being, yet I fancy I discern a very bright light a good way further on, and this makes me care much less about the cloudiness & indistinctness which is near.[109]

At its core, science starts from unclear and indistinct ideas. But in the ''creative process'' that constitutes scientific endeavour, unclarity and indistinctness become eliminated in exchange for clear and distinct understanding. This is, then, what ''creativity'' or ''originality'' presupposes: the emergence of understanding in the midst of confusion.

Lovelace argues that the Analytical Engine cannot possibly possess originality. In fact, it always performs according to a fixed set of input and instructions. Influenced by Romantic thinking, Lovelace thought that true ''understanding'' and ''originality'' presupposes a realm of unclarity and indistinctness, ruled by creativity and imagination. Precisely this is what the Analytical Engine cannot achieve.

Returning the correct result therefore did not imply that the machine understood mathematics. In fact, the Analytical Engine could not possibly 'assist directly with solving theoretical problems in mathematics': this would require the capacity of

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[106] Although Lovelace's comments are historically distinct from the philosophical discussion in which Searle's thought experiment figures, the core idea remains the same: that ''correct manipulation'' does not imply ''originality'' or ''understanding''.
[107] John Searle, ''Can Computers Think?'' in *Mind and Cognition. An Anthology*, ed. William G. Lycan and Jesse Prinz (Malden: Blackwell, 2008), 215.
[108] Toole, *Ada, The Enchantress of Numbers*, 134.
[109] Ibidem, 72.

originating something.[110] Thus, theoretical understanding of mathematics lay beyond its functionalities, which were, in the end, restricted to the execution of mathematics.

[110] Essinger, *A Female Genius*, 180.

Conclusion

In this paper, I argued that Babbage and Lovelace did not "prophesize", "heralded" nor "necessitated" the computer. Instead, their conceptions denoted something that widely differed from the modern-day computer. Historically, Babbage designed his machine to resolve the problem of defective and inefficient mathematical labor. Whereas Watt's self-regulating steam engines held the promise of industrial progress, Babbage's machine meant to make mathematical calculation error-free and more efficient. After all, calculation was a vital backbone of Britain's key industries. Rather than resembling the modern-day "computer", the Analytical Engine was thus only a "calculator".

Besides industrial motivations, Babbage's conception of the Analytical Engine was strongly inspired by mechanistic ideas. For him, mathematical thought was mechanizable precisely because mathematics was nothing more than a mechanistic thought process. In the end, mathematics was only a function of a certain configuration of simple, indivisible tasks. In Babbage's eyes, this configuration could easily be constructed in a mechanical system. Mathematics was therefore not a faculty specific to humans only, but one that could equally well be "inherited" by inanimate machinery.

For Lovelace, however, the Analytical Engine could not possibly "inherit" mathematics. Mathematics namely demanded more than a mechanistic construction: it required the faculty of imagination. According to her, the Analytical Engine could only work with the input and instructions it was given. Therefore, it could not possibly possess imagination, nor could it "originate" something by itself. So, the Analytical Engine could execute parts of mathematics, but it could not possibly arrive at understanding of mathematics.

For Babbage the question was not whether mathematics could be mechanized. Instead, the mechanization of mathematics was only a matter of time. Lovelace however explicitly refuted this view: as such, the Analytical Engine could never originate something "out of the blue".

In a sense, Babbage's and Lovelace's remarks are applicable to the modern-day computer. It might therefore be tempting to say that Babbage and Lovelace "prophesied" the computer. But this claim holds only if one stretches the meaning of the word "computer" to its old-fashioned sense, namely "that which calculates". To claim that Babbage's and Lovelace's prophesied the modern-day computer, would be to claim that they in some sense already understood the subsequent course of events. Furthermore, it would insinuate that a device designed for mathematical calculation deterministically implies the invention of the modern computer, or that the modern computer is, in some way, reducible to mathematical calculation. Both are false assumptions.

As I have shown, Babbage's and Lovelace's conceptions were indebted to another context, another way of doing science and, most importantly, another machine. One should not abstract the meaning of their rem carks to more substantial conclusions about the modern-day computer, but should instead understand them from the historical context in which they were uttered. If one reduces the Analytical Engine to a pre-anticipation of the modern-day computer, then there is little hope of forming a historically correct picture.

Then again, it does not follow that one may not reflect upon our own age through the ideas of Babbage's and Lovelace's ideas. Indeed, contemporary discussions on artificial intelligence demand that we do just that. Ultimately, the ideas about the Analytical Engine might help us in reconsidering, rethinking and revising our own historically situated presuppositions regarding human intelligence. But this will not work if one iterates or projects our own presuppositions upon the past. Rather, one has to recognize that the distance between Babbage's Analytical Engine and the modern-day computer exists not merely in measurable time, but in the long chain of contingent events between them as well.

Bibliography

Babbage, Charles. *Passages from the Life of a Philosopher.* London: Longman, Green, Longman, Roberts & Green, 1864.

Bringsjord, Selmer, Clarke Caporale and Ron Noel. "Animals, Zombanimals and the Total Turing Test: the Essence of Artificial Intelligence." *Journal of Logic, Language and Information* 9, 4 (2000): 397-418.

Brock, W.H. "British Science Periodicals and Culture: 1820-1850." *Victorian Periodicals Review* 21, 2 (1988): 47-55.

Casaliggi, Carmen and Porscha Fermanis. *Romanticism. A Literary and Cultural History.* London: Routledge, 2016.

Collier, Bruce and James MacLachlan. *Charles Babbage and the Engines of Perfection.* Oxford: Oxford University Press, 1998.

Craciun, Adriana and Simon Schaffer. *The Material Cultures of Enlightenment Arts and Sciences.* London: Springer Nature, 2016.

Dawson, Gowan and Sally Shuttleworth. "Introduction: Science and Victorian Poetry." *Victorian Poetry* 41, 1 (2003): 1-10.

Essinger, James. *A Female Genius. How Ada Lovelace, Lord Byron's Daughter, started the Computer Age.* London: Gibson Square, 2014.

Fuegi, John and Jo Francis. "Lovelace & Babbage and the Creation of the 1843 'Notes'." *IEEE Annals of the History of Computing* 25, 4 (2003): 16-26.

Hyman, Anthony. "Charles Babbage: Science and Reform." In *Cambridge Scientific Minds*, edited by Peter Harman and Simon Mitton, 79-93. New York: Cambridge University Press, 2002.

Jones, Matthew L. "Improvement for Profit: Calculating Machines and the Prehistory of Intellectual Property." In *Nature Engaged. Science in Practice from the Renaissance to the Present*, edited by Mario Biagioli and Jessica Riskin, 125-146. New York: Palgrave Macmillan, 2012.

Kuskey, Jessica. "Math and the Mechanical Mind: Charles Babbage, Charles Dickens, and mental labor in 'Little Dorrit'." *Dickens Studies Annual* 45, 1 (2014): 247-274.

Lehleiter, Christine, ed. *Fact and fiction. Literary and scientific cultures in Germany and Britain.* Toronto: University of Toronto Press, 2016.

Lightman, Bernard, ed. *Victorian Science in Context.* Chicago: The University of Chicago Press, 1997.

Menabrea, Luigi. "Sketch of the Analytical Engine invented by Charles Babbage." In *Scientific Memoirs*, translated and annotated by Ada Lovelace and edited by Richard Taylor, 666–731. London: Richard and John E. Taylor, 1843.

Morus, Iwan Rhys. "Manufacturing Nature: Science, Technology and Victorian Consumer Culture." *The British Journal for the History of Science* 29, 4 (1996): 403-434.

Purbrick, Louise. "The Dream Machine: Charles Babbage and his Imaginary Computers." *Journal of Design History* 6, 1 (1993): 9-23.

Schaffer, Simon. "Babbage's Intelligence: Calculating Engines and the Factory System." *Critical Inquiry* 21, 1 (1994): 203-227.

Searle, John. ''Can Computers Think?'' In *Mind and Cognition. An Anthology*, edited by William G. Lycan and Jesse Prinz, 213-219. Malden: Blackwell, 2008.
Shapin, Steven and Simon Schaffer. *Leviathan and the Air-Pump. Hobbes, Boyle, and the experimental life.* Princeton, New Jersey: Princeton University Press, 1985.
Stein, Dorothy K. ''Lady Lovelace's Notes: Technical Text and Cultural Context.'' *Victorian Studies* 28, 1 (1984): 33-67.
Sussman, Herbert. *Victorian Technology. Invention, Innovation, and the Rise of the Machine.* California: ABC-CLIO, LLC, 2009.
Swade, Doron. *The Difference Engine. Charles Babbage and the Quest to Build the First Computer.* New York: Viking Penguin, 2001.
Toole, Betty Alexandra. *Ada, The Enchantress of Numbers.* Sausalito: Critical Connection, 1992.
Toole, Betty Alexandra. ''Ada, an Analyst and a Metaphysician.'' *Ada Letters* 11, 2 (1991): 60-71.
Turing, Alan. ''Computing Machinery and Intelligence.'' *Mind* 59, 236 (1950): 433-460.

Appendix. Blueprints and schematics for Babbage's engines

Figure 1. Babbage's example of mathematical tables. From: Charles Babbage, *Passages from the life of a philosopher* (London: Longman, Green, Longman, Roberts & Green, 1864), 50.

	Table.	1st Difference.
1	5	5
2	10	5
3	15	5
4	20	5
5	25	

Figure 2. Example of incremental complexity of mathematical functions. From: Charles Babbage, *Passages from the life of a philosopher* (London: Longman, Green, Longman, Roberts & Green, 1864), 55.

Number.	Table.	1st Difference.	2nd Difference.	3rd Difference.
1	1	3	3	1
2	4	6	4	1
3	10	10	5	1
4	20	15	6	
5	35	21		
6	56			

Figure 3. Cogwheel system of the Difference Engine. From: Charles Babbage, *Passages from the life of a philosopher* (London: Longman, Green, Longman, Roberts & Green, 1864), not numbered front page.

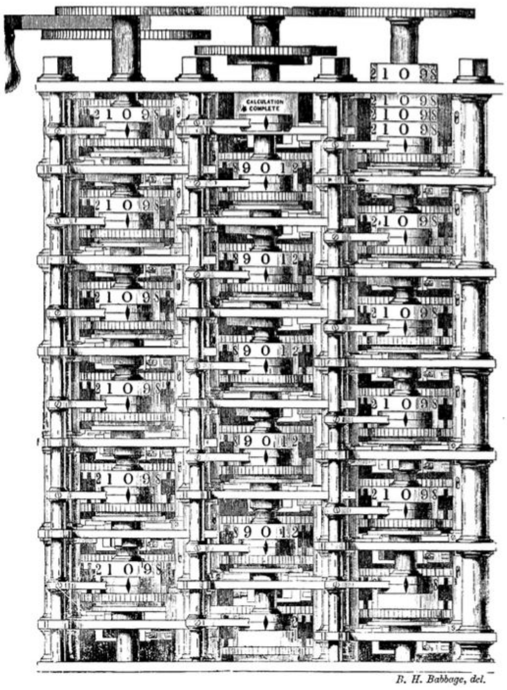

Figure 4. Punched cards for arithmetic operations. From: Charles Babbage, *Passages from the life of a philosopher* (London: Longman, Green, Longman, Roberts & Green, 1864), 127.