

Impact case study (REF3)

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| Institution: University of Oxford | | |
| Unit of Assessment: 10: Mathematical Sciences | | |
| Title of case study: Ada Lovelace's mathematics: catalysing creative collaborations and commemoration. | | |
| Period when the underpinning research was undertaken: 2014 - 2018 | | |
| Details of staff conducting the underpinning research from the submitting unit: | | |
| Name(s): | Role(s) (e.g. job title): | Period(s) employed by submitting HEI: |
| Christopher Hollings Ursula Martin | PDRA/Lecturer Professor | Oct 2013 – present Feb 2014 – June 2018 |
| Period when the claimed impact occurred: September 2015 – 31 July 2020 | | |
| Is this case study continued from a case study submitted in 2014? N | | |
| 1. Summary of the impact | | |
| <p>Ada Lovelace, 1815-1852, has an iconic, but controversial, international reputation as the “first programmer”. Oxford mathematicians’ research is the first study of her extensive manuscripts by historians of mathematics, and resolves earlier disputes by showing that she was a gifted, perceptive and knowledgeable mathematician. Oxford’s research has been a catalyst for new collaborations between mathematicians and curators, composers, and a variety of other partners, who have been empowered and enabled in new creative work [text removed for publication]; BBC Newsnight featured a discussion on Lovelace’s mathematical ability; and two British composers have created new works based on Lovelace’s mathematics. The work has contributed to the commemoration of Lovelace, attracted, inspired and enthused new audiences, changing perceptions of the importance of mathematics, and of female contributions, and stimulated new working practices among Oxford’s collaborators.</p> | | |
| 2. Underpinning research | | |
| <p>Ada Lovelace has been celebrated since the 1950’s as the “first programmer”, a computing and AI pioneer, and an icon of women in science, but before 2015 there was much scepticism as to her mathematical talent. This was resolved by Oxford mathematicians Christopher Hollings and Ursula Martin, working with sabbatical visitor Adrian Rice, in two papers in leading academic journals [1, 2], with supplementary material on a website [3]. This was the first investigation of Lovelace’s manuscripts by historians of mathematics, and showed that she was a gifted, perceptive and knowledgeable mathematician.</p> <p>Lovelace’s reputation rests on her 1843 paper, which is a sophisticated account of Charles Babbage’s designs for his unbuilt mechanical computer. It sets out the principles of the machine, drawing on novel advanced mathematics of the time, such as functional algebra, culminating in a manipulation of power series to explain how the machine might compute the Bernoulli numbers. It also includes broad speculations on computer music, and on thinking machines. While these have brought Lovelace celebrity as a computing and AI pioneer, and as an icon of women in science, her mathematical ability has, until Oxford’s work, been misunderstood and controversial. Dorothy Stein’s widely cited 1984 biography dismissed her mathematical ignorance and “tenuousness”, and Doron Swade, then computing curator at the London Science Museum, claimed her knowledge was so “rudimentary” she could not have understood, let alone written, the 1843 paper. These views have influenced a vast secondary literature (Amazon lists approximately 200 popular books), often downplaying Lovelace’s mathematical ability, while making wildly unrealistic claims about her supposed contribution to Babbage’s designs, and her influence on modern AI.</p> <p>In contrast, Hollings, Martin and Rice [1] made the first scholarly analysis of Lovelace’s early manuscripts in their mathematical context, showing that her early mathematical education encompassed older traditions of “practical geometry”, alongside newer textbooks influenced by continental approaches. Stein’s and Swade’s understandings were shown to be at fault, with Lovelace’s supposed “tenuousness” a perceptive response to inconsistencies in the material she read.</p> <p>In [2] Hollings, Martin and Rice analysed 350 pages of letters exchanged between Lovelace and Augustus De Morgan in 1841-1842 (part of Oxford’s Bodleian Library Lovelace family archive),</p> | | |

which form essentially a “correspondence course” in calculus at the level of De Morgan’s classes at the University of London. This was the first account by historians of mathematics of these letters; they identified Lovelace’s keen eye for detail, often correcting errors in De Morgan’s textbooks; her fascination with big questions, such as the power and limits of functional algebra; and her mathematical insight, for example identifying De Morgan’s problematic appeals to Peacock’s Principle, at the time a widely accepted axiom of algebra. This detailed contextual analysis countered previous claims of Lovelace’s mathematical inadequacies. Hollings’s painstaking transcriptions [3] of the De Morgan correspondence from 2014-2015 required detailed knowledge of mathematical content, notations and conventions of the period. They are hosted, with images of the originals, on the Clay Mathematics Institute website.

3. References to the research

[1] Journal article: C Hollings, U Martin and A Rice, *The early mathematical education of Ada Lovelace*, BSHM Bulletin: Journal of the British Society for the History of Mathematics, 32, 221-234 (2017) Available open access at <https://www.tandfonline.com/doi/full/10.1080/17498430.2017.1325297>

[2] Journal article: C Hollings, U Martin and A Rice, *The Lovelace-De Morgan Mathematical Correspondence: A Critical Re-Appraisal*, *Historia Mathematica* 44, 202-231 (2017) Available open access at <https://www.sciencedirect.com/science/article/pii/S0315086017300319>

[3] Other (curatorial project): Christopher Hollings, *Transcripts of folios 1-179, Box 170, The Lovelace Byron Papers*, Bodleian Library, Oxford, 2015
<http://www.claymath.org/sites/default/files/transcripts.pdf>

[1] and [2] both appear in high quality internationally refereed academic journals, and best indicate the quality of the underpinning research. As of 1 June 2020 [1] was the “most viewed” paper in the 35-year online archive of the journal. [3] was published via a website sponsored and hosted by the Clay Mathematics Institute. As of 1 June 2020 it had been accessed over 13,000 times.

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4. Details of the impact

We present impacts in the area of *creativity, culture and society* on a network of collaborators: curators; composers; and a diverse group of media and other professionals who themselves influence public culture and society, together with *impact on understanding, learning and participation* through contributing to the public commemoration of Ada Lovelace.

Impacts on creativity, culture and society: museums and libraries

In 2014, Oxford Mathematics were invited by Oxford’s Bodleian Library, which holds extensive archives of the Lovelace family, to collaborate in marking Ada Lovelace’s 2015 Bicentenary. Following this invitation Hollings, Martin and Rice were given access to the archive during 2014-15 in order to analyse the manuscripts described in section 2. The transcription of the letters [3] was made available online in late 2015. The early (pre-publication) results of this striking research underpinned two events: Oxford’s Lovelace Bicentenary Conference (8 Dec 2015, 400 attendees); and a display of Lovelace’s mathematical papers co-curated by Martin and Hollings at Oxford’s Bodleian Library (Oct-Dec 2015) [A] [text removed for publication]. In parallel, material from the Lovelace letter archive was loaned to the Science Museum in London for their exhibition on Ada Lovelace (Oct 2015-Mar 2016) [A]. A *Lancet* review of the two exhibitions praised a “*nuanced picture of an original thinker*” [C]. The publicity surrounding the conference, exhibition and publication of the transcripts led to enthusiastic approaches from a number of potential collaborators [text removed for publication].

Oxford’s authoritative work [1, 2, 3] led to further approaches from curators keen to collaborate to present Lovelace, having previously been hampered by the absence of scholarly research to inform curatorial judgement of this controversial figure. Leading on from the Bodleian exhibition, Martin was invited to co-curate a display of facsimile material at the world’s largest computing museum, the Computer History Museum in Mountain View, located next to the Google campus at the heart of Silicon Valley. *Thinking Big: Ada, Countess of Lovelace* opened in late December

2015, with major sponsorship from Google, and ran for 4 years [text removed for publication] [D, B]. A substantial outreach programme attracted new visitors, especially from under-represented groups: it included a lecture by Martin and Rice to an audience of 600 in person and 6,000 online [G]; weekly “Women in Computing” museum tours for families and the general public; and monthly workshops for local schools targeting girls and minorities [F]. Prior to COVID-19, a version of the display was “on tour”, most recently at Facebook’s Silicon Valley campus.

For the Royal Holloway Exhibition Space in Egham, Martin co-curated *200 Years of Becoming Digital* (Sept-Nov 2018), winner of the 2018 Great Exhibitions Prize of the British Society for the History of Science, who praised how it “*excellently portrayed the overlooked contribution of women...and captured the audiences’ imaginations*” [H]. Advice on using material from the Lovelace archive has been given to curators of other Oxford exhibitions, most notably *Sappho to Suffrage* (Mar 2018-Feb 2019), and to Hinckley and District Museum (Oct 2019), Guildhall Museum (May-Oct 2018), and Gunnersbury Park Museum (June 2018). The impact on museum professionals was assessed through professional impact evaluation [F, G] commissioned by Oxford Mathematics, including in-depth interviews with 13 collaborators, evaluation of sample events, and wider contextual analysis, and is summed up by the Project Evaluator [E]: “*The robustness and novelty of the research has empowered curators, cutting through controversy and enabling new activities which use history to provoke audience reflection on current and future cultural issues. In a change to current practice, curators now recognise the value of future such collaborations with mathematicians.*”

[Text removed for publication]

Impacts on creativity, culture and society: composers

Emily Howard is a British composer with regular commissions from leading international orchestras and concert halls. She presented a 2011 song-cycle inspired by Lovelace at Oxford’s 2015 conference, and as a result of discovering the new Oxford research into Lovelace’s mathematics she invited Martin to collaborate on a project on Lovelace and AI for London’s Barbican Concert Hall. Martin worked with Howard and other composers to interpret Lovelace’s mathematical writings, and to recast algorithmic aspects of her work, particularly the functional algebra of [2], in terms of modern AI for use in composition. Howard’s resulting composition, *But then, what are these numbers?*, was a setting of a Lovelace text proposed by Martin, who also advised rising young composer Robert Laidlow on the novel Lovelace percussion instrument he built for his AI-inspired piece *Alter*. These and other works were premiered by the Britten Sinfonia on 2 November 2019 in a concert *Ada Lovelace Imagining the Analytical Engine*, part of the Barbican’s 2019 AI Festival [I]. The Guardian reviewer enjoyed a “*gratifying sense of theatrics*”, and audience evaluation [G] evidenced enthusiasm for the new concepts (typical comment: “*it gave my mind a real work-out*”). The significance of the impact on composers, as summarised by the Project Evaluator, was “*its catalytic role in the creative processes of composition, in stimulating both well-received new work, and new approaches to composition expected to be of increasing future importance*” [E].

[Text removed for publication]

Impacts on understanding, learning and participation: contributing to commemoration of Lovelace and making mathematics accessible

As visibility grew, numerous potential collaborators got in touch, seeing the potential for Oxford’s research to be a catalyst for devising their own activities which, in turn, influence others in public culture and society. Many of these approaches were associated with Ada Lovelace Day, a global celebration of women in STEM held every October since 2009: its 10th anniversary was marked by a US Senate resolution, drafted with Martin’s advice [J].

Science writer Georgina Ferry approached Oxford to collaborate on a two-part BBC Radio 4 dramatisation of Lovelace’s letters (‘The Letters of Ada Lovelace: The Poetry of Mathematics’; 14 Sept 2015 + 3 repeats) [text removed for publication] [F, K]. Invited presentations at literary festivals included Hay (2016, 2018), Edinburgh (2018) and Oxford (2018); media work included Radio 3’s *the Verb* (20 April 2018, audience 60,000); BBC *Newsnight* (11 April 2018, audience 600,000) interviewed Martin about Lovelace’s mathematical learning and her ‘connectedness’

with scholars and others in the society of her time [K]. Oxford Mathematics was approached [text removed for publication] to co-create a Lovelace special issue of its *cs4fn* magazine (Autumn 2015, 20,000 copies distributed to 2000 schools) [L]. COVID-19 disrupted planned Continuing Professional Development for computing teachers, using Lovelace's work, due for pilot and evaluation from May 2020.

Between 2015 and 2019, the Oxford team accepted approximately 40 invitations to work with schools, companies, maths and computing organisations, and local history groups, creating bespoke activities which used the past to stimulate thinking about the present and future, for example presenting Lovelace in the context of technology, local history, or today's women in mathematics. These have reached a total live audience of approximately 7,500, often amplified online, for example as part of the free open lecture programme at Gresham College (150 live + 12,000 online) [G]. Professional evaluation of the audience response to events held in 2019 found that they changed perceptions of participants, who found mathematics *"more practical, more socially engaged than I thought"*; were surprised and sad at *"the erasing of women from history"*; with the account of 19C mathematicians as a *"community providing support for its members so they can achieve"* providing a *"more inspiring, more hopeful view"* [G].

A general interest book by Hollings, Martin and Rice, *Ada Lovelace: the making of a computer scientist*, 2018, (translated into Spanish as *Ada Lovelace: la formación de una científica informática*, 2020) enhanced the accessibility of the research of [1, 2] to non-mathematicians, by-passing the technicalities of Victorian algebra to explain the mathematical content and context at roughly GCSE level: for example, Lovelace's striking diagrams of the Bridges of Königsberg problem are used to illustrate her algorithmic thinking. As of 1 June 2020 the book had sold 2,520 copies and received positive reviews in mainstream, literary and educational publications [M]; comments include *"Dusty archives dance into life"* (New York Review of Books), *"admirable clarity"* (Women's History Review), *"mathematics explained clearly and in detail"* (London Mathematical Society Newsletter) and *"The one I'd recommend ... much excitement, of a mathematical flavour"* (Association for Women in Mathematics, in a survey for educators of books about Lovelace).

Impacts on creativity, culture and society: other collaborators

The Project Evaluator's summary reveals that the significance of the impact on the professionals involved in such collaborations was [E]: *"The confidence generated by the calibre of the research, and the additional insights provided through working with the Oxford team, empowered collaborators to incorporate Lovelace material in their own professional work. This in turn influenced others, through changing perceptions of the current and future importance of mathematics, and of women's contributions"*.

[Text removed for publication]

5. Sources to corroborate the impact

[A] Bodleian Libraries website announcement of the Bicentenary exhibition, 8 Oct 2015, naming Martin as co-curator, and corroborating the loan of items to the Science Museum.

[B] [Text removed for publication]

[C] Review of Ada Lovelace exhibitions at the Bodleian Library and London Science Museum, *The Lancet*, 31 Oct 2015, including quote in section 4.

[D] Computer History Museum press release for their Ada Lovelace exhibition on the Globe Newswire website, 10 Dec 2015, corroborating details of the exhibition.

[E] Letter, Project Evaluator, the Principal of the Technology Development Group, summarising the benefits of this project for curators, composers and other professional collaborators.

[F] Impact Evaluation of Ada Lovelace Project 2015 - 2020, Technology Development Group, June 2020, corroborating benefits to curators, composers and other professional collaborators.

[Text removed for publication]

[G] Audience Evaluation of Ada Lovelace presentations 2019, Technology Development Group, June 2020, corroborating benefits to participants in events connected to the research. Includes details of the lecture at the Computer History Museum (p.3).

[H] Royal Holloway website announcement of the 2018 Great Exhibitions Prize of the British Society for the History of Science, corroborating Martin's involvement in the exhibition

- [I]** Barbican concert programme for 'Ada Lovelace - Imagining the Analytical Engine', 2 Nov 2019, confirming details of the musical works; Martin's participation in the after-show discussion; and the influence on Emily Howard's piece (p.9) and Robert Laidlow's piece (p.10)
- [J]** US Senate Resolution on Ada Lovelace Day: (1) Letter from the Founder of Ada Lovelace Day, who worked on drafting the Resolution, confirming the contribution made by Martin; (2) US Senate Resolution 592 on Ada Lovelace Day, 25 July 2018
- [K]** Media appearances featuring Ursula Martin and the new analysis of the Lovelace archive: (1) BBC Radio 4's 'The Letters of Ada Lovelace', 14 Sept 2015, crediting the Bodleian Library's Lovelace archive; (2) Twitter clip of Ursula Martin's interview on BBC Newsnight, 11 April 2018; (3) BBC Radio 3's The Verb on 'Algorithms', 20 April 2018, with Ursula Martin
- [L]** [Text removed for publication]
- [M]** Reviews of 'Ada Lovelace: The Making of a Computer scientist': (1) New York Review of Books, 22 Nov 2018, by Jenny Uglow; (2) Women's History Review, 30 Sept 2018, by Patricia Fara; (3) London Mathematical Society Newsletter, May 2019, by Allan Grady, pp.37-38; (4) Association for Women in Mathematics Newsletter, May-June 2019, pp. 20-21.