Lovelace & Babbage and the Creation of the 1843 'Notes'

John Fuegi and Jo Francis
Flare/MITH

Augusta Ada Lovelace worked with Charles Babbage to create a description of Babbage's unbuilt invention, the Analytical Engine, a highly advanced mechanical calculator often considered a forerunner of the electronic calculating computers of the 20th century. Ada Lovelace's "Notes," describing the Analytical Engine, published in *Taylor's Scientific Memoirs* in 1843, contained a ground-breaking description of the possibilities of programming the machine to go beyond number-crunching to "computing" in the wider sense in which we understand the term today. This article expands on research first presented by the authors in their documentary film, *To Dream Tomorrow*.

> What shall we do to get rid of Mr. Babbage and his calculating Machine? Surely if completed it would be worthless as far as science is concerned?
>
> —British Prime Minister Sir Robert Peel, 1842[1]

> The Analytical Engine does not occupy common ground with mere 'calculating machines.' … In enabling mechanism to combine together general symbols, in successions of unlimited variety and extent, a uniting link is established between the operations of matter and the abstract mental processes of the most abstract branch of mathematical science. A new, a vast and powerful language is developed for the future use of analysis …
>
> —A.A. Lovelace, "Notes by A.A.L.," 1843[2]

Charles Babbage's Difference Engine and Analytical Engine, conceived in the first half of the 19th century, are often seen as anticipating key design features used in modern computing, even though none of Babbage's extraordinary devices was fully built in his lifetime. Augusta Ada Lovelace, née Byron, who worked against the restrictions on women of her day to successfully train as a mathematician, worked closely with Babbage to describe the more advanced of his Engines, the Analytical Engine, in a collection of "Notes" published in *Taylor's Scientific Memoirs* in 1843. Lovelace's vision of the Engines' potential for the future of computation may now be seen as having exceeded Babbage's own vision for his machines in several key ways. She became the first person known to have crossed the intellectual threshold between conceptualizing computing as only for calculation on the one hand, and on the other hand, computing as we know it today: with wider applications made possible by symbolic substitution.

In an early background interview at the Science Museum (London) for the historical documentary film about collaboration between Lovelace and Babbage, *To Dream Tomorrow*,[3] Babbage authority Doron Swade mentioned that he thought Babbage and Lovelace had "very different qualities of mind." Swade's observation proved to be of enormous value for our subsequent research.

An examination of the original Lovelace and Babbage documents shows that, whereas Babbage concentrated on the number-crunching possibilities of his new designs, Lovelace went beyond number-crunching to see possibilities for wider applications. She wrote:

> Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of music of any degree of complexity or extent.[4]

Aware that the punched card mechanism guiding the decision list of the Analytical Engine was taken by Babbage from the Jacquard loom and that Jacquard had created pictures of great complexity by this means, she noted: "We may

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say most aptly, that the Analytical Engine *weaves algebraical patterns* just as the Jacquard-loom weaves flowers and leaves."[5] Making her own independence of thought clear within the "Notes," she wrote:

> Whether the inventor of this engine had any such views in his mind while working on the invention, or whether he may subsequently ever have regarded it under this phase, we do not know; but it is one that forcibly occurred to ourselves[6] on becoming acquainted with the means through which analytical combinations are actually attained by the mechanism.[4]

In order for us to look closely at the original Lovelace and Babbage documents written at the time the "Notes" were being created, we had to go to a number of different archives. We also had to take care when examining most published accounts. Most extant books tended to be either primarily accounts of Lovelace with Babbage as an important but subsidiary figure, or accounts of Babbage with Lovelace often reduced to a largely marginal figure. In contrast, it was our intention in making *To Dream Tomorrow* to examine and acknowledge what each one did as an individual, as well as what the two achieved working together.

Since the "Notes" are the single most comprehensive description of the more advanced capabilities of the Analytical Engine and since a full-scale Analytical Engine was never built, the "Notes" constitute the main conduit through which Babbage's extraordinarily advanced engineering ideas influenced future generations. Consequently, the "Notes" and Lovelace's role in creating them, and the question of the extent to which she went beyond the ideas of Babbage are of historical significance.

Lovelace's letters to Babbage, with a large array of other vital Babbage materials, are held at the British Library in London. A large number of Babbage's drawings and notes, used by Doron Swade and the late Allan Bromley to reconstruct plans for Babbage's various "Engines" (some of the plans of which have been published in the *IEEE Annals*), are at London's Science Museum. A number of Babbage's letters to Lovelace are in the Byron/Lovelace collection at Oxford's Bodleian Library. Lovelace Estate Records (the documents showing the financial and other material conditions under which Ada worked after she married in 1835), are held at the County Historical Archive in Woking, UK. As these historic materials have never been published in their entirety, their interrelationship has often remained almost entirely unexamined.

Over the last four years, to gain access to and to use Augusta Ada Lovelace materials, we needed to obtain the permission of Ada's great-great-grandson, the current Earl of Lytton. Lord Lytton was pleased at, among other things, the idea of taking a fresh look at the role in Ada's education of his great-great-great-grandmother, Lady Byron. Ada grew up essentially in a single-parent home; Lady Byron left the abusive household of the famous poet Lord Byron when Ada was five weeks old. Lady Byron (who had herself received some training in mathematics) was primarily responsible for Ada's education up to and including the time Ada met Charles Babbage when she was 17 and he 42, and she first saw Babbage's prototype Difference Engine, a mechanical calculator.

It is important to note what happens both for Ada and Charles Babbage in the 10 years that lie between Ada Byron's first view of the prototype Difference Engine in 1833 and the creation of the "Notes" in 1843. In this period, the ideas of Babbage undergirding the more advanced calculating device, the Analytical Engine, emerged. Ada was present as the key new ideas were discussed between Charles Babbage and the great science expositor, Mary Somerville. By 1834, both Somerville and Babbage were mentors for the then 18-year-old Ada, and Babbage supplied Ada with a number of engineering drawings so she could better understand his newest designs.

Though Ada Byron (like her mother before her) was barred, as a woman, from attending university in England at that time, she worked with a series of tutors in mathematics. After meeting Babbage, her mathematical studies began to focus on what she needed to know to advance her understanding of the principles behind Babbage's Difference and Analytical Engines. Her study advanced even after she married William, soon-to-be named Earl of Lovelace, and had three children in a little over three years; the last born in July 1839. In 1840 she began a series of tutorials with Augustus De Morgan, professor of mathematics at University College, London.

Babbage had first received a grant from the British government in 1823 to begin to build a Difference Engine. Yet, despite expending large sums of public funds and a great deal of his own money, by 1833 he had failed to complete more than the small prototype Difference Engine. This prototype is a fully functioning device that can be seen today at the Science Museum in London. By 1834, however, Babbage began talking about having an even more complex undertaking to displace the ear-

lier one. As Ada, over a span of a decade, extended her capacities for understanding Babbage's Engines, in the same period, Babbage himself felt frustrated by being unable to convince British authorities of the importance of his latest design, a proposal for an Analytical Engine of vastly greater scope than his earlier Difference Engine. But, by now, the British government was frustrated by almost two decades of dealings with Babbage. On 11 November 1842 the inventor had a meeting with the Prime Minister, Sir Robert Peel. Babbage (as we know from his own notes[7]) spent more time attacking the government than describing the new Engine. Peel, for his part, had, prior to the meeting, solicited support to call Babbage's work officially worthless. The meeting was a disaster. Both men talked past one another. On January 5, 1843, Babbage was informed that the government had sent the prototype of the Difference Engine to the King's College Museum.[8] In March, Peel formally withdrew support for the project, and only a single voice in Parliament was raised on Babbage's behalf. By 1843 it was clear that Babbage, for all his technical brilliance, had been rejected in England for further government funding for completing either the older Difference Engine or the newer Analytical Engine.

Before the formal rejection by Peel in 1842–1843, Babbage had gone to Turin in the fall of 1840 hoping to line up foreign support for his plans. Before going to Turin he had had printed the 24-in. by 36-in. "Plan, #25," one version of the ever-changing Analytical Engine design. In Turin, a young engineer, Luigi Menabrea, took notes on Babbage's talks and began to prepare an article based on what Babbage presented. Menabrea's article, "Notions sur la machine analytique," was published in the journal *Bibliothèque Universelle de Genève*, in October 1842.

When copies of the Menabrea article reached England in the fall of 1842 and Babbage had had his disastrous meeting with Peel, the French language article was discussed by Ada Lovelace and the inventor, Charles Wheatstone. Both Lovelace and Wheatstone were probably better informed about the Difference and Analytical Engines than anyone other than Babbage himself and possibly Somerville, and they had more knowledge than Menabrea, who had met Babbage only briefly in Turin. Wheatstone, a close friend of Babbage and Lovelace, was one of the best informed people in Britain on developing and marketing new technologies. By 1837, the Cooke/Wheatstone Telegraph had been patented, financed, built and marketed with a highly successful advertising campaign promoting the device. Wheatstone had also worked on designs for calculating by machinery as we know from an 18 May 1839 entry in Babbage's Notebook: "Yesterday saw Wheatstone's model for telegraph and his drawings for Multiplication Engine." According to Anthony Hyman who cites the Babbage Notebook, "Wheatstone's apparatus gave Babbage the idea that he might use electromechanical switching instead of mechanical techniques for the Calculating Engines."[9]

Considering the date, 1839, the idea is breathtaking, coming almost a century ahead of Howard Aiken making his first advanced calculator proposals to IBM.[10] Even though Babbage had not adopted Wheatstone's electromechanical switching in 1839, in 1937 Aiken directly mentioned Babbage's engine designs as a precursor and joked, "If Babbage had lived 75 years later I would have been out of a job."[11] Descriptions of Babbage's designs were also turned up by Konrad Zuse in Berlin as part of his "prior art" patent search in 1937, and similar references crop up as well in accounts of the work of John von Neumann. H.J. Gray notes: "John von Neumann urged that all the machine units be connected ... so that the machine could be used as a computer of the Babbage type ... This was done and ENIAC was operated in this fashion until it retired."[12] A further link is a reported conversation of John von Neumann with S. Frankel cited by Andrew Hodges.[13] Hodges also notes that Turing was aware both of Babbage and Lovelace.[14] Thus some links can be shown between key 20th-century figures in computer history (Turing, Aiken, von Neumann), and the work done in England in the early 1840s, but dismissed by the British government then as worthless.

In the fall of 1842, aware of what had happened between Babbage and Peel, Wheatstone and Lovelace, not yet mentioning the idea to Babbage as he was ill after his meeting with Peel, thought it could help the cause of advancing Babbage's work in England if Ada would translate the Menabrea article into English. She was skilled in French, as her mother had arranged for her to study languages from childhood on and encouraged her to polish her skills during a 15-month period they had spent abroad. Lovelace went ahead with the translation over the winter of 1842–1843. As she was far more knowledgeable than Menabrea about Babbage's designs, she provided footnotes as she went along, tactfully correcting a number of Menabrea's errors.

In early 1843, Lovelace showed Babbage what she had been working on over the winter. Babbage's response shows the high regard in which he held Lovelace's intellect and her

understanding of his work. Babbage recollected 20 years later:

> Some time after the appearance of [Menabrea's] memoir the late Countess of Lovelace informed me that she had translated the memoir of Menabrea. I asked why she had not herself written an original paper on a subject with which she was so intimately acquainted? To this Lady Lovelace replied that the thought had not occurred to her. I then suggested that she should add some notes to Menabrea's memoir; an idea which was immediately adopted.[15]

The resulting "Notes" are three times the length of Menabrea's essay and contain the most influential insights.

Lovelace (as we can confirm from her letters held at the British Library), wrote the "Notes" mainly at Ockham Park, an hour south of London. Babbage wrote back to her from his Dorset Street house in London, adjacent to his custom-built, fireproof workshop. They met together to discuss problems and to do proofreading at Ada's London house, 12 St. James's Square. Records in Lovelace's, Babbage's, and Wheatstone's handwriting at the British Library and at the Bodleian Library allow us to follow in an almost hourly way how the "Notes" came into being over the summer of 1843. With multiple mail deliveries each day, and with more missives delivered by personal messenger, one gets a sense of the mutual excitement, collegiality, but sometimes fierce frustration on both sides of the exchange. The letters crossed and recrossed as Lovelace's working days sometimes stretched to 18 hours.

One remarkable feature of Lovelace's "Notes" is that they describe not the physical reality of a single existing Analytical Engine but what historian of technology Sadie Plant has called "a virtual machine." "It is virtual on two levels," said Plant when interviewed for *To Dream Tomorrow*. "She is," notes Plant, "writing the program for a virtual machine, for a future machine in effect." Most of the mechanical parts for the Engine did not yet exist, and the drawings, even when they did exist and Babbage could put his hands on them, were incompatible as they reflected different stages of design over a nine-year period. We know that, even at the last stage, as the "Notes" were in press, Babbage told Lovelace on 18 August 1843:

> My Dear Lady Lovelace I much fear the drawings will not be very intelligible. They were never published and only a few proofs were taken. I will endeavour to find a complete set and bring them with me on Monday."[16]

To create a comprehensive description of the Analytical Engine that did not (and indeed does not) exist, a machine that was in a constant state of flux in Lovelace's and Babbage's lifetime and for which Babbage had difficulty turning up a full, internally consistent set of drawings—was to attempt something of almost inconceivable difficulty. Swade reports in *The Cogwheel Brain* how immensely difficult it was for him and Allan Bromley, even over a period of several years, to work through thousands of pages of Babbage's "Notes" in order to understand a vast, unbuilt, constantly changing entity. Groping to arrive at correct formulations during a single intense summer of work in 1843, Lovelace and Babbage exchanged letters that are startlingly modern, almost email-like: abrupt, often informal, dashed off, and sent with uncorrected errors.

Lovelace in the summer of 1843 was 27 years old and saw herself, as she noted in a letter to a relative, as "a fully professional person."[17] Her letters to Babbage mix respect with banter, and sometimes the bluntest frankness when he loses papers or fails to remain focused on the task at hand. Tellingly, she often wrote "My Dear Babbage," using the form of male-to-male, colleague-to-colleague address of the Victorian era. Babbage, who was in 1843 in his early fifties, addressed her as "My Dear Lady Lovelace."

The following letters give us a sense from Babbage's perspective of how the work was proceeding. Babbage, from Dorset St. 30 June 1843, writes to Lovelace at Ockham Park in such a hurry that not enough postage was put on the letter, so it is marked on the envelope "More To Pay."

> My Dear Lady Lovelace
>
> I am delighted with Note D. It is in your usual clear style and requires only one triffling [sic] alteration which I will make. This arises from our not having yet had time to examine the outline of the mechanical part. …
>
> I enclose a copy of the integration. I am still working at some most entangled notations of Division but see my way through them at the expense of heavy labour, from which I shall not shrink as long as my head can bear it. I have been somewhat impeded for the last few days. Your latest information was the most agreeable. Ever my dear Lady Lovelace Sincerely yours C. Babbage.[18]

On Sunday, 2 July 1843, Babbage wrote:

> I am very reluctant to return the admirable and philosophic view of the Abral. [sic] Engine contained in Note A. Pray do not alter it and do let me have it returned on Monday. I send also the rest of Note D. There is still one triffling (sic) misapprehension about the Variable cards—A Variable card may order any number of Variables to receive the same number upon theirs at the same instant of time—But a Variable card never can be directed to order more than one Variable to be given off at once because the mill could not receive it and the mechanism would not permit it. All this was impossible for you to know by intuition and the more I read your Notes the more surprised I am at them and regret not having earlier explored so rich a vein of the noblest metal.
>
> The account of them stands thus
>
> | | |
> |---|---|
> | A Sent to Lady L. | F Retained by Lady L |
> | B With CB | G Where is it gone?? |
> | C Ditto | H With CB |
> | D Sent to Lady L | |
> | E With CB | |
>
> I have not seen Mr. Wheatstone and am ashamed to write until I can positively put the *whole* of the Notes into his hands.
>
> I will attend your commands tomorrow And am ever most truly yours C. Babbage[19]

Lovelace wrote back at once to Babbage, her second letter to him that day. She had decided that, since Babbage had made a mistake about how she viewed the variable cards, she would need to see him the next day in London to get several points clarified. She playfully and tactfully points out that in fact no Note C had ever existed.

> Ockham, Sunday 6 o'clock. I have worked incessantly and most successfully all day. You will admire the *Table and Diagram* extremely.
>
> They have been made out with extreme care and all the indices most minutely and scrupulously attended to. Lord L[ovelace] is at this moment kindly *inking it all over* for me. I had to do it in pencil.
>
> You must bring *all* the Notes with you tomorrow as I have observations to make on each one and especially on this final one H.
>
> There never *was* a note *C*. I do not know why I chose H instead of C and thus insulted the latter worthy letter.
>
> I cannot imagine what you mean about the Variable-Cards; since I never either supposed in my own mind that one Variable-card *could give off* more than one Variable at a time; nor have (as far as I can make out) expressed such an idea in any passage whatsoever … [20]

Having met with Babbage in London to work through the observations each had made, Lovelace wrote to him, both to clarify the issue of the variable cards and to convey her decision to assert her authorship of the "Notes" in a letter dated 4 July 1843:

> Ockham, Tuesday Morning … Lord L. suggests my *signing* the translation and the Notes, by which he means simply putting … *"translated by A.A.L;"* & adding to each Note the initials A.A.L.
>
> It is not my wish to *proclaim* who has written it; at the same time that I rather wish to appear anything that may tend hereafter to *individualize* and *identify* it with other productions of the said A.A.L.
>
> My third topic, tho' my last is my most anxious and important. I have yesterday evening and this morning very amply analyzed the question of the *number* of Variable Cards, as mentioned in the final Note H (or G?). And I find that you and I between us have made a *mess* of it; (for which I can perfectly account in a very natural manner). I enclose what I wish to inscribe *instead* of that which is now there. I think the present wrong passage is only about eight or ten lines, & is I believe on the *second* of the three great sheets which are to *follow* the diagram.
>
> The fact is that if my own composition about the Variable Cards in *Note D* had been strictly followed by myself in Note H this error would not have occurred. The confusion has arisen simply from the circumstance of applying to the *Variable* Cards, facts which relate to the *Operation*-Cards. In Note D it is very well and lucidly demonstrated that every simple operation demands the use of at least those Variable Cards. It does not signify whether the operations be in *cycles* or not. A million successive additions would each demand the use of these new Variable Cards under ordinary circumstances. In Note H, the erroneous lines are founded on the hasty supposition that the cycle or recurring group of *Operation*-Cards (13 . . . . . 23) will be fed by a cycle or recurring group of *Variable*-Cards.
>
> I enclose what I believe it ought to be. If already gone to the printer we must alter that passage in the proofs unless you could call at the printers and there paste over the amendment.[21]

She commented further on the technical issues in another letter to Babbage, probably also of 4 July. This letter is dated only "Tuesday 1843," but the context makes plain that it was written near the time of the 4 July letter:

> My Dear Babbage.
>
> I hope you will approve of what I send. I have taken *much* pains with it. I have explained that there would be, in his instance & in many others, a recurring group or cycle of *Variable* as well as of *Operation* Cards; and I have (I think very judiciously and easily) touched on the only departures from *perfect* identity which *could* exist during the repetitions of (13 . . . . . 23); and yet have not *committed* myself by saying if the departures would require to be met by the introduction of one or more *new* cards or not; but have simply indicated that as the associations follow a regular rule, they would be easily provided for. I think I have done it admirably and diplomatically (*Here* comes in the *intrigante* and *politician!*) Ever yours A.L.[22]

Lovelace's Note F describes how the Analytical Engine could be used to calculate the values of the Bernoulli numbers. Lovelace, knowing that Babbage believed the Engine could have the capacity to handle Bernoulli numbers, as he had discussed in a letter circa January 1841 to the German savant Alexander von Humboldt,[23] took it upon herself to make sure there was a written description and demonstration of how this could be done. She writes from Ockham Park on Wednesday, 5 July 1843:

> I do not go to town until Monday. Keep yourself open if you can for that day in case there is anything I wish to see you about which is very likely. But the *evening* I think is most likely to be my time for you, as I rather expect to be engaged incessantly until after 6 o'clock. I shall sleep in town that night.
>
> I am doggedly attacking and sifting to the very bottom all the ways of deducing the Bernoulli Numbers. In the manner I am grappling with this subject; and connecting it with the others, I shall be some days upon it. …
>
> "Labore ipse voluptas" [Labor Is Its Own Reward] is in very deed my motto! And (as I hinted just now), it is perhaps well for this world that my line and inclination is more the *spiritual*; and that I have not taken it into my head or lived in times or circumstances calculated to put into my head to deal with the sword, poison, and intrigue in the place of x, y, & z. … [24]

In the archive, this letter is followed in folio 354 by a very brief note from Babbage dated Wednesday, July 1843, presumably of 5 July: "Return sheet with two corrections. Right about Card requiring new Variable."[25]

This was typical of a staccato to and fro. Ada, writing the "Notes," queried Babbage, as the inventor of the yet unbuilt Engine, as to whether or not he anticipated his Engine could do something and do it as she understood it. Babbage's replies suggest that he had learned something new about his own machine from Lovelace's queries and speculations. For instance, a letter headed "Ockham Thurs. Morn. 1843" reminds us that Lovelace was attempting a description of what Babbage himself was still in the process of clarifying. She wrote:

> My Dear Babbage. I have read your papers over with great attention. But I want you to answer me the following question by return post. The day I called on you, you wrote off on a scrap of paper (which I have unluckily lost); that the *Difference* Engine would do [Authors' note: Lovelace draws a small triangle here] (something or other) [Authors' note: The parentheses are hers] but that the *Analytical* Engine would do [Authors' note: Lovelace again draws a triangle here] (something else that is absolutely general). Be kind enough to write this out properly for me; and then I think I can make some *very* good Notes. … [26]

On 10 July 1843, Lovelace wrote:

> My Dear Babbage. … I want to put in something about Bernouilli's Numbers in one of my Notes as an example of how an implicit function may be worked out by the engine without having been worked out by human head or hands first. Give me the necessary data and formulae. Yours ever AAL [27]

The correspondence brings to life the actual process of editing and proofreading:

> July 1843 Ockham Tuesday Morning. My Dear Babbage. … What I want to know is this: can you be with me in town at 4 o' clock. This is in order that I may *read over* aloud with you all the Notes. ...[28]

The fact Lovelace wanted to go through the "Notes" with Babbage, and had previously sent him her translation of Menabrea to check makes it clear that proofreading was a joint undertaking, supplemented in the customary way by the printers. Given this fact, it seems odd to dismiss (as one severe critic has done)[29] only Lovelace for failing to catch an error made by the Swiss printer (an error of "cas" for "cos."

uncaught by Menabrea), and then using this to claim Lovelace knew little about mathematics.

By the end of July, Lovelace and Babbage appeared to be on the final lap. Lovelace, the mother of three children with the Earl of Lovelace, jokingly wrote about the "Notes" as though they were her first child:

> Ockham Thursday morning July 27, 1843: My Dear Babbage. … To say the truth I am rather amazed at them [the Notes] & I have made Lord Lovelace laugh much by the dryness with which I remarked "Well. I am very much satisfied with this first child of mine. He is an enormously fine baby and will grow to be a *man* of the first magnitude and power."[30]

A meticulous worker, Lovelace struggled not only with the difficulty of the material but also with the errors of the printers and Babbage himself. On 28 July 1843, Lovelace wrote to Babbage from St James's Square:

> The beginning of Note G (by which I mean the Table & all that precedes it) never has been returned into my hands; a small part of the remainder was, but that I speedily gave you back, & there it is, now printed.—
>
> The missing part *must* be either at your house or at the printer's; & it seems to me *very* unlikely that you should have retained it. So altogether I would wager almost anything that it is at the *office*; or that if lost, it has been lost *there*.
>
> At the same time, I have also fancied you were a little harum-scarum & inaccurate now & then about the exact *order* & *arrangement* of sheets, pages, & paragraphs & c. (witness that paragraph which you so carelessly *pasted* over!)
>
> I suppose I must set to work to write something better, if I can, as a substitute. The *same precisely* I could not recall. I think I should be able in a couple of days to do something. However I should be deucedly inclined to *swear at you*, I will allow.
>
> I desire my messenger to wait; as it possible you may have something to communicate more agreeable.
>
> I go soon after seven. I believe I shall *not* be in Town myself on Monday as I expected. Yours A.L.[31]

"Ockham Sunday Afternoon August 1, 1843," Lovelace writes:

> I am half beside myself with hurry and work. … I wish you were as accurate and as much to be relied on as I am myself. You might often *save* me much trouble if you were; whereas you in reality *add* to my trouble not infrequently and there is at any rate always the anxiety of *doubting* if you will not get me into a scrape even when you don't.
>
> By the way, I hope you do not take upon yourself to alter any of my corrections. I must *beg* you not. They all have some very sufficient reason. And you have made a pretty mess and confusion in one or two places (which I will show you sometime) where you have ventured on my *M.S.'s* to *insert* or *alter* a phrase or word and have utterly muddled the sense …[32]

From Lovelace's letters, it is clear that she thought the intense working period was yielding the desired result: a strong, persuasive article, describing the capabilities and functioning of the Analytical Engine, to generate interest and support for its construction. But, by early August the tone of exchanges is increasingly acerbic as Lovelace realizes that Babbage is trying to convince the printer to include one of his diatribes (which he was, however, unwilling to sign). Babbage wanted, at the last minute, to prevent the publication of the article unless he could fulminate at length in the same issue about the way he had been and was being treated by the government. But Lovelace overrode him and had the printer proceed as originally planned. A key Babbage letter does not appear to have survived as it is not at the Bodleian in the Lovelace/Byron Collection. His letter must have been written around the beginning of August 1843 because Ada Lovelace's letter of 5 August 1843 is clearly in response to something from him about her overruling him on going ahead with the article. She made her views clear in a letter to Babbage from Ockham on Sunday, 6 August 1843:

> My Dear Babbage … On the *one point* of *not withdrawing* the translation & Notes from the Memoir, or consenting to its *separate* publication, I was entirely and finally decided; as I think neither for *your advantage* nor my own, to do so; added to my opinion that it would under the circumstances be dishonorable and unjustifiable … Be assured that I am your best friend; but that I never *can* or *will* support you in acting on principles which I conceive to be not only wrong in themselves, but *suicidal*.[33]

In his reply of Tuesday, 8 August 1843, Babbage protested her decision, yet seemed to acknowledge her authority to make it:

> My Dear Lady Lovelace
>
> I leave the Ms and also the proofs of the Notes I recd. last night and promised to send this evening.

I will write to Printer to say you will send them up by post direct to them.

This direct communication will save time and there is very little to spare for this Number *ought* to be out in the course of a very few days.

I have nothing to add at present except that you do me injustice in supposing I wished you to break any engagement with the Editor. I wished you to ask him to allow you to withdraw from it. Had the Editor been in England I believe he would at my request have inserted my defense or forborn to have printed the paper—As it stands I have done all I can at present to defend myself and having failed in the most important part shall make the best I can of the rest. Ever truly yours C. Babbage[34]

Babbage's supposition about the editor's wishes did not turn out to be true. The editor backed Lovelace, not Babbage. Opposition to Babbage's diatribe idea was unanimous. Neither Wheatstone nor Charles Lyell, the eminent geologist and mutual friend of Lovelace and Babbage, thought Babbage's interests would be served by yet another attack. Despite the advice of his closest friends, Babbage published his diatribe separately, in a different magazine, a few weeks later.[35]

Whatever Babbage might decide to do, Lovelace keenly felt her own responsibility for this project. On Tuesday, 8 August 1843, she wrote to her mother:

I have been harassed and puzzled in a most perplexing manner by the conduct of Mr. Babbage … I am sorry to come to the conclusion that he is one of the most *impracticable*, *selfish*, and *intemperate* persons one can have to do with … But I am happy to find that W. [Authors' note: "W." indicated William, her husband.] & Wheatstone entirely approves my conduct and means. I declared at once to Babbage that no power should induce me to lend myself to any of his quarrels … and that I should myself communicate in a direct manner with the editors … *He* was *furious*. I imperturbable … I only want you to understand that all my *time* and my *energy* have been miserably absorbed the last few days; for what between Babbage and the editors both pressing hard in different directions, I have been torn to pieces … [36]

Angry or not, Lovelace remained focused on the central issue that the specific purpose of the translation and "Notes" was to advance the actual building of a machine, rather than again to attack the government. In a candid letter to Babbage, she offered her talents and resources to pursue the building of the Analytical Engine, provided he himself would stick to the technical aspects of the project. From Ockham Park on Monday, 14 August 1843, Lovelace wrote to Babbage:

I have now touched on all the grounds which can be taken on the supposition of its *really being pernicious to your interests* that I have thus allowed the article to appear … My moral standard, such as it is, I must stick to; as long as it *is* my moral standard. … I *have* a right to expect from you the belief that I do sincerely and honestly take this view. [I]f *your* knowledge of *me* does not furnish sufficient grounds for doing so, then I can only say that no natural knowledge of any two human beings in this life can give fixed and stable grounds for faith and confidence then Adieu to *all* truth and to everything most generous in this world!

I must now come to a practical question respecting the future. …

If I am able to lay before you in the course of a year or two explicit and honourable propositions for *executing your engine* (such as are approved by persons whom you may *now* name to be referred to for their approbation) would there be any chance of you allowing myself and such parties to conduct the business for you; your own *undivided* energies being devoted to the execution of the work; all these matters being arranged for you on terms which your *own* friends should approve?

You will *wonder* over this last query. But I strongly advise you not to reject it as chimerical. You do *not* know the grounds I have for believing that such a contingency may come within my power and I wish to know before I allow my mind to employ its energies any further on the subject, that I shall not be wasting thought and power for no purpose or result … Yours ever most sincerely A.A.L.[37]

A letter she wrote to her mother the next day confirms that the printers were recognizing her as author of the "Notes." Tuesday, 15 August 1843:

… I was unexpectedly summoned by the printers who needed a further supervision and as it is *actually to be out* I understand tomorrow, there was no time for *post* communications. No one can estimate the trouble of *interminable* labour of having to revise the printing of *mathematical* formulae. You will receive a few copies (amongst a hundred that are printed separately for me). …

If he [Babbage] does consent to what I propose, I shall probably be enabled to keep him out

> of much hot water; and to bring his engine to *consummation* (which all I have seen of him and his habits the last 3 months, makes me scarcely anticipate it ever *will* be, unless someone really exercises a strong co-ercive influence over him). He is beyond measure *careless* and *desultory* at times. … [38]

With the final material delivered to the printer and with most of the errors corrected, and after months of 18-hour days spent describing the possibilities of an extraordinarily complex virtual machine, Lovelace now confessed herself often very tired. Lovelace came up to London around 18 August to meet Babbage. He was still furious about not having had his own way on the idea of appending a diatribe to the "Notes." He scribbled a curt memo in the margin of Lovelace's letter of 14 August: "Saw AAL this morning and refused all the conditions." Instead of using publication of the *Memoir* with the "Notes" as a descriptive model of a strategy for gaining public understanding and support to get the Engine financed and constructed, Babbage would continue until his death in 1871 to go his own, often irascible, way.

By 24 August 1843, the volume of *Taylor's Scientific Memoirs* with the translation of Menabrea's "Memoir" and the "Notes" appeared. Lovelace wrote to her mother: "We are by no means desirous of making it [Authors' note: authorship of the "Notes"] a secret although I do not wish the importance of the thing to be exaggerated and overrated."[39] Charles Wheatstone wrote on 25 August 1843:

> My Dear Lady Lovelace, I called yesterday at the printer's and was informed that a separate copy of your paper had been forwarded by post to Ockham, and the new number of the Scientific Memoirs sent to St. James' Square … Yours very truly C. Wheatstone.[40]

Reaction to the work was swift and positive. The paper, so Michael Faraday, famous for his chemical and electrical experiments, declared to Babbage on 1 September, was so complex it was well over his own head.[41] Menabrea asked Babbage to pass along his congratulations "à cette noble Dame, A.A.L."[42] With congratulations pouring in, even Babbage was pleased, and he swiftly reconciled with Lovelace, concluding a letter to her of 12 September 1843, with the extravagant: "Ever my fair Interpretess Your faithful slave C. Babbage"[43]

Babbage expert, Doron Swade (having examined the extensive exchange of letters and the resulting "Notes"), when interviewed for *To Dream Tomorrow,* commented:

> Ada saw something that Babbage in some sense failed to see. In Babbage's world his engines were bound by number. He saw that the machines could do algebra in the narrow sense that they could manipulate plus and minus signs. But all his calculating engines, his Difference Engine and his Analytical Engine, which is the programmable general-purpose machine, were all bound by number: They manipulated number as a manifestation of quantity, as a measure of quantity. What Lovelace saw—what Ada Byron saw—was that number could represent entities other than quantity. So once you had a machine for manipulating numbers, if those numbers represented other things, letters, musical notes, then the machine could manipulate symbols of which number was one instance, according to rules. It is this fundamental transition from a machine which is a number cruncher to a machine for manipulating symbols according to rules that is the fundamental transition from calculation to computation—to general-purpose computation—and looking back from the present high ground of modern computing, if we are looking and sifting history for that transition, then that transition was made explicitly by Ada in that 1843 paper.

As Swade is fully aware, "[T]he Analytical Engine," as A.A.L. so clearly stressed, "does not occupy common ground with mere 'calculating machines'." This formulation, based on what only existed as a virtual machine in 1843, went beyond any known statement of Babbage, and beyond distinguished predecessors in mechanical calculation such as Blaise Pascal and Gottfried Wilhelm Leibniz. A.A.L. anticipated advanced work in the next century of Alan Turing, Konrad Zuse, Howard Aiken, Grace Hopper, and John von Neumann. Looking far ahead to that time when a general-purpose machine would no longer be declared worthless but would in fact be built, Lovelace argued that such a machine would serve as a springboard for an ever-increasing number of discoveries, many of which would remain unimaginable until such time as the machine was built and could be run. She wrote in Note A:

> [V]ery valuable practical results would be developed by the extended powers of the Analytical Engine, some of which would be brought forth by the daily increasing requirements of science and by a more intimate practical acquaintance

with the powers of the engine, were it in actual existence.[44]

Lovelace was to be proven right, but it would take over 100 years. Only after the early ENIAC ("a computer of the Babbage type," as H.J. Gray described it) was built to run rapid calculations for ballistics tables did engineers and programmers, such as John von Neumann and Grace Hopper, begin to move beyond what Lovelace had called "mere calculating machines" and begin, in Swade's words, "to manipulate symbols according to rules." With these developments in the mid-20th century, the paradigm shift Lovelace had made in 1843 would start to become our everyday reality.

References and notes

1. British Library, London, additional manuscript (hereafter "add'l ms.") 40,514, folio 223.
2. A.A. Lovelace, "Notes by A.A.L. [August Ada Lovelace]," *Taylor's Scientific Memoirs*, London, vol. III, 1843, pp. 666-731. These notes were originally printed in both *Charles Babbage and His Calculating Engines: Selected Writings by Charles Babbage and Others*, P. Morrison and E. Morrison, eds., Dover Publications, 1961 (which includes the full text of the Menabrea translation and the 1843 Notes, pp. 225-297), and in *Faster Than Thought*, B.V. Bowden, ed., Sir Isaac Pitman & Sons, Ltd., 1953, pp. 341-408. A.A. Lovelace's translation of Menabrea together with her "Notes" are also on the Web: http://www.fourmilab.ch/babbage/sketch.html.
3. For information about the film, see http://www.mith.umd.edu/flare and http://www.computer.org/annals/an2002/extras/a405602x.htm.
4. P. Morrison and E. Morrison, eds., *Charles Babbage and His Calculating Engines …,* p. 249.
5. Ibid., p. 252.
6. She is, of course using the customary plural of scholarly writers of the time.
7. British Library, add'l ms. 37,192, folios 189-194.
8. British Library, add'l ms. 37,192, folio 326.
9. A. Hyman, *Charles Babbage, Pioneer of the Computer*, Princeton Univ. Press, 1982, p. 227.
10. I.B. Cohen, *Howard Aiken: Portrait of a Computer Pioneer,* MIT Press, p. 63.
11. Cited by D. Swade, *Charles Babbage and His Calculating Engines*, Science Museum, 1991, p. 34.
12. Cited from H.J. Gray's *Digital Computer Engineering*, Prentice-Hall, 1963, in the annoted bibliography given by B. Randell, ed., *The Origins of Digital Computers: Selected Papers*, Springer Verlag, 1973, p. 420.
13. A. Hodges, *Alan Turing: The Enigma*, Vintage, p. 304.
14. Ibid., p. 297 and pp. 357-358.
15. Cited by D. Swade, *The Cogwheel Brain*, pp. 160-161.
16. Byron/Lovelace Collection, Bodleian Library, Oxford, UK, box 168, folio 47, recto and verso.
17. Cited by B.A. Toole, *Ada, the Enchantress of Numbers*, p. 225. We might note that as we did our own transcriptions of letters, in a number of cases our reading and dating differs from Toole's. Ideally, all these documents should be put directly on the Web so that various people can do their own decipherments of texts that are often extremely hard to read. In some cases, Toole has very usefully included facsimiles of some of the handwritten documents, an excellent practice.
18. Byron/Lovelace Collection, Bodleian Library, box 168, folio 43, recto and verso.
19. Byron/Lovelace Collection, Bodleian Library, box 168, folio 45, recto and verso, and folio 46, recto.

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20. British Library, add'l ms. 37,192, folio 337.
21. British Library, add'l ms. 37,192, folio 344.
22. British Library, add'l ms. 37,192, folio 348.
23. British Library, add'l ms. 37,191, folio 638.
24. British Library, add'l ms. 37,192, folios 351-352.
25. British Library, add'l ms. 37,192, folio 354.
26. British Library, add'l ms. 37,192, folios 357-358.
27. British Library, add'l ms. 37,192, folio 362.
28. British Library, add'l ms. 37,192, folios 386-725.
29. See D.A. Stein, *Ada, A Life and a Legacy*, MIT Press, 1985, p. xi, where much is made of "*her* [emphasis added] curiously ignored translation of a printer's error." Stein claimed that if Lovelace missed a proofreading error, she must have been unsound in mathematics. Stein then argues we must see Babbage as the primary author of the "Notes" (though he, too, missed the printer's error) and see Lovelace's centrality as what Stein calls a "mythology" (p. ix). However, from the surviving letters of Babbage, Lovelace, Wheatstone, Lyell, Faraday, Menabrea, and the editors of *Taylor's Scientific Memoirs*, it is clear that proofreading was done with Babbage, and that the original typesetting error was missed by Menabrea. The original documentation shows that all contemporaries of Lovelace and Babbage, having first-hand knowledge of how the "Notes" came into being, acknowledged Lovelace at the time as the primary author.
30. British Library, add'l ms. 37,192, folios 393-394.
31. British Library, add'l ms. 37,192, folios 398-399.
32. British Library, add'l ms. 37,192, folios 414-415.
33. Letter is given in full in B.A. Toole, *Ada*, pp. 219-222.
34. Byron/Lovelace Collection, Bodleian Library, box 168, folios 41 and 42.
35. D. Swade, *Cogwheel*, p. 163.
36. Byron/Lovelace Collection, Bodleian Library, box 42, folio 76.
37. British Library, add'l ms. 37,192, folios 425-426.
38. Byron/Lovelace Collection, Bodleian Library, box 42, folios 86-88.
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41. British Library, add'l ms. 37,192, folio 445.
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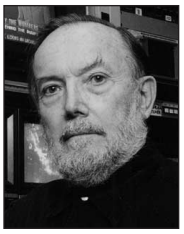

John Fuegi is currently a Maryland Institute for Technology in the Humanities (MITH) Fellow and the Clara and Robert Vambery Distinguished Professor of Comparative Studies at the University of Maryland, College Park. He has taught at Harvard University, the Freie Universität, Berlin, and has held American Council of Learned Societies, Guggenheim, and Rockefeller Awards. He founded and currently chairs Flare Productions.

Jo Francis taught for many years in Thailand and the US before joining Flare Productions, a not-for-profit educational filmmaking organization affiliated with the Maryland Institute for Technology in the Humanities (MITH). She is a MITH Fellow and has received national and international recognition for her teaching and her work in film.

Readers may contact John Fuegi and Jo Francis at jf@flarefilms.org.